SIET School of Industrial Education and Technology

KMITL สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

DRLE 22nd

The 22nd International Conference

Research and Innovation Ecosystem

"Developing Real-Life Learning Experiences:
Technology and AI Driving Research and Innovation"

22-23 May 2026

School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang

siet.kmitl.ac.th/interdrle2026

DRLE 2026

The 22nd International Conference
"Research and Innovation Ecosystem"

Developing Real-Life Learning Experiences:
Technology and AI Driving Research and Innovation

School of Industrial Education and Technology
King Mongkut's Institute of Technology Ladkrabang
Thailand Education Deans Council, Consortium of Education Deans of Thailand,
Association of Professional Development of Educational Administration of Thailand,
Association of Industrial Education (Thailand), Thai IoT Association,
The Association of Siamese Architects under Royal Patronage,
The faculty of Technical Education,
King Mongkut's University of Technology North Bangkok,
Negros Oriental State University, and Benguet State University

PREFACE

The 22nd International Conference, under the theme "Research and Innovation Ecosystem: Developing Real-Life Learning Experiences – Technology and AI Driving Research and Innovation," is organized through the collaboration of the School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang, in partnership with the Thailand Education Deans Council, the Consortium of Education Deans of Thailand, the Association of Professional Development of Educational Administration of Thailand, the Association of Industrial Education (Thailand), the Thai IoT Association, and the Association of Siamese Architects under Royal Patronage, the faculty of Technical Education, King Mongkut's University of Technology North Bangkok, along with international partner institutions including Negros Oriental State University and Benguet State University.

This conference aims to disseminate educational research conducted by national researchers and academics, and to serve as a platform for presenting research findings, creative works, and educational innovations. It is intended to promote the role of research in advancing a sustainable educational system. The event features the presentation of 57 national and 30 international research papers, covering a wide range of key topics, including science and technology teaching, competency-based learning and teaching, educational administration and management for lifelong learning, architecture and design education, engineering education, agricultures and agricultural education, and technology and innovation in educational learning. In addition, the conference showcases 19 creative works in the fields of design arts, architecture, and interior design. The event also includes special lectures by distinguished experts in areas related to the research and innovation ecosystem.

The organizing committee would like to express its sincere gratitude to all co-hosting institutions and organizations for their invaluable support in making this conference possible. Our heartfelt thanks also go to all researchers, academics, students, and participants for their contributions and active engagement, which have greatly contributed to the success of this academic conference. Their participation has helped fulfill the objectives of the event and brought meaningful benefits to the academic and educational communities in Thailand.

The 22nd International Conference Organizing Committee
School of Industrial Education and Technology
King Mongkut's Institute of Technology Ladkrabang

MESSAGE FROM THE PRESIDENT

"Research is the Light of Wisdom."

King Mongkut's Institute of Technology Ladkrabang embraces its mission to advance wisdom; to this end, it generates tangible value through research—serving as both the compass and the spirit of the institution. This commitment reflects the intellectual excellence of its personnel and the university's capacity for evidence-based academic contributions to society, laying a strong foundation for national development and enabling the nation to thrive with distinction on the global stage, in line with its vision of becoming "The World Master of Innovation."

Reflecting this core belief, this Joint International Conference unites four distinguished schools of KMITL—the School of Industrial Education and Technology, the School of Liberal Arts, KMITL Business School, and the College of Innovation and Industrial Management— in collaboration with our esteemed co-hosts: the Thai IoT Association, Thailand, Education Deans Council, the Consortium of Education Deans of Thailand, the Association for Professional Development in Educational Administration of Thailand, the Association of Industrial Education (Thailand), the Association of Siamese Architects under the Royal Patronage, the faculty of Technical Education, King Mongkut's University of Technology North Bangkok, Negros Oriental State University, and Benguet State University. This powerful collaboration fosters a dynamic ecosystem of interdisciplinary research and innovation, driving meaningful real-world impact beyond traditional academic boundaries.

Through this valued partnership, the School of Industrial Education and Technology proudly presents the 22nd International Conference and the 16th National Conference on Developing Real Life Learning Experiences (DRLE 2026) under the theme: "Developing Real-Life Learning Experiences: Technology and AI Driving Research and Innovation." In today's rapidly evolving world, this theme powerfully addresses the growing demand for adaptive, ethical, and globally minded leadership—qualities uniquely cultivated through industrial education and technology.

This academic conference serves as a distinguished intellectual platform that fosters the dissemination of scholarly work among faculty members, researchers, students, and interested participants. Such engagement lies at the heart of human capital development, guiding society toward becoming a community of Smart Global Citizens. It also cultivates sustainable intellectual momentum through strategic collaboration networks at both national and international levels, thereby laying a strong foundation for navigating social, economic, and cultural transformations in an ever-evolving world with grace. Thank you for being part of this important journey.

Associate Professor Komsan Maleesee, D.Eng
President
King Mongkut's Institute of Technology Ladkrabang

MESSAGE FROM THE DEAN

The School of Industrial Education and Technology (SIET) is committed to its core mission of preparing learners for the digital world, creating educational innovations grounded in research, practicing good governance in administration, and providing academic services that meet societal needs. The school also promotes lifelong learning, enhances the digital education ecosystem, develops incubator space for innovators, supports the international dissemination of research, and drives the organization forward through data and technology. These efforts aim to elevate the identity of industrial education to keep pace with the transformations of the 21st century. To realize this mission, SIET has collaborated with the Thailand Education Deans Council, the Consortium of Education Deans of Thailand, the Association of Professional Development of Educational Administration of Thailand, the Association of Industrial Education (Thailand), the Thai IoT Association, and the Association of Siamese Architects under Royal Patronage, the faculty of Technical Education, King Mongkut's University of Technology North Bangkok, as well as international partner institutions including Negros Oriental State University and Benguet State University, to organize The 22nd International Conference under the theme "Research and Innovation Ecosystem: Developing Real-Life Learning Experiences – Technology and AI Driving Research and Innovation."

This conference encompasses research across a wide range of disciplines, including science and technology teaching, competency-based learning and teaching, educational administration and management for lifelong learning, architecture and design education, engineering education, agricultures and agricultural education, and technology and innovation in educational learning.
The conference serves as a platform for researchers, students, and interested individuals to disseminate their work, exchange knowledge, and share experiences. This engagement forms a crucial foundation for human resource development, which is essential for driving the country toward stability and sustainability. As such, the conference marks a significant step forward in academic collaboration, fostering the advancement of research, the enhancement of learning management practices, and the strengthening of professional capacities among educational personnel.

We would like to express our sincere appreciation to the distinguished experts who kindly served as reviewers for the research and creative works across various fields, as well as to the researchers from different academic institutions, all presenters, and participants. Our gratitude also extends to both domestic and international partner organizations for their valuable support. Lastly, we wish to thank all members of the organizing committee whose dedication and collaboration have contributed to the successful achievement of this conference's objectives. We sincerely hope that this academic conference will serve as a platform that inspires, promotes research, advances knowledge, and fosters new collaborations that are beneficial at both the national and international levels.

Professor Dr. Pariyaporn Tungkunanan
Dean of the School of Industrial Education and Technology

CONFERENCE ORGANIZATION COMMITTEE

Honorary Chairperson

- Associate Professor Dr. Komsan Maleesee
  President of King Mongkut's Institute of Technology Ladkrabang

General Chairperson

- Professor Dr. Pariyaporn Tungkunanan
  Dean of School of Industrial Education and Technology
  King Mongkut's Institute of Technology Ladkrabang

Co-Chairpersons

- Assistant Professor Dr. Oraphan Toujinda
  President of Thailand Education Deans Council
  Dean of Faculty of Education, Nakhon Pathom Rajabhat University
- Professor Dr. Pakorn Prachanban
  President of the Consortium Education Deans of Thailand
  Dean of Faculty of Education, Naresuan University
- Associate Professor Dr. Somsak Akatimagool
  Dean of Faculty of Technical Education,
  King Mongkut's University of Technology North Bangkok
- Associate Professor Dr. Jinnawat Pakotang
  President of the Educational Administration Professional Development Association of Thailand
- Assistant Professor Dr. Panarit Sethakul
  President of the Association of Industrial Education (Thailand)
- Dr. Suthat Krongchon
  President of the Thai IoT Association
- Mr. Asae Sukhyanga
  President of the Association of Siamese Architects under Royal Patronage
- Dr. Noel Marjon E. Yasi
  President of Negros Oriental State University
- Dr. Kenneth A. Laruan
  President of Benguet State University

Organizing Committee

- Associate Professor Dr. Sunti Tuntrakool
  Head of Collaborative Development and International Studies Center
  School of Industrial Education and Technology, KMITL
- Associate Professor Dr. Piya Supavarasuwat
  Vice Dean for Academic Affairs
  School of Industrial Education and Technology, KMITL
- Associate Professor Dr. Boonchan Sisan
  Vice Dean for Administration and Asset
  School of Industrial Education and Technology, KMITL
- Assistant Professor Dr. Pornthep Jewpailrojkij
  Vice Dean for Student Affairs and Alumni Relations
  School of Industrial Education and Technology, KMITL
- Assistant Professor Pongkiat Jongtriluck
  Vice Dean for Strategic Management and Educational Quality
  School of Industrial Education and Technology, KMITL
- Assistant Professor Dr. Sarawut Intorrathed
  Assistant Dean for Student Development and Alumni Relations
  School of Industrial Education and Technology, KMITL
- Dr. Attama Saributr
  Assistant Dean for Physical Resource and Environment
  School of Industrial Education and Technology, KMITL
- Dr. Kwantisara Apisuksakul
  Assistant Dean for Experiential Training
  School of Industrial Education and Technology, KMITL
- Dr. Mai Charoentham
  Head of Center for Educational Innovation and Technology
  School of Industrial Education and Technology, KMITL

Academic Committee

- Associate Professor Dr. Sunti Tuntrakool — Chairperson
- Professor Dr. Pakkapong Poungsuk — Committee Member
- Associate Professor Dr. Sirirat Petsangsri — Committee Member
- Associate Professor Dr. Thanin Ratanaolarn — Committee Member
- Assistant Professor Dr. Ampapan Tuntinakhongul — Committee Member
- Assistant Professor Dr. Poonsri Vate-U-Lan — Committee Member
- Assistant Professor Dr. Kanyarat Sriwisathiyakun — Committee Member
- Associate Professor Dr. Chaturong Louhapensang — Committee Member
- Assistant Professor Dr. Apisak Sindhuphak — Committee Member
- Associate Professor Dr. Suriyan Supapvanich — Committee Member
- Associate Professor Dr. Chairat Techavuthiporn — Committee Member
- Associate Professor Dr. Thiyaporn Kantathanawat — Committee Member
- Associate Professor Dr. Pornpimon Chayratsami — Committee Member
- Associate Professor Dr. Worawit Somha — Committee Member
- Associate Professor Dr. Prasert Kenpankho — Committee Member
- Assistant Professor Dr. Pitsini Mano — Committee Member
- Assistant Professor Dr. Apirath Limmanee — Committee Member

Research Peer Review Committee

External Peer Review Committee

- Associate Professor Dr. Kriangsak Khiaomang
- Associate Professor Dr. Kittisak Ariyakruea
- Associate Professor Dr. Jukkaphong Poung-Ngamchuen
- Associate Professor Dr. Nattaphon Rampai
- Associate Professor Dr. Tanes Tanitteerapan
- Associate Professor Dr. Tawat Payim
- Associate Professor Dr. Punyawi Jamjareegulgarn
- Assistant Professor Dr. Thaweesak Yingthawornsuk
- Assistant Professor Dr. Sumate Noklang
- Assistant Professor Dr. Sathit Laowattanaphong
- Assistant Professor Dr. Sopida Wisansakkul
- Assistant Professor Dr. Khanittha Saleemad
- Assistant Professor Poramintra Wongcharoen
- Dr. Somjai Klin-Ngam
- Dr. Peeradet Prakongpan
- Dr. Phadungchai Pupat

Internal Peer Review Committee

- Associate Professor Dr. Sunti Tuntrakool
- Associate Professor Dr. Sirirat Petsangsri
- Associate Professor Dr. Jirarat Sitthiworachart
- Associate Professor Dr. Thanin Ratanaolarn
- Associate Professor Dr. Aukkapong Sukkamart
- Associate Professor Dr. Ratchadakorn Phonpakdee
- Associate Professor Dr. Pastraporn Thipayasothorn
- Assistant Professor Dr. Somchai Maunsaiyat
- Assistant Professor Dr. Ampapan Tuntinakhongul
- Assistant Professor Dr. Apirath Limmanee
- Assistant Professor Dr. Somchai Seviset
- Assistant Professor Dr. Poonsri Vate-U-Lan
- Assistant Professor Dr. Wasana Boonsong

TABLE OF CONTENTS

	Page
CONFERENCE ORGANIZATION COMMITTEE	ix
TABLE OF CONTENTS	xiii
CONFERENCE PROGRAM	xvii
KEYNOTE SPEAKERS' PAPERS	A-1
TECHNOLOGY AND INNOVATION IN EDUCATIONAL LEARNING	
THE NEXUS OF SELF-LEARNING ABILITY AND SOCIAL SCAFFOLDING: A NEW CONCEPTUAL FRAMEWORK FOR DIGITAL INNOVATION ADOPTION AMONG THAI OLDER ADULTS *Pimnatchaya Satchasin, Toosrangrasame Tetakew, and Amnuay Saengnoree*	1
FROM SATISFACTION TO ENGAGEMENT: A BIBLIOMETRIC ANALYSIS OF THE THEMATIC SHIFT IN GREEN TRAINING RESEARCH (2016–2026) *Xue Zhao, Anusit Anmanatarkul, Mongkhon Narmluk, Santirat Nansaarng, and Tanatorn Tongsumrith*	14
DIGITAL MEDIA LITERACY AND COGNITIVE RESILIENCE AMONG OLDER ADULTS: SOCIOCULTURAL DRIVERS OF INNOVATION *Pimnatchaya Satchasin, Toosrangrasame Tetakew, and Amnuay Saengnoree*	25
DEVELOPING A PRIDE MODEL: A DIGITAL PROJECT-BASED BLENDED LEARNING APPROACH TO ENHANCE TEACHERS' RESEARCH COMPETENCY *Kemmawat Iedkhao, Thanin Ratanaolarn, and Sirirat Petsangsri*	35
TRANSFORMING TEACHER-RESEARCHERS IN THAILAND: A NEEDS ASSESSMENT FOR DEVELOPING RESEARCH COMPETENCIES *Kemmawat Iedkhao, Thanin Ratanaolarn, and Sirirat Petsangsri*	51
INVESTIGATING THE EFFECT OF AI INFLUENCER-GENERATED CONTENT ON CONSUMERS' PSYCHOLOGICAL WELL-BEING: A PLS-SEM ANALYSIS *Sher Singh Yadav*	63
EDUCATIONAL ADMINISTRATION AND MANAGEMENT FOR LIFELONG LEARNING	
STRATEGIC ACADEMIC MANAGEMENT APPROACHES IN THE DIGITAL ERA FOR ENHANCING STUDENT QUALITY AT WATYANNARANGSARAM SCHOOL *Daoprakai Nanthaprom*	81

TABLE OF CONTENTS (CONTINUED)

Page

A STUDY OF NEEDS FOR STRATEGIC DIGITAL LEADERSHIP DEVELOPMENT IN THE AI ERA UNDER THE SECONDARY EDUCATIONAL SERVICE AREA OFFICE CHONBURI RAYONG 91
Jakkarin Jamsai

A STUDY OF SKILL COMPONENTS OF ADMINISTRATORS IN THE DISRUPTIVE ERA OF PRIVATE HIGHER EDUCATION IN THAILAND 106
Totsaporn Lertpichate, Pariyaporn Tungkunanan, and Boonchan Sisan

SERVANT LEADERSHIP OF EDUCATIONAL ADMINISTRATORS UNDER THE OFFICE OF THE BASIC EDUCATION COMMISSION 114
Sanguthai Moto and Boonchan Sisan

ARCHITECTURE AND DESIGN EDUCATION

EFFECT OF AIR SUPPLY DUCT CONFIGURATIONS ON TEMPERATURE DISTRIBUTION IN OPEN PLUG-IN REFRIGERATED DISPLAY CABINETS 119
Nutthakit Hanboonyanon, Songwut Egwutvongsa, and Thanate Piromgarn

ENERGY EFFICIENCY IMPROVEMENT OF OPEN REFRIGERATED DISPLAY CABINETS VIA AIR DUCT DESIGN: A CASE STUDY OF PLUG-IN UNITS 131
Nutthakit Hanboonyanon, Songwut Egwutvongsa, and Thanate Piromgarn

PHYSICAL AND SPATIAL FACTORS INFLUENCING THE ADAPTIVE REUSE OF SHOPHOUSES AS CREATIVE PRODUCTION STUDIOS IN BANGKOK, THAILAND 140
Ladapan Chokchaiyakul and Piyarat Nanta

HOW VR SHAPES VISIT INTENTION IN AN INTANGIBLE CULTURAL HERITAGE MUSEUM: A KOLB LEARNING CYCLE PERSPECTIVE 157
Ran Shao and Atit Tippichai

ENHANCING USER SATISFACTION IN HAINING SHADOW PLAY LAMPSHADE DESIGN THROUGH QUESTIONNAIRE AND INTERVIEW-BASED RESEARCH 169
Hua Tong and Pastraporn Thipayasothorn

APPLYING NANCHONG'S THREE KINGDOMS CULTURE TO THE OUTER PACKAGING DESIGN OF CHUANBEI LIANGFEN: A DESIGN-ORIENTED STUDY WITH YOUNG CONSUMERS 176
Lanping Wang and Pastraporn Thipayasothorn

TABLE OF CONTENTS (CONTINUED)

Page

ENGINEERING AND ENGINEERING EDUCATION

ATMOSPHERIC PARTICLE MATTER CONTENT MEASURING BY USING SINGLE FREQUENCY GPS SATELLITES DATA 189
Wanwisa Mantonghlang, Pattawut Wongsak, Supawit Nambut, Aswin Kingjumpa, and Prasert Kenpankho

GEOMAGNETIC FIELD DISTRIBUTION BY USING FLUXGATE MAGNETOMETER 201
Thapanan Namniwong, Burin Phutthong, Patiphan Sumniang, and Prasert Kenpankho

ATMOSPHERIC WATER GENERATOR AT KHAI ISLAND, CHUMPHON, THAILAND 213
Aswin Kingjumpa, Wanwisa Mantonghlang, Prasert Kenpankho, and Piya Supavarasuwat

TOTAL ELECTRON CONTENT MEASUREMENT BY USING GLONASS SATELLITE 221
Jedsada Puang-im, Pattawut Wongsak, and Prasert Kenpankho

SINGLE STATION POSITIONING ERROR BASED ON GPS SATELLITE 233
Uthai Kaiphalang, Burin Putthong, and Prasert Kenpankho

PARTICULATE MATTER BY USING GLONASS SATELLITE 245
Pattawut Wongsak, Jedsada Puang-im, and Prasert Kenpankho

ASSESSMENT OF IONOSPHERIC TEC USING A LOW-COST NEO-6M SINGLE-FREQUENCY GPS TEC MEASUREMENT 257
Thanapon Keokhumcheng, Pharinya Phothila, Samatchaya Maichuen, Patiphan Sumniang, and Prasert Kenpankho

GPS SIGNAL DELAY CAUSED BY THE IONOSPHERE MEASUREMENT BY USING SINGLE GPS SATELLITE RECEIVER 271
Burin Phutthong, Uthai Kaiphalang, Patiphan Sumniang, and Prasert Kenpankho

TOTAL ELECTRON CONTENT MEASUREMENT BY USING BEIDOU SATELLITE 283
Jianfeng Zhang, Pattawut Wongsak, Thanapon Keokhumcheng, and Prasert Kenpankho

TABLE OF CONTENTS (CONTINUED)

Page

THE DEVELOPMENT OF INSTRUCTIONAL MATERIALS BASED ON HOLISTIC LEARNING PRINCIPLES FOR THE DESIGN AND ANALYSIS OF AUDIO FREQUENCY AMPLIFIER CIRCUITS 293
Kitipong Mano and Pitsini Mano

AGRICULTURES AND AGRICULTURAL EDUCATION

SMART DECISION-MAKING ECOSYSTEM FOR ORGANIC RICE ADOPTION: INTEGRATING SOCIO-ECONOMIC FACTORS AND DIGITAL AGRICULTURAL EXTENSION 304
Kunlada Timkhaoprasert and Pakkapong Poungsuk

NEEDS ASSESSMENT FOR KNOWLEDGE AND INNOVATION DEVELOPMENT IN TECHNOLOGY TRANSFER AMONG FARMERS IN SALINITY-AFFECTED AREAS: A CASE STUDY OF BANG BO DISTRICT, SAMUT PRAKAN PROVINCE, THAILAND 316
Thanapon Prangkratok and Pakkapong Poungsuk

OTHER RELATED FIELDS

DIGITAL HEALTH COMMUNICATION FOR ONLINE PUBLIC RELATIONS TO PROMOTE AWARENESS ON HEALTH RISKS OF SMOKING AMONG UNDERGRADUATE STUDENTS 330
Chadatarn Auesirisophon, Tapanat Buttirachai, Pimmada Jitthawesrisuk, Kuntida Thamwipat, Pornpapatsorn Princhankol, and Teerawan Opasbut

EXAMINING ENGLISH COMMUNICATION CHALLENGES AND REAL-WORLD WORK EXPERIENCE AMONG AIRLINE RESERVATION AND TICKETING STAFF IN THAILAND 340
Chalobon Nuntitrakarn, Thapanee Khemanuwong, Ekkapon Phairot, Tanassanee Jitpanich, and Nagorn Bunyarit

Conference Program
The 22nd International Conference on
Research and Innovation Ecosystem
Developing Real-Life Learning Experiences (DRLE):
Technology and AI Driving Research and Innovation
May 22, 2026
at KMITL Business School and Learning Innovation Building,
School of Industrial Education and Technology
King Mongkut's Institute of Technology Ladkrabang

Time	Event
9.00 a.m. - 9.30 a.m.	**Registration** **Venue:** in front of Rooms 101–103, 1st Floor, KMITL Business School
9.30 a.m. - 9.45 a.m.	Opening Remarks by the Representative of the Dean
9.45 a.m. - 10.00 a.m.	Opening Address by Associate Professor Dr. Komsan Maleesee President of King Mongkut's Institute of Technology Ladkrabang
10.00 a.m. - 10.15 a.m.	Souvenir Presentation and Group Photo
10.15 a.m. - 10.30 a.m.	Coffee Break at KMITL Business School
10.30 a.m. - 11.30 a.m.	Keynote Speech **"AI, Complexity and Research-Driven Innovation in Food Safety"** *By Dr. Massimo Martinelli, ISTI-CNR Institute of Information Science and Technologies – National Research Council of Italy* **Venue:** at Wolf Hub, 1st Floor, KMITL Business School
11.30 a.m. - 1.00 p.m.	Lunch Break at School of Industrial Education and Technology
1.00 p.m. - 2.40 p.m.	**Presentation Sessions** Rooms IE1307, IE1308, IE1309 (3rd Floor) Learning Innovation Building, School of Industrial Education and Technology
2.40 p.m. - 2.50 p.m.	Presentation Break
2.50 p.m. - 4.30 p.m.	**Presentation Sessions** Rooms IE1307, IE1308, IE1309 (3rd Floor) Learning Innovation Building, School of Industrial Education and Technology
4.30 p.m. - 5.00 p.m.	**Announcement of the Best Paper Awards and Closing Ceremony** By Professor Dr. Pariyaporn Tungkunanan Dean of School of Industrial Education and Technology, KMITL **Venue:** Kaewjaojom Auditorium, 1st Floor, Learning Innovation Building, School of Industrial Education and Technology

Remark: The schedule is subject to change as appropriate.

Presentation Schedule

Fields: Engineering and Engineering Education

Room: IE1307 (3rd Floor), Learning Innovation Building, School of Industrial Education and Technology

Time	No.	Article Title
Moderator: Asst. Prof. Dr. Thaweesak Yingthawornsuk and Assoc. Prof. Dr. Sunti Tuntrakool		
1.00 p.m. – 1.20 p.m.	1	GEOMAGNETIC FIELD DISTRIBUTION BY USING FLUXGATE MAGNETOMETER by Thapanan Namniwong, Burin Phutthong, Patiphan Sumniang, and Prasert Kenpankho
1.20 p.m. – 1.40 p.m.	2	THE DEVELOPMENT OF INSTRUCTIONAL MATERIALS BASED ON HOLISTIC LEARNING PRINCIPLES FOR THE DESIGN AND ANALYSIS OF AUDIO FREQUENCY AMPLIFIER CIRCUITS by Kitipong Mano and Pitsini Mano
1.40 p.m. – 2.00 p.m.	3	TOTAL ELECTRON CONTENT MEASUREMENT BY USING BEIDOU SATELLITE by Jianfeng Zhang, Pattawut Wongsak, Thanapon Keokhumcheng, and Prasert Kenpankho
2.00 p.m. – 2.20 p.m.	4	ATMOSPHERIC WATER GENERATOR AT KHAI ISLAND, CHUMPHON, THAILAND by Aswin Kingjumpa, Wanwisa Mantonghlang, Prasert Kenpankho, and Piya Supavarasuwat
2.20 p.m. – 2.40 p.m.	5	ATMOSPHERIC PARTICLE MATTER CONTENT MEASURING BY USING SINGLE FREQUENCY GPS SATELLITES DATA by Wanwisa Mantonghlang, Pattawut Wongsak, Supawit Nambut, Aswin Kingjumpa, and Prasert Kenpankho
2.40 p.m. – 2.50 p.m.		Presentation Break
Moderator: Asst. Prof. Dr. Wasana Boonsong and Assoc. Prof. Dr. Winai Jaikla		
2.50 p.m. – 3.10 p.m.	6	TOTAL ELECTRON CONTENT MEASUREMENT BY USING GLONASS SATELLITE by Jedsada Puang-im, Pattawut Wongsak, and Prasert Kenpankho
3.10 p.m. – 3.30 p.m.	7	SINGLE STATION POSITIONING ERROR BASED ON GPS SATELLITE by Uthai Kaiphalang, Burin Putthong, and Prasert Kenpankho
3.30 p.m. – 3.50 p.m.	8	PARTICULATE MATTER BY USING GLONASS SATELLITE by Pattawut Wongsak, Jedsada Puang-im, and Prasert Kenpankho
3.50 p.m. – 4.10 p.m.	9	ASSESSMENT OF IONOSPHERIC TEC USING A LOW-COST NEO-6M SINGLE-FREQUENCY GPS TEC MEASUREMENT by Thanapon Keokhumcheng, Pharinya Phothila, Samatchaya Maichuen, Patiphan Sumniang, and Prasert Kenpankho
4.10 p.m. – 4.30 p.m.	10	GPS SIGNAL DELAY CAUSED BY THE IONOSPHERE MEASUREMENT BY USING SINGLE GPS SATELLITE RECEIVER by Burin Phutthong, Uthai Kaiphalang, Patiphan Sumniang, and Prasert Kenpankho

Remark: Each presenter will have 15 minutes for presentation and 5 minutes for Q&A (total of 20 minutes).

Presentation Schedule

Fields: Technology and Innovation in Educational Learning/Agricultures and Agricultural Education/ Other related fields

Room: IE1308 (3rd Floor), Learning Innovation Building, School of Industrial Education and Technology

Time	No.	Article Title
Moderator: Dr. Chontawat Meedee		
1.00 p.m. – 1.20 p.m.	1	THE NEXUS OF SELF-LEARNING ABILITY AND SOCIAL SCAFFOLDING: A NEW CONCEPTUAL FRAMEWORK FOR DIGITAL INNOVATION ADOPTION AMONG THAI OLDER ADULTS by Pimnatchaya Satchasin, Toosrangrasame Tetakew, and Amnuay Saengnoree
1.20 p.m. – 1.40 p.m.	2	DIGITAL MEDIA LITERACY AND COGNITIVE RESILIENCE AMONG OLDER ADULTS: SOCIOCULTURAL DRIVERS OF INNOVATION by Pimnatchaya Satchasin, Toosrangrasame Tetakew, and Amnuay Saengnoree
1.40 p.m. – 2.00 p.m.	3	FROM SATISFACTION TO ENGAGEMENT: A BIBLIOMETRIC ANALYSIS OF THE THEMATIC SHIFT IN GREEN TRAINING RESEARCH (2016–2026) by Xue Zhao, Anusit Anmanatarkul, Mongkhon Narmluk, Santirat Nansaarng, and Tanatorn Tongsumrith
2.00 p.m. – 2.20 p.m.	4	DEVELOPING A PRIDE MODEL: A DIGITAL PROJECT-BASED BLENDED LEARNING APPROACH TO ENHANCE TEACHERS' RESEARCH COMPETENCY by Kemmawat Iedkhao, Thanin Ratanaolarn, and Sirirat Petsangsri
2.20 p.m. – 2.40 p.m.	5	TRANSFORMING TEACHER-RESEARCHERS IN THAILAND: A NEEDS ASSESSMENT FOR DEVELOPING RESEARCH COMPETENCIES by Kemmawat Iedkhao, Thanin Ratanaolarn, and Sirirat Petsangsri
2.40 p.m. – 2.50 p.m.		Presentation Break
Moderator: Assoc. Prof. Dr. Ratchadakorn Phonpakdee		
2.50 p.m. – 3.10 p.m.	6	INVESTIGATING THE EFFECT OF AI INFLUENCER-GENERATED CONTENT ON CONSUMERS' PSYCHOLOGICAL WELL-BEING: A PLS-SEM ANALYSIS by Sher Singh Yadav
3.10 p.m. – 3.30 p.m.	7	SMART DECISION-MAKING ECOSYSTEM FOR ORGANIC RICE ADOPTION: INTEGRATING SOCIO-ECONOMIC FACTORS AND DIGITAL AGRICULTURAL EXTENSION by Kunlada Timkhaoprasert and Pakkapong Poungsuk
3.30 p.m. – 3.50 p.m.	8	NEEDS ASSESSMENT FOR KNOWLEDGE AND INNOVATION DEVELOPMENT IN TECHNOLOGY TRANSFER AMONG FARMERS IN SALINITY-AFFECTED AREAS: A CASE STUDY OF BANG BO DISTRICT, SAMUT PRAKAN PROVINCE, THAILAND by Thanapon Prangkratok and Pakkapong Poungsuk
3.50 p.m. – 4.10 p.m.	9	DIGITAL HEALTH COMMUNICATION FOR ONLINE PUBLIC RELATIONS TO PROMOTE AWARENESS ON HEALTH RISKS OF SMOKING AMONG UNDERGRADUATE STUDENTS by Chadatarn Auesirisophon, Tapanat Buttirachai, Pimmada Jitthawesrisuk, Kuntida Thamwipat, Pornpapatsorn Princhankol, and Teerawan Opasbut
4.10 p.m. – 4.30 p.m.	10	EXAMINING ENGLISH COMMUNICATION CHALLENGES AND REAL-WORLD WORK EXPERIENCE AMONG AIRLINE RESERVATION AND TICKETING STAFF IN THAILAND by Chalobon Nuntitrakarn, Thapanee Khemanuwong, Ekkapon Phairot, Tanassanee Jitpanich, and Nagorn Bunyarit

Remark: Each presenter will have 15 minutes for presentation and 5 minutes for Q&A (total of 20 minutes).

Presentation Schedule

Fields: Educational Administration and Management for Lifelong Learning/Architecture and Design Education

Room: IE1309 (3rd Floor), Learning Innovation Building, School of Industrial Education and Technology

Time	No.	Article Title
Moderator: Asst. Prof. Dr. Ampapan Tuntinakhongul and Asst. Prof. Sher Singh Yadav		
1.00 p.m. – 1.20 p.m.	1	SERVANT LEADERSHIP OF EDUCATIONAL ADMINISTRATORS UNDER THE OFFICE OF THE BASIC EDUCATION COMMISSION by Sanguthai Moto and Boonchan Sisan
1.20 p.m. – 1.40 p.m.	2	STRATEGIC ACADEMIC MANAGEMENT APPROACHES IN THE DIGITAL ERA FOR ENHANCING STUDENT QUALITY AT WATYANNARANGSARAM SCHOOL by Daoprakai Nanthaprom
1.40 p.m. – 2.00 p.m.	3	A STUDY OF NEEDS FOR STRATEGIC DIGITAL LEADERSHIP DEVELOPMENT IN THE AI ERA UNDER THE SECONDARY EDUCATIONAL SERVICE AREA OFFICE CHONBURI RAYONG by Jakkarin Jamsai
2.00 p.m. – 2.20 p.m.	4	A STUDY OF SKILL COMPONENTS OF ADMINISTRATORS IN THE DISRUPTIVE ERA OF PRIVATE HIGHER EDUCATION IN THAILAND by Totsaporn Lertpichate, Pariyaporn Tungkunanan, and Boonchan Sisan
2.20 p.m. – 2.30 p.m.		Presentation Break
Moderator: Dr. Thadharphut Limapornvanitr		
2.30 p.m. – 2.50 p.m.	5	PHYSICAL AND SPATIAL FACTORS INFLUENCING THE ADAPTIVE REUSE OF SHOPHOUSES AS CREATIVE PRODUCTION STUDIOS IN BANGKOK, THAILAND by Ladapan Chokchaiyakul and Piyarat Nanta
2.50 p.m. – 3.10 p.m.	6	EFFECT OF AIR SUPPLY DUCT CONFIGURATIONS ON TEMPERATURE DISTRIBUTION IN OPEN PLUG-IN REFRIGERATED DISPLAY CABINETS by Nutthakit Hanboonyanon, Songwut Egwutvongsa, and Thanate Piromgarn
3.10 p.m. – 3.30 p.m.	7	ENERGY EFFICIENCY IMPROVEMENT OF OPEN REFRIGERATED DISPLAY CABINETS VIA AIR DUCT DESIGN: A CASE STUDY OF PLUG-IN UNITS by Nutthakit Hanboonyanon, Songwut Egwutvongsa, and Thanate Piromgarn
3.30 p.m. – 3.50 p.m.	8	HOW VR SHAPES VISIT INTENTION IN AN INTANGIBLE CULTURAL HERITAGE MUSEUM: A KOLB LEARNING CYCLE PERSPECTIVE by Ran Shao and Atit Tippichai
3.50 p.m. – 4.10 p.m.	9	ENHANCING USER SATISFACTION IN HAINING SHADOW PLAY LAMPSHADE DESIGN THROUGH QUESTIONNAIRE AND INTERVIEW-BASED RESEARCH by Hua Tong and Pastraporn Thipayasothorn
4.10 p.m. – 4.30 p.m.	10	APPLYING NANCHONG'S THREE KINGDOMS CULTURE TO THE OUTER PACKAGING DESIGN OF CHUANBEI LIANGFEN: A DESIGN-ORIENTED STUDY WITH YOUNG CONSUMERS by Lanping Wang and Pastraporn Thipayasothorn

Remark: Each presenter will have 15 minutes for presentation and 5 minutes for Q&A (total of 20 minutes).

AI, COMPLEXITY AND RESEARCH-DRIVEN INNOVATION IN FOOD SAFETY

Massimo Martinelli [1]*, Davide Moroni [1],
Thaweesak Yingthawornsuk[2], and Sunti Tuntrakool[3]

massimo.martinelli@isti.cnr.it, davide.moroni@isti.cnr.it,
thaweesak.yin@kmutt.ac.th, and sunti.tu@kmitl.ac.th

[1]Department of Engineering, Signals and Images Laboratory, Institute of Information Science and Technologies of Information, ICT and Technologies for Energy and Transport, National Research Council, 56024, Italy

[2]Department of Media Technology, Faculty of Architecture and Design,
King Mongkut's University of Technology Thonburi,
Bangkok 10510 Thailand

[3]Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang,
Bangkok 10520 Thailand

*Corresponding Author Email: massimo.martinelli@isti.cnr.it

ABSTRACT

In the twenty-first century, food safety is a challenge requiring increasingly capable systems for detecting hazards that often remain invisible to sight, including microbial contamination, oxidative deterioration, small changes in composition, adulterations hidden by globalized and fragmented supply chains. Ensuring the quality and integrity of food today requires both regulatory compliance and real-time monitoring. In this complex environment, Artificial Intelligence (AI) can support us effectively through controls based on past problems and errors and by predicting risks in advance.

Methodologically, this article relies on a narrative review of peer-reviewed scientific works, synthesizing broad international research as well as key studies conducted at the Signals and Images Laboratory of the National Research Council (CNR-ISTI). The analysis covers advancements in precision agriculture related to wheat quality, image classification and segmentation, visible and hyperspectral assessment of milk quality, and the potential of extending these methodologies to rice bran oil authenticity.

The results describe five main points: 1) the significant contribution of AI to prediction, anomaly detection, and multimodal information interpretation; 2) how modern methodologies use computer vision with hyperspectral imaging, spectroscopy, and machine learning methods; 3) concrete cases demonstrating that computational systems can detect information invisible to sight and unaided human perception, though they remain dependent on domain-specific data and expert validation; 4) AI allows for the analysis of huge amounts of data that a human could not handle quickly, however, it should not be used as an autonomous solution, but as a decision support tool that only works when integrated into a well-organized system of laboratory tests, sensors, and clear rules; 5) the final decision about using AI for new problems, must be made by expert researchers and scientists who have to study it to ensure it is seeing and learning information correctly, and that are essential to validate the integrity of automatic results.

Keywords: Food safety, Artificial intelligence, Hyperspectral imaging, Wheat quality, Milk quality, Authenticity, Food systems complexity

1. Statement of the Problem

Food safety is essential for the health of all living things, not just humans. It determines consumer trust and is an essential component that cannot be guaranteed by end-of-production checks alone. According to recent estimates by the World Health Organization (WHO), unsafe food causes approximately 600 million human illnesses and 420,000 deaths each year, of these, 40% are children under 5 years old, moreover, more than 200 foodborne diseases are known (World Health Organization, 2024).

Besides being important for human health, safe food is also useful for promoting sustainable trades and tourism, and to foster consumer confidence.

However, food safety has become more complex today due to global warming altering crops: before reaching our tables, food is subjected to stress because products travel thousands of kilometers in different conditions, and during the various stages of their preservation, they are exposed to various risks.

Today's production processes have become scientifically complex, because problems are often invisible to the naked eye: some adulterations could make food appear perfect, but they may hide dangerous defects such as bacteria, oxidation, or other chemical alterations.

The quality of the controls is fundamental not only for the product examined, and as we have above said for human and animal health, but also for the waste of resources and money, US$ 110 billion is lost each year in productivity and medical expenses resulting from unsafe food in low- and middle-income countries, as well as for the image of the food producer which is damaged (World Health Organization, 2024).

The challenge is therefore both technical and strategic, appearances are often deceiving, and it is necessary to find methods to make any risks visible as soon as possible so that intervention can be made antecedent or at least in time to avoid damage when it is already too late.

The Food and Agriculture Organization of the United Nations (FAO) defines the right to food as a universal human right, while WHO places food safety in a general One Health context in which human, animal, and environmental health are interconnected and influence each other. Therefore, it is not enough to check a label or the expiration date of a product; it is essential to protect the entire ecosystem and agricultural life cycle to have safe food on our tables (Food and Agriculture Organization of the United Nations, n.d.; World Health Organization, 2023).

Ensuring food safety requires more than simply complying with regulations and conducting random post-production checks. A holistic system capable of considering health needs, ecosystems, and market dynamics is essential.

In this context, where the factors at play are complex and multiple, Artificial Intelligence is an essential tool capable of integrating various data sources, not to replace, but to support the decisions of experts in the sectors involved, enabling and improving controls and making them predictive and comprehensive (Dimitrakopoulou and Garre, 2025; Food and Agriculture Organization of the United Nations, 2025).

2. Objectives

This article pursues five objectives.

2.1 First objective: Food safety cannot consist of a final check to discard non-compliant products, but must be the ability to monitor and make transparent all stages of the supply chain,

so as to enable risk prevention and intervention as early as possible upstream, transforming safety into a proactive system that runs continuously throughout the entire production process.

2.2 Second objective: The main AI methods most used in research must be integrated in order to classify products, select them based on their qualities in a non-destructive way so as to analyze food in the most precise and smart way.

2.3 Third objective: This paper presents an analysis of some artificial intelligence techniques used in research to classify and analyze food quality, providing several practical examples of real-world cases to make the theoretical concepts more concrete, showing applications that demonstrate how these technologies work.

2.4 Fourth objective: In addition to the results obtained and already tested, ideas for the future are hypothesized that require further testing.

2.5 Fifth objective: A series of practical tips aimed at researchers, institutions and professionals are provided, in order to explain how to use and transform experimental prototypes into real, safe, and reliable systems.

2.6 Secondary objective: Beyond the primary objectives, the true scientific frontier lies in integrating artificial intelligence as a 'third eye' for the expert, a tool that amplifies perception, capable of bringing out latent details and connections in multidimensional spaces that the human eye, random checks, and traditional working methods could not see.

3. Conceptual Framework and Hypothesis

AI can improve food safety by addressing at least the following areas: managing the complexity of the modern food system, influenced by climate and logistics; improving observability by identifying invisible danger signals within fragmented and confusing data; and providing human "help" to help experts make evidence-based decisions. Often the essential in food is invisible to our eyes, because many of the potential risks are chemical and biological, and their identification requires analytical tools that go beyond human perceptions. On the other hand, we have an invisibility of the technologies since it is complex to decipher the models that can be black boxes, and, therefore, we have to implement and request transparent tools and rules to know how they work.

AI efficacy depends on fundamental pillars such as: a) the quality of information, such as clear images or precise parameters to “see” what is happening; b) models must be trained on verified information or acquired from certified laboratory systems or from the opinion of human experts so as not to learn from incorrect data; c) the results of a system cannot be evaluated with a single test; they must be tested several times and in different situations to exclude the possibility of random responses; d) when information concerns public health, humans must control the results and have the final decision; it can't be left to a machine. Without this foundation, disasters are a risk.

4. Research Methodology

This article adopts a narrative review supported by evidence from scientific practical cases. Regarding the state of the art about observability, complexity, and translational food-safety innovation, authoritative sources such as the WHO and FAO are used, as well as recent studies on AI, hyperspectral imaging, Deep and Machine Learning for image and food quality analysis.

Instead of a narrative overview, agro-industrial cases, including wheat and milk quality, the Efficient Adaptive Ensembling method, visible and hyperspectral analysis of milk quality, and a forward-looking application scenario in rice-bran oil, are treated with scientific rigor. Here the core is the abductive logic, starting from solid cases taken from the literature to verify whether the theory is confirmed in practice, so as to be able to draw conclusions and ideas for future

collaborations and innovations, maintaining due caution with the results and providing a strategic vision for the food safety sector.

5. Results

5.1 Results from the literature synthesis

Artificial intelligence is transforming food safety management, from a system based on final product inspection to a proactive and predictive prevention model. As described by FAO (Food and Agriculture Organization of the United Nations, 2025), this enables the analysis of huge, complex, and heterogeneous data to anticipate risks before they are even visible. The value of this new technology as in (Dimitrakopoulou and Garre, 2025) is the ability to perceive data, reason about it, and act in a continuous cycle supporting real-time decisions. This is in line with this work thesis claiming that the key role of AI is to support early interventions when risk is still invisible (or barely visible) or can be distributed across data sources.

International research, which began with "simple" models for image recognition, is now producing more advanced models capable of considering both minute details and the general context, enabling the identification of complex objects, useful for the analyses required for precision agriculture.

Innovative techniques that adapt pre-trained models, such as Transformer-based architectures and CNN-transformer hybrids, have achieved very high accuracies in recognizing food components (Lin et al., 2025).

Foundation-model approaches (Lan et al., 2025) are also becoming relevant in food-image segmentation. Alahmari et al. (2024) showed that Segment Anything, combined with Low-Rank Adaptation (LoRA), can outperform prior food-image segmentation approaches, reaching 94.14% accuracy on the target task.

Furthermore, the use of deep-learning regression to analyze chemically or physically latent information, obtained for example through spectroscopy, near-infrared (NIR) and hyperspectral imaging (HSI) (Yang et al., 2025) allows to measure food quality and freshness in a non-destructive way (Xiao et al., 2025), and also to monitor oxidation, to detect adulterations, to assess authenticity and other classification issues in which ordinary vision is insufficient.

To measure the effectiveness of a ready-to-use AI, it is not enough to consider only the success rate in tests, because even when it is very high, scientific literature brings us back down to earth by telling us that in reality there may be problems that can compromise its reliability, such as the quality of the data or annotations used to train it, domain shift, calibration transfer, instrument variability, and limited interpretability (Dimitrakopoulou & Garre, 2025; Xiao et al., 2025; Yang et al., 2025).

These results reinforce the thesis that AI systems' ability to identify latent patterns hidden from human perception cannot be left to act autonomously, therefore, a Human-in-the-Loop (HITL) approach is crucial, requiring continuous and rigorous validation, final human control, in addition to clear regulatory frameworks.

5.2 Representative research streams in AI-enabled food safety (summarized in Table 1A)

Many are the examples demonstrating an effective transition from theory to practice in the real-world use of artificial intelligence (some of them are represented in Figure 1).

Imagine having cereals or nuts that appear healthy but as a matter of fact contain dangerous toxins (mycotoxins). Since these substances are invisible to the naked eye and unevenly distributed, it is very difficult to detect them without destroying the product and analyzing it in a chemical laboratory.

To detect them, hyperspectral cameras can be used, which see beyond human vision and are able to detect differences in reflectance between the different chemicals present, creating a true light fingerprint. Artificial intelligence (AI) models are trained to distinguish the typical reflections of healthy foods from those of contaminated foods in order to identify any chemical risks quickly and without damaging them. While these methods require periodic calibration in the laboratory, they represent a significant advance because they allow for the automatic measurement and detection of hazards before they become visible, making foods much safer (Kabir et al., 2025).

Artificial intelligence is essential to ensure food authenticity and safety. Risks can come from accidental contamination, but also from fraud, for example mixing high quality ingredients with lower quality ones, false labelling, and not providing information on the origin of the product.

The latest research is using a suite of advanced tools to tackle these problems, from DNA analysis and chemical signals to technologies like blockchain and the Internet of Things. Such approaches are particularly useful for cases such as rice bran oil, where authenticity is secured by entering the product into a global control system.

The strength of this method resides in the combination of scientific information with mathematical models able to predict irregularities and to guarantee maximum transparency under the control of experts who validate (Marín et al., 2025).

There is also a need for better tools to validate the origin and certainty of information, that is, when, how and where the data was collected, to guarantee that codified knowledge is authentic and unaltered.

Genomic surveillance provides a complementary type of AI-enabled observability by providing microbiological risk information at the level of pathogen relatedness, clustering, and source attribution. The power of whole-genome sequencing for surveillance of foodborne pathogens Pijnacker et al., (2025) describe the implementation of whole-genome sequencing for surveillance of foodborne pathogens, highlighting both its analytical power and the organizational requirements. This stream goes beyond images and spectra to expand the paper, demonstrating that food safety complexity also comprises microbial evolution, antimicrobial resistance, outbreak detection, and one health data exchange. The example supports the case that AI and advanced analytics should be embedded in expert-led surveillance systems and not seen as autonomous decision-makers.

Artificial Intelligence for shelf-life prediction and predictive microbiology, shelf-life prediction adds the time dimension to food safety. The aim is not to classify a product at the time of inspection, but to predict how risk, quality, and degradation will change over time during storage, transport, and distribution. Rashvand et al. (2025) discuss recent AI-based methods for predicting shelf life of different food products using machine learning, deep learning, hybrid models, and non-destructive sensing data. This is a sector directly linked to complex supply chains where interaction over time between temperature, humidity, logistics, packaging, and product composition occurs. It also reinforces the need for validation in real operating conditions, as a model working on a controlled dataset may fail when the distribution context changes (Rashvand et al., 2025).

Industrial machine vision for defects, foreign materials, and process monitoring. A more operational example of AI-enabled food safety is machine vision, particularly on high-throughput production lines where rapid inspection is required. Zhao et al. review the application of machine vision in food computing, including applications in quality assessment, safety monitoring, process control, classification, and industrial production. Unlike hyperspectral or genomic systems, this family of methods frequently finds visible or near-visible anomalies like defects, foreign

materials, packaging mistakes, surface damage, or process deviations. It is valuable for this article because it connects advanced AI methods to common industrial inspection problems, where speed, low cost, and reliability are central requirements (Zhao et al., 2025).

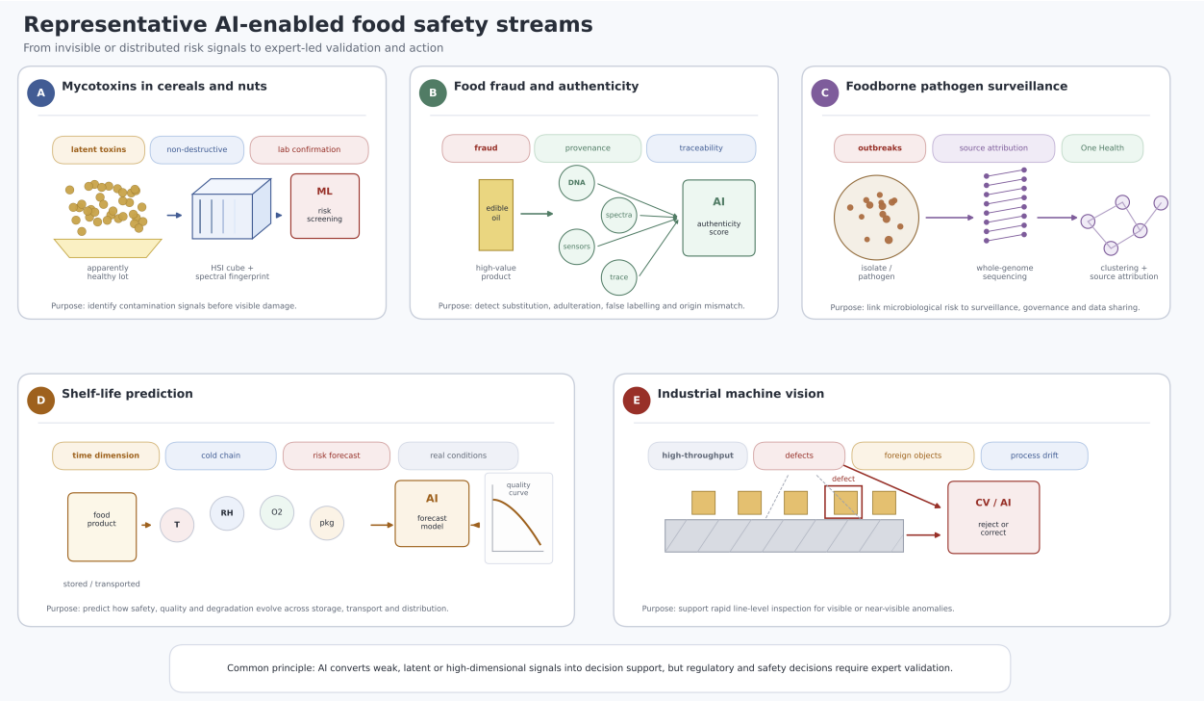

Figure 1 Representative AI-enabled food safety streams: from invisible risk to expert decision

Table 1 Literature-based examples of AI-enabled food safety applications

Case	Data modality	Computational / AI-related task	Evidence status	Limitations
Mycotoxins in cereals and nuts (Kabir et al.)	HSI + machine learning	non-destructive contamination screening	recent international review	requires standardized sampling, spectral calibration, external validation, and reference-method confirmation for regulatory use
Food fraud and authenticity (Marín et al.)	spectroscopy, imaging, chromatographic/spectrometric methods, DNA assays, sensors, ML/AI, blockchain	adulteration, substitution, and authenticity detection	recent international review	requires product-specific validation and traceability

Table 1 (continued)

Case	Data modality	Computational / AI-related task	Evidence status	Limitations
Foodborne pathogen surveillance (Pijnacker et al.)	whole-genome sequencing + epidemiological data	clustering, source attribution, and outbreak surveillance	expert guidance	requires infrastructure, data sharing, expertise, and governance
Shelf-life prediction (Rashvand et al.)	sensors, spectroscopy, HSI, machine vision, metadata	dynamic quality and risk forecasting	recent AI review	product-specific variability, data availability, model generalizability, and computational cost
Industrial machine vision (Zhao et al.)	machine-vision / image-based data	defect, foreign-object, and process-anomaly detection	recent review	limited to image-capturable traits; requires dataset representativeness and line-specific validation

5.3 Applied research cases and translational scenarios (summarized in Table 2)

In the GranoScan project (Dainelli et al., 2024), funded by Barilla S.p.A. to improve wheat quality and health monitoring: today, thanks to this application, farmers can use an app directly in the field that very simply allows them to take a photograph from a cell phone or tablet and have an analysis of what was captured by the camera in almost real time (0.2 seconds).

The images are in fact sent to the most suitable Deep Learning model among a series of models developed to manage them as quickly and safely as possible, demonstrating that methods and technologies can arise from concrete needs in the real world and not just within laboratories.

Figure 2 GranoScan mobile output for early weed identification: Papaver rhoeas seedling, approximately 2 mm, classified from a smartphone image

The implemented Deep Learning models are able to detect the presence of about 100 issues among weeds, insects, and plant diseases that can interfere with proper wheat development, facilitating the initial diagnosis. This application provides targeted, science-based advice for precise and sustainable field interventions, reducing environmental impact and ensuring healthier, residue-free wheat, optimizing yields and minimizing waste while ensuring the rigorous safety standards required to produce pasta and baked goods.

Of course, there are limitations that can be overcome by correcting incorrectly annotated images, increasing the number of images needed to train the models, or improving the models themselves.

However, it is also true that in most cases, those models developed have advanced the state of the art, and in the case of young wheat weeds, it is often observed that AI models outperform agronomists in identifying them (Figure 2), given that experts only know which plant it is because the pot indicates what was sown, but they are unable to recognize it with the naked eye.

Furthermore, the system works with extremely low resource consumption as it only requires a smartphone from the user and a computer with minimal resources from the service manager.

Another example is of a methodological nature: in (Bruno et al., 2025) was proposed a novel method to boost image classification performances without increasing complexity in contrast to the current trend of significantly increasing it despite yielding negligible improvements A new ensemble has been proposed, named Efficient Adaptive Ensemble, the algorithm is based on training two "weak" EfficientNet-B0 models, the least complex EfficientNet architecture that optimizes the balance between depth, width, and network resolution, ensuring high accuracy with low complexity. Then, unlike traditional ensembles that average the final results, this method does

not use a final classification layer but performs feature-level integration: it concatenates the vectors extracted by the two "weak learners" (Figure 3).

This adaptive fusion transforms the ensemble into a data-driven process, where a single final linear layer processes the combined information very efficiently, capable of achieving high performance with dramatically reduced complexity and therefore computational load, outperforming the state of the art on several major benchmarking datasets by an average of 0.5 percentage points, using 5 to 60 times fewer parameters and 10 to 100 times fewer FLOPs.

While this example wasn't specifically designed for food matrices, but was later integrated into the GranoScan app, its relevance to food inspection is straightforward: production systems require high accuracy, even when faced with latency, cost, and implementation constraints.

These, like other examples, for instance connected to plant diseases including Olive tree (Bruno et al., 2023), are chosen to demonstrate the technical solutions needed when the image-based quality control must meet real-time and low-cost constraints.

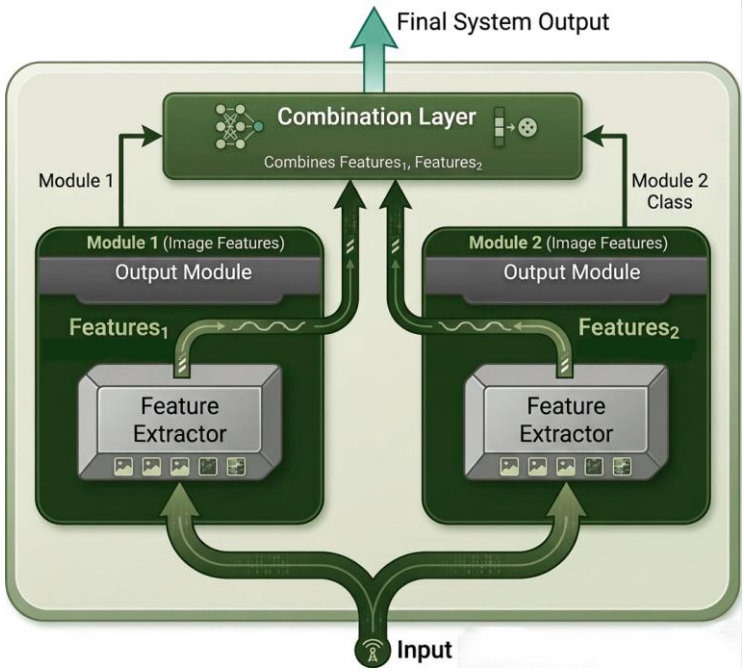

Figure 3 Efficient Adaptive Ensembling architecture: feature fusion of two EfficientNet-B0 weak models for final classification

Another laboratory example deals with semantic segmentation of maize fields and weeds from RGB images taken by unmanned aerial vehicles (UAVs). In this study (Martinelli et al. 2026a), 142 images from two maize fields were processed with U-Net-based models for the segmentation of maize plants, weeds, and bare soil using grouped 5-fold cross-validation. An ablation study on a comprehensive U-Net baseline with ResNet-101 encoder, attention, deep supervision and physics-inspired regularization showed that the best overlap-based performance was achieved after removing deep supervision, while the lowest boundary error was achieved without attention.

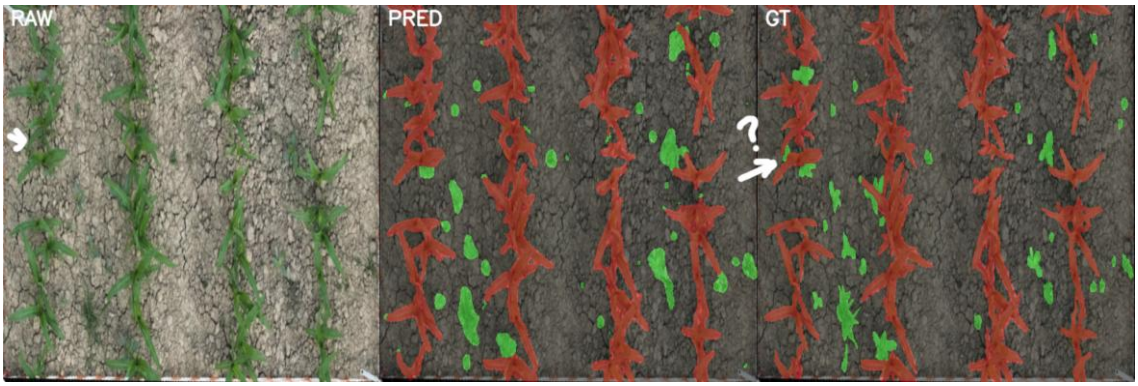

Figure 4 UAV RGB segmentation of maize and weeds: raw image (RAW), model prediction (PRED), and ground-truth annotation (GT). Marked regions highlight small-plant and annotation/boundary issues affecting segmentation metrics

The Excess Green parameter did not provide any benefit. Fixed-threshold reconstruction was always worse. Our results also indicated that the quality of the annotation is important: isolated mislabeled weed pixels at the edges of the image (Figure 4) can increase the distance-based metrics such as HD95. Therefore, the overlap metrics and visual inspection were more reliable for evaluating the weed segmentation in this dataset.
Furthermore, there is a lack of tools that determine the origin and certainty of the information, that is, the conditions relating to the times, methods and places of origin of the information and proof and certainty that the codified knowledge is actually such.

In another recent study the analysis of milk was documented (Martinelli et al. 2026b): 52 cow's milk samples were analyzed using visible imaging analyzing photos taken with a cell phone, and images acquired using a near-infrared hyperspectral camera (Figure 5) capable of seeing beyond the visible spectrum.

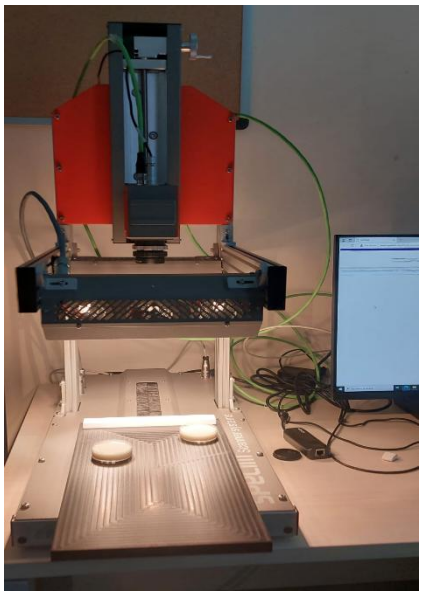

Figure 5 Hyperspectral imaging setup used for non-destructive milk quality assessment

By correlating these data with laboratory biochemical measurements, Machine Learning methods were able to distinguish milk samples by storage time (T0 vs. T12 weeks) with a very high accuracy and determine whether the cows had been treated with antibiotics. The system was also able to measure chemical and nutritional properties (e.g. fatty acids and antioxidants) with a high precision.

Table 2 Application-oriented research cases and prospective extension scenario

Case	Data modality	Computational / AI-related task	Evidence status	Limitations
Wheat quality / GranoScan	RGB/mobile images	classification, early warning	applied industrial case / peer-reviewed method	insufficient or inconsistent annotations in some cases
Efficient Adaptive Ensembling	image datasets	efficient classification	peer-reviewed method	not originally developed for food matrices; food-safety transfer tested in selected application contexts
Maize and weeds	RGB UAV images	semantic segmentation	preprint / empirical case	difficulty in segmenting small plants; annotation noise
Milk quality assessment	visible + hyperspectral imaging	classification/regression	preprint / empirical case	limited sample size
Rice bran oil authenticity	spectral/compositional data	authenticity assessment	prospective research scenario	transferability still unvalidated

5.4 Cross-case interpretation

A number of research studies on mycotoxin detection in cereals, oilseeds and nuts as reviewed by Kabir et al. (2025), confirms that hyperspectral imaging information combined with Machine Learning can reveal contamination-related signals that are not detectable by visual inspection alone, confirming that AI-based observability is particularly valuable when risk is latent, distributed, and chemically mediated.

In the specific case of fusariosis, AI-based imaging can support the early identification of Fusarium-related symptoms and potential mycotoxin risk in this way the system can be able to predict the risk of accumulation of mycotoxins such as deoxynivalenol (DON).

Such systems should be interpreted as screening and decision-support tools rather than replacements for chemical confirmation. Their practical value lies in helping experts decide whether separate batch management, additional testing, or targeted intervention is required before milling.

The examples provided should not be considered isolated findings, but as concrete examples of extensive international research. In mycotoxin detection, food authentication, pathogen genomics, predictive microbiology, and industrial visual inspection, artificial intelligence is increasingly being used to transform weak, latent, or high-dimensional signals into useful information to support expert decisions.

In the samples related to wheat and milk, the AI showed capabilities that exceeded unaided visual inspection in specific, well-defined tasks, being able to determine chemical details or tiny signs of deterioration that the human eye could not detect.

Although AI is faster and better at calculating, it relies on data collected and provided by humans and cannot decide what is acceptable and what is not without human judgment. Responsibility cannot be delegated to AI in cases where human safety, laws, or market quality are at stake, because without transparency, it would also damage consumer trust.

AI must be designed to support and enhance the humans not to replace them, both are imperfect, but humanity must provide wisdom guiding AI in order it can provide suggestions acting also as a critical counterweight, stimulating reflection in case of doubts and even for human mistakes.

Regarding the rice bran oil example, a clarification and a caveat are necessary: if a method, whether AI or otherwise, is capable of distinguishing a good product from a bad one, for example, good wheat and wheat from weeds, or milk with high antioxidant qualities from less valuable milk, it's not guaranteed that it can be reused to identify other problems, such as whether rice bran oil is high-quality or not.

Each item or product has different physical and chemical characteristics, and we can't say whether the AI already used for milk will work equally well for oil; that would be unprofessional. Humbly, what works in the field is an excellent hypothesis for trying to understand whether research is effective for other problems. Furthermore, what the human eye can see can be indicative of whether AI can be applied to help us, but there is no scientific certainty without the scientific method.

6. Conclusion and Discussion

The greatest challenges and dangers today are not, or at least no longer, identifying a damaged food or a bad odor. They are rather the things we don't see, like bacteria and chemical residues. Unfortunately, we often only notice problems when someone is already sick or when it becomes necessary to throw away large quantities of products, sometimes resulting in enormous economic losses.

AI has become useful today because it extends human capabilities, analyzing spectral information that can reveal the chemical composition of food, statistical data to predict where a new foodborne epidemic might start based on previously collected data, and complex information such as transportation connections, temperatures, and humidity that a human would be unable to mentally assess, analyses that only scientists can interpret responsibly.

Having powerful AI isn't enough to make a difference; it must be built on solid and responsible foundations. The question we need to ask ourselves isn't how powerful the model is, but whether it has been implemented using an ecosystem of solid components, made up of high-quality, non-randomly collected information, capable of providing explainable results, evaluated by human experts who certify its correct functioning, and ethically sound, with each component having clear accountabilities.

Only under these conditions, an AI can be considered a credible, trustworthy tool for health protection, that is safe, traceable, and efficient.

These cases help to better understand the problem. With wheat, for example, it's clear how automation serves first and foremost to eliminate the arbitrariness of human judgments in the factory. Adaptive Ensembling demonstrates a simple fact: a huge and expensive model doesn't necessarily perform better than a lean one.

Milk hyperspectral imaging is also interesting, indicating that sometimes a seemingly basic image is enough for extracting complex chemical data, as long as it is supported by a solid analysis method behind it. With rice bran oil instead, the message is of caution, since we can't take a system's flexibility for granted until we test it in the field.

In essence, AI can make food safety much more transparent, but only if we maintain a rigorous scientific approach.

It's important to stay grounded on rice bran oil, because until it's tested, it won't be clear whether the system will work.

In conclusion, Artificial Intelligence can help us understand the food we eat, but the data must be validated in the field by experts. The use of hyperspectral cameras allows us to see beyond the visible, but it complicates matters because the data must be interpreted and correlated with traditional instrumentation. Food safety must be supported by an integrated system of checks, and humans must perform the final check responsibly.

7. Suggestions

This work would like to suggest some directions for future research, starting with the creation of multimodal benchmarking datasets including images, spectral data, laboratory reference values, and information related to industrial processes to facilitate comparisons between different studies.

To prevent risks, it is essential that AI models applied to food and health safety, especially when systems are proposed for early warning or screening rather than retrospective classification, should be tested regularly, assessing their ability to adapt to different cases, and also their reliability.

At the same time, research must focus on developing low-complexity, efficient models capable of operating accurately even with instruments with power and speed limitations, thus consuming less energy.

For valuable products, such as rice bran oil or comparable matrices, clear control protocols must be defined including precise sampling, testing under different conditions, and comparative analyses with reference compositional analytics to explain the results, as well as optical and hyperspectral acquisitions.

Academia and funders should also reward the novelty and accuracy of the work, as well as its replicability and governance readiness.

Given that this paper originated from a keynote lecture, future work could extend this reflective and translational perspective by more broadly comparing international research contributions and placing the suggested cases in the wider scientific and technological context of AI-enabled food safety.

8. Acknowledgements

The authors gratefully acknowledge Professor Paryiaporn for providing the institutional environment within which the underlying research and reflections matured. Particular thanks go to Professor Laura Pucci, whose biochemical expertise was essential for interpreting complex biological scenarios and whose support helped make this opportunity possible. The authors also thanks Professor Giuseppe Riccardo Leone; without their joint efforts, the effective collaboration with Thailand would not have begun. Sincere thanks are also extended to the School of Industrial Education and Technology KMITL and the King Mongkut's University of Technology Thonburi

KMUTT. The author further thanks the organizing committee of the 22nd International Conference on Developing Real-Life Learning Experiences: Technology and AI Driving Innovation and Research for the invitation to deliver the keynote lecture from which this article was developed.

9. References

Alahmari, S. S., Gardner, M., & Salem, T. (2024). Segment anything in food images. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (pp. 2133-2138). https://doi.org/10.1109/CVPRW63382.2024.00375

Bruno, A., Moroni, D., & Martinelli, M. (2023). Efficient deep learning approach for olive disease classification. 2023 18th Conference on Computer Science and Intelligence Systems (FedCSIS), 889–894. https://doi.org/10.15439/2023F4794

Bruno, A., Moroni, D., & Martinelli, M. (2025). Efficient adaptive ensembling for image classification. Expert Systems, 42(1), e13424. https://doi.org/10.1111/exsy.13424

Dainelli, R., Bruno, A., Martinelli, M., Moroni, D., Rocchi, L., Morelli, S., Ferrari, E., Silvestri, M., Agostinelli, S., La Cava, P., & Toscano, P. (2024). GranoScan: An AI-powered mobile app for in-field identification of biotic threats of wheat. Frontiers in Plant Science, 15, 1298791. https://doi.org/10.3389/fpls.2024.1298791

Dimitrakopoulou, M.-E., & Garre, A. (2025). AI's intelligence for improving food safety: Only as strong as the data that feeds it. Current Food Science and Technology Reports, 3, Article 15. https://doi.org/10.1007/s43555-025-00060-0

Food and Agriculture Organization of the United Nations. (n.d.). Right to food. Retrieved April 20, 2026, from https://www.fao.org/right-to-food/en/

Food and Agriculture Organization of the United Nations. (2025). Artificial intelligence for food safety. https://doi.org/10.4060/cd7242en

Kabir, M. A., Lee, I., Singh, C. B., Mishra, G., Panda, B. K., & Lee, S.-H. (2025). Detection of mycotoxins in cereal grains and nuts using machine learning integrated hyperspectral imaging: A review. Toxins, 17(5), Article 219. https://doi.org/10.3390/toxins17050219

Lan, X., Lyu, J., Jiang, H., Dong, K., Niu, Z., & Zhang, Y. (2025). FoodSAM: Any food segmentation. IEEE Transactions on Multimedia, 27, 2795–2808. https://doi.org/10.1109/TMM.2023.3330047

Lin, M., Gao, Z., Liao, W., & Cai, H. (2025). A systematic review of transformer-based vision models for object detection in food and agriculture. Acta Scientiarum Polonorum Technologia Alimentaria, 24(4), 489-511. https://doi.org/10.17306/J.AFS.001425

Marín, X., Grau-Noguer, E., Gervilla-Cantero, G., Ripolles-Avila, C., & Castillo, M. (2025). Emerging technologies for detecting food fraud: A review of the current landscape in the 2020s. Trends in Food Science & Technology, 165, Article 105313. https://doi.org/10.1016/j.tifs.2025.105313

Martinelli, M., Ercolini, L., Grossi, N., Silvestri, N., & Moroni, D. (2026a). What improves UAV RGB segmentation of maize and weeds? An ablation study of U-Net components. IEEE Conference on Federated Conference on Computer Science and Information Systems (FedCSIS), Workshop on AI in Agriculture (AgriAI).

Martinelli, M., Tomassi, E., Arouna, N., Gabriele, M., Fabbri, L. P., Pozzo, L., Conte, G., Moroni, D., & Pucci, L. (2026b). Visible and hyperspectral imaging for quality assessment of milk: Property characterisation and identification. arXiv. https://arxiv.org/abs/2602.12313

Pijnacker, R., van den Beld, M., Ullrich, A., Ceyssens, P.-J., van Cauteren, D., Jore, S., Nielsen, E. M., Ethelberg, S., Morabito, S., Lanzl, M., & Franz, E. (2025). Implementing whole genome sequencing for foodborne pathogen surveillance: Insights and recommendations based on expert experiences. Frontiers in Microbiology, 16, Article 1707621. https://doi.org/10.3389/fmicb.2025.1707621

Rashvand, M., Ren, Y., Sun, D.-W., Senge, J., Krupitzer, C., Fadiji, T., Sanzo Miró, M., Shenfield, A., Watson, N. J., & Zhang, H. (2025). Artificial intelligence for prediction of shelf-life of various food products: Recent advances and ongoing challenges. Trends in Food Science & Technology, 159, Article 104989. https://doi.org/10.1016/j.tifs.2025.104989

World Health Organization. (2023, July 3). One Health definitions and principles. https://www.who.int/publications/m/item/one-health-definitions-and-principles

World Health Organization. (2024, October 4). Food safety. https://www.who.int/news-room/fact-sheets/detail/food-safety

World Health Organization. (2025, November 13). Food safety. https://www.who.int/health-topics/food-safety

Xiao, Y., Zhou, L., Zhao, Y., Qi, H., Pu, Y., & Zhang, C. (2025). Deep learning-based regression of food quality attributes using near-infrared spectroscopy and hyperspectral imaging: A review. Food Chemistry, 472, 145932. https://doi.org/10.1016/j.foodchem.2025.145932

Yang, C., Guo, Z., Barbin, D. F., Dai, Z., Watson, N., Povey, M., & Zou, X. (2025). Hyperspectral imaging and deep learning for quality and safety inspection of fruits and vegetables: A review. Journal of Agricultural and Food Chemistry, 73(17), 10019-10035. https://doi.org/10.1021/acs.jafc.4c11492

Zhao, Z., Wang, R., Liu, M., Bai, L., & Sun, Y. (2025). Application of machine vision in food computing: A review. Food Chemistry, 463(Part 4), Article 141238. https://doi.org/10.1016/j.foodchem.2024.141238

THE NEXUS OF SELF-LEARNING ABILITY AND SOCIAL SCAFFOLDING: A NEW CONCEPTUAL FRAMEWORK FOR DIGITAL INNOVATION ADOPTION AMONG THAI OLDER ADULTS

Pimnatchaya Satchasin*, Toosrangrasame Tetakew, and Amnuay Saengnoree

pimnatchaya.s@gmail.com, toosrangrasame.te@kmitl.ac.th, and amnuay.sa@kmitl.ac.th

College of Innovation and Industrial Management,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: pimnatchaya.s@gmail.com

ABSTRACT

This research aimed to examine the factors influencing behavioral intention and the adoption of digital media literacy platforms among Thai older adults while proposing an integrated conceptual framework that reflects both technological determinants and the socio-cultural needs of aging learners. Developed as a conceptual paper based on a systematic literature review and methodological synthesis, the study combines the Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB), and Diffusion of Innovations (DOI) to formulate a Socio-Technical Negotiation Paradigm for digital innovation adoption. In addition, the paper outlines directions for future empirical validation through Structural Equation Modeling (SEM), with a recommended sample of approximately 200 Thai older adults and 30 in-depth interviews to provide contextual insights and refine the proposed model.

Results: The findings reveal that individual cognitive readiness, represented by Self-Learning Ability (SL), serves as a significant antecedent to both Attitude (ATT) and Behavioral Intention (Beh). Furthermore, the platform's systemic innovation (DMLI) significantly moderates the adoption process. Notably, the study demonstrates that digital adoption is not merely a rational individual choice but a collaborative process mediated by Social Scaffolding—familial support and intergenerational validation—which significantly narrows the Intention-Action Gap. The proposed framework highlights that perceived ease of use functions as a prerequisite for Digital Empowerment rather than mere operational efficiency.

Contribution: This research provides a novel paradigm for digital aging, offering three strategic contributions: (1) redefining media literacy as Relational Literacy that preserves social harmony, (2) operationalizing AI/Algorithmic Literacy as a defensive cognitive tool for the elderly, and (3) establishing a policy roadmap that integrates state infrastructure, corporate digital responsibility (CDR), and pedagogical support to transform older adults from passive media consumers into Empowered Digital Citizens. These findings serve as a cornerstone for future lifelong learning policies in collectivist societies.

Keywords: Digital media literacy, Aging society, Socio-technical negotiation, Social scaffolding, Digital empowerment, KMITL platform

1. Statement of the Problem

Thailand is undergoing a rapid transition toward an aging society, with the proportion of individuals aged 60 and above projected to exceed 20percent of the total population (National Statistical Office, 2025). This demographic shift, consistent with global trends (UN, 2022), is accompanied by declining fertility rates and a shrinking workforce, resulting in increasing socio-

economic pressures. As a result, the need for inclusive policies that promote active aging, social participation, and lifelong learning has become increasingly important (WHO, 2021).

Learning, as a process of behavioral and cognitive change (Gagné, 1985; Piaget, 1972), has evolved into a lifelong necessity in the digital era. Lifelong learning enhances cognitive functioning, well-being, and social inclusion (Field, 2019). However, older adults continue to face important barriers, including limited digital skills, physical constraints, and low motivation, which restrict their participation in digital learning environments (Rasi et al., 2021; Zaid et al., 2022). In this context, digital media literacy has become a crucial competency because it enables individuals to access, analyze, evaluate, and use information critically and responsibly (UNESCO, 2023). This competency is especially important for older adults, who are more vulnerable to cyber risks such as misinformation, fraud, and privacy threats (Livingstone et al., 2021).

Despite the expansion of digital learning platforms, significant gaps remain in the literature. Existing studies have primarily focused on younger populations or general digital skills, resulting in limited understanding of technology adoption among older adults, particularly in aging societies and emerging economy contexts such as Thailand (Venkatesh et al., 2003; Spante et al., 2018). Moreover, the prevailing discourse tends to overlook important socio-cultural characteristics of the Thai context, including intergenerational hierarchy, communal learning values, and the concept of kreng jai, which reflects deference and social consideration, all of which may significantly shape how older adults perceive and engage with digital technologies. In addition, prior research has frequently examined digital literacy, attitudinal factors, and technology acceptance as separate constructs, leading to a fragmented understanding of how these variables, when influenced by local cultural contexts, jointly affect behavioral intention and actual use. Consequently, empirical and conceptual evidence that integrates self-learning ability, digital media literacy innovation, attitude, behavioral intention, and actual use within a unified and culturally grounded framework remains limited.

To extend the traditional Technology Acceptance Model (TAM), this study proposes an 'Integrated Cognitive-Technological Readiness Framework' which specifically addresses the idiosyncrasies of older adults in emerging economies. By augmenting the exogenous variables of Perceived Ease of Use and Perceived Usefulness with Self-Learning Ability (as a psychological enabler) and Digital Media Literacy Innovation (as a technological affordance), this framework shifts the focus from mere functional utility to 'empowerment-oriented adoption.' This novelty lies in conceptualizing Attitude not merely as a precursor to intention, but as a dynamic psychological 'filter' that mediates the interaction between an individual's cognitive readiness and the platform's nuanced usability. By employing Structural Equation Modeling (SEM) to test these multi-dimensional interdependencies, this study offers a sophisticated departure from conventional models, providing a robust, user-centric paradigm for designing digital environments that foster resilient lifelong learning and meaningful digital participation among aging populations.

"Guided by this framework, this study primarily aims to empirically validate the causal relationships among self-learning ability, digital media literacy innovation, attitude, behavioral intention, and actual use of digital learning platforms. By bridging the Technology Acceptance Model (TAM) with these contemporary constructs, this research addresses two core objectives: first, to examine the complex causal interplay between individual readiness and technological drivers in digital learning; and second, to develop a validated conceptual framework that explains older adults' behavioral intention and actual usage. Ultimately, this study contributes to a more nuanced understanding of technology adoption, offering actionable insights for the design of user-centered platforms that narrow the digital divide, promote active aging, and foster sustainable lifelong learning in the digital era (WHO, 2021)."that support lifelong learning, reduce the digital divide, and promote active aging in the digital era (WHO, 2021).

2. Objectives

2.1 To examine the causal relationships among self-learning ability, digital media literacy platform innovation, attitude, behavioral intention, and actual use in digital learning environments.

2.2 To develop a conceptual framework that explains users' behavioral intention and actual use by integrating individual and technological factors in digital learning contexts.

3. Conceptual Framework

3.1 Toward a Socio-Technical Paradigm of Digital Adoption

The theoretical foundation of this study departs from conventional "autonomy-centric" models, such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT). These traditional frameworks primarily view technology adoption as a linear, individualistic decision-making process rooted in rational choice. By critically interrogating the assumptions inherent in these frameworks, this research posits that technology adoption among Thai older adults is not a rational, isolated endeavor, but a socially-situated process of negotiation. In this paradigm, the "Intention-Action Gap" is addressed by acknowledging that individual cognitive readiness is constantly mediated by familial influence and intergenerational validation—dynamics that are foundational to the Thai aging experience.

3.2 The Integrated Framework: Key Theoretical Divergences

To reconcile global theoretical constructs with the practical realities of the Thai aging society, the proposed framework integrates three critical paradigm shifts:

From Decoding to Relational Literacy: Moving beyond the T.A.P. model's focus on individual text analysis, this study adopts a socio-technological competence framework. It acknowledges the "relational cost" of critical inquiry within kinship dynamics, emphasizing the preservation of social harmony alongside digital resilience.

From Algorithmic Blindness to AI Empowerment: By framing AI Literacy as a critical cognitive tool rather than mere technical training, the model incorporates "social scaffolding"—an architecture that leverages familial support to mitigate cognitive load and algorithmic manipulation risks.

From Rational Choice to Collective Validation: Departing from the binary of "acceptance vs. rejection," this framework conceptualizes technology adoption as a journey of continuous integration. Here, "Perceived Ease of Use" is re-envisioned as a prerequisite for Digital Empowerment rather than a mere operational metric.

3.3 Theoretical Integration: Reconciling Global Constructs

The following synthesis reconciles global theoretical paradigms with the practical realities of the Thai aging society:

Table 1 Theoretical re-conceptualization for Thai older adults

Theoretical Anchor	Classical Assumption	Research Innovation (Thai Context)
TAM/UTAUT	Rational, autonomous user	Socio-technical negotiation (Familial mediation)
DOI (Rogers)	Individual opinion leadership	Collective social validation & kinship ties
Media Literacy	Individual critical decoding	Relational literacy & algorithmic resilience
Learning Theory	Procedural skill acquisition	Cognitive empowerment & self-actualization

Synthesis of Literature and Research Gap Identification

"A critical review of the existing literature—both international and within the Thai context—reveals that while Digital Media Literacy (DML) has garnered significant academic interest, there remain critical research gaps that this study aims to address. Specifically, three key dimensions are identified:

1. Beyond Technical Skills to Socio-Technical Negotiation: Existing research predominantly focuses on measuring foundational digital skills and adoption through standard frameworks, such as TAM or UTAUT. However, these models often overlook the 'socio-technical negotiation' inherent in the Thai context, where digital adoption is not an isolated individual pursuit, but a collaborative process mediated by family networks and kinship dynamics.

2. The Imperative of Algorithmic and AI Literacy: In an era where misinformation is increasingly sophisticated due to generative AI, prior studies (e.g., Celik et al., 2021) have established foundational theories regarding epistemological beliefs. Yet, there remains a notable lack of research concerning how Thai older adults can develop 'digital resilience' against opaque algorithmic manipulation.

3. From Passive Receivers to Agents of Change (Empowerment through Social Scaffolding): Previous studies have largely framed older adults as a 'vulnerable' demographic. This research proposes a paradigm shift, positioning older adults as active co-creators of media and community leaders. By conceptualizing the learning platform as a form of 'social scaffolding,' this study aims to bolster digital self-efficacy and ensure sustainable quality of life.

Consequently, this research integrates Innovation Adoption theories (DOI/TAM/UTAUT) with Humanist learning perspectives and digital competence frameworks. This synthesis provides a nuanced paradigm designed to develop a learning platform that is authentically aligned with the unique lifestyle and socio-cultural fabric of Thai aging society."

4. Research Methodology

This study adopts an exploratory research approach to investigate the factors influencing users' behavioral intention and actual use of a digital media literacy innovation platform. This approach is appropriate for examining emerging phenomena in digital learning contexts, where existing knowledge is still evolving, allowing for the identification of key variables and the exploration of relationships among them through theoretical and empirical perspectives.

To ensure the theoretical rigor and empirical validity of this study, a systematic literature review (SLR) approach was adopted. The search strategy was conducted across prominent academic databases—including Scopus, Web of Science, and Google Scholar—focusing on literature published between 2020 and 2026. Keywords utilized for the search included a strategic combination of terms: "Digital Media Literacy," "Older Adult Technology Adoption," "Self-Directed Learning," "Technology Acceptance Model (TAM)," and "Structural Equation Modeling." The selection of articles followed strict inclusion and exclusion criteria: (1) peer-reviewed academic journals in the fields of Public Administration, Communication, and Information Systems; (2) studies specifically addressing the digital learning behaviors of the elderly or aging populations; and (3) empirical research utilizing quantitative methodologies, particularly those employing Structural Equation Modeling (SEM). This rigorous screening process ensured that the conceptual framework was built upon high-quality, relevant, and recent evidence, effectively bridging the gap between theoretical constructs and the practical realities of the Thai digital aging society.

4.1 Sampling Plan

The target population of this study consists of Thai older adults (aged 60 and above) who engage with digital learning platforms. To ensure representativeness and robust data for Structural Equation Modeling (SEM), this study employs a stratified random sampling technique, categorized by geographical region. The sample size is calculated based on the criteria established

by Hair et al. (2019), aiming for a ratio of 10–15 observations per indicator to ensure the stability of the model's parameters and statistical power.

4.2 Research Instruments

Data collection will be conducted using a structured online questionnaire consisting of five key constructs:

1. Self-Learning Ability (SL): Measured using items adapted from the Self-Directed Learning Readiness Scale (SDLRS), covering self-awareness, self-development, and critical thinking.
2. Digital Media Literacy Platform Innovation (DMLI): Operationalized through platform-specific affordances, focusing on ease of registration, interface accessibility, and content relevance.
3. Attitude (ATT): Evaluated through cognitive, affective, and behavioral dispositional scales toward the platform.
4. Behavioral Intention (Beh): Measured based on the user's planning, trial usage, and willingness to recommend the innovation.
5. Actual Use (Use): Assessed through self-reported frequency and duration of platform engagement.

4.3 Instrument Quality and Validation

1. To guarantee the validity and reliability of the research instruments, the following procedures will be implemented:
2. Content Validity: An expert panel (3–5 specialists in Public Administration, Communication, and Educational Technology) will evaluate the items to calculate the Item-Objective Congruence (IOC) index, requiring a minimum score of 0.5 for all items.
3. Pilot Testing: A pilot study will be conducted with a sample of 30 older adults to assess the internal consistency of the constructs using Cronbach's Alpha, with a threshold of alpha > 0.75.
4. Construct Validity: During the data analysis phase, Confirmatory Factor Analysis (CFA) will be employed to ensure that the measurement model achieves acceptable goodness-of-fit indices and satisfies convergent and discriminant validity criteria.

4.4 Variables and Conceptual Model

The variables in this study are derived from established theories and recent empirical research in digital learning and information systems. The conceptual model consists of five key constructs:

1. Self-Learning Ability (SL): encompassing basic needs, self-directed learning, self-awareness, self-development, self-worth, and critical thinking skills.
2. Digital Media Literacy Platform Innovation (DMLI): encompassing platform registration, platform understanding, and Media and Information Literacy (MIL).
3. Attitude (ATT): representing users' cognitive, affective, and behavioral dispositions.
4. Behavioral Intention to Use (Beh): reflecting users' planning, trial usage, and willingness to recommend the innovation.
5. Actual Use (Use): representing the final outcome of the model.

These variables collectively form the conceptual framework used to explain technology adoption in digital media literacy platforms, as illustrated in Figure 1.

4.5 Hypotheses Development

Based on the theoretical foundation, this study proposes that both individual and technological factors influence users' attitudes and behavioral intentions. Self-learning ability is expected to positively influence both attitude and behavioral intention to use, as individuals with higher learning autonomy are more capable of adapting to digital environments. Digital media literacy platform innovation is also hypothesized to significantly affect users' attitudes and behavioral intention to use, particularly through platform usability and accessibility.

Furthermore, attitude is proposed as a key mediating variable linking self-learning ability and behavioral intention to use, while also directly influencing behavioral intention. Finally, behavioral intention is expected to significantly predict actual use, representing the ultimate outcome of the model. These relationships are summarized in the following research objectives:

1. To investigate the impact of self-learning ability on users' attitudes and behavioral intention to use a digital media literacy platform.
2. To examine the influence of digital media literacy platform innovation on users' attitudes toward the platform.
3. To determine the role of digital media literacy platform innovation in shaping users' behavioral intention.
4. To analyze the effect of attitude on behavioral intention.
5. To test the mediating role of attitude in the relationship between self-learning ability and behavioral intention.
6. To assess the influence of behavioral intention on the actual use of the platform.

As illustrated in Figure 1, the framework integrates individual factors, such as self-learning ability, and technological factors, such as digital media literacy innovation, to explain users' decision-making processes and actual usage behavior in digital learning environments. Self-learning ability (SL) is proposed as a key individual factor that directly affects both attitude (ATT) and behavioral intention (Beh), while digital media literacy innovation (DMLI) represents the technological dimension, influencing users' perceptions and intention to use the platform. Attitude (ATT) serves as the central mediating construct, and behavioral intention (Beh) is positioned as the direct predictor of actual use (Use). The relationships among these variables are summarized and presented in Table 2.

Table 2 The direct and indirect relationship of relevant variables:

Variables	**Relationship**	**References**
Self-learning ability includes (SL)	SL → Beh	Dwivedi et al. (2020); Nikou & Economides (2021)
Self-learning ability includes (SL)	SL → ATT	Salloum et al. (2021); Haleem et al. (2022)
Digital Media Literacy Platform Innovation (DMLI)	DMLI → ATT	Al-Emran et al. (2020); Bond et al. (2020)
Digital Media Literacy Platform Innovation (DMLI)	DMLI → Beh	Chatterjee et al. (2021); Almaiah et al. (2020)
Attitude (Att)	Att → Beh	Nikou & Economides (2021); Salloum et al. (2021)
Self-learning ability includes (SL)	SL → Beh, SL → Att, Att → Beh	Dwivedi et al. (2020); Salloum et al. (2021); Chatterjee et al. (2021)
Attitude (Att)	Att → Beh, DMLI → Att, DMLI → Beh	Nikou & Economides (2021); Salloum et al. (2021); Al-Emran et al. (2020) Chatterjee et al. (2021); Dwivedi et al. (2020); Haleem et al. (2022)

Operational Definitions of Research Constructs

Table 3 outlines the operationalization of the research constructs, transforming latent theoretical concepts into measurable variables to ensure empirical rigor. The operationalization process reflects the integration of psychological readiness, systemic innovation, and behavioral outcomes within the proposed Socio-Technical Negotiation Paradigm.

1. Self-Learning Ability (SL)

SL serves as the foundational independent variable, representing the user's cognitive and psychological capital. Rather than measuring mere knowledge acquisition, this construct focuses on autonomy and self-directedness. Operationally, it is defined by the user's capacity to initiate learning (self-awareness), sustain it (self-development), and evaluate information critically.

2. Digital Media Literacy Platform Innovation (DMLI)

DMLI constitutes the systemic antecedent, representing the platform's technological and design affordances. Operationally, this construct is defined by its user-centric functionality—measuring whether the platform facilitates a seamless transition from registration to practical content engagement, thereby reducing cognitive load and technological anxiety for older adults.

3. Attitude (ATT)

ATT functions as the central mediating construct. It bridges the gap between the learner's intrinsic readiness (SL) and the platform's systemic quality (DMLI). By assessing the cognitive, affective, and behavioral dispositions toward the innovation, this construct captures the "socio-technical negotiation" the process where older adults reconcile their beliefs, feelings, and behavioral tendencies before committing to the technology.

4. Behavioral Intention (Beh)

This construct captures the motivational state of the user. It moves beyond passive interest to evaluate proactive commitment. Operationally, it measures the likelihood of adoption through concrete indicators: planning to engage, performing trial usage, and the willingness to act as an agent of change by recommending the platform to others (social validation).

5. Actual Use (Use)

As the dependent variable and the study's ultimate outcome, Actual Use evaluates the sustainability of the digital adoption process. It shifts the definition of success from mere registration to meaningful engagement—quantified by interaction frequency and duration—which serves as a proxy for the successful integration of digital literacy into the older adult's daily learning life.

6. Results

This study aims to explore the following aspects: (1) the impact of self-learning ability on users' attitudes and behavioral intention to use a digital media literacy innovation platform, (2) the influence of digital media literacy platform innovation on users' attitudes toward the platform,(3) the role of digital media literacy platform innovation in shaping users' behavioral intention to use the platform,(4) the effect of attitude on behavioral intention,(5) the mediating role of attitude in the relationship between self-learning ability and behavioral intention, and (6) the influence of behavioral intention on actual use of the platform.

These relationships are interconnected and collectively form the conceptual framework of this study, as illustrated in Figure 1. The framework integrates both individual factors, such as self-learning ability, and technological factors, such as digital media literacy innovation, to explain users' decision-making processes and actual usage behavior in digital learning environments.

Figure 1 illustrates the conceptual framework of this study, integrating both individual cognitive readiness and technological innovation factors to explain the adoption of the digital media literacy platform.

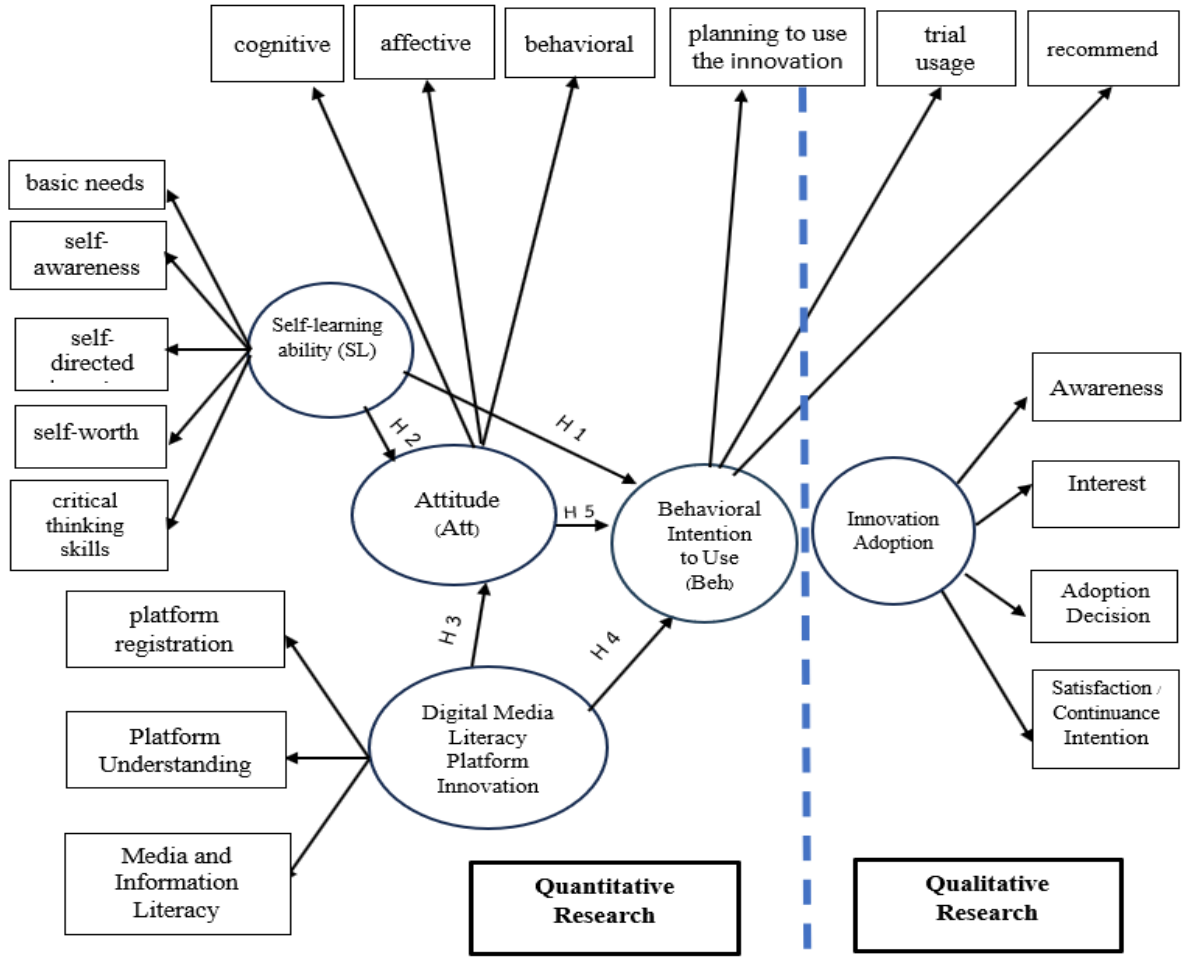

Figure 1 Conceptual framework of the relationship of relevant variables

Individual Factor: Self-Learning Ability (SL) is proposed as a core antecedent, reflecting the user's psychological capacity to manage learning processes.

Technological Factor: Digital Media Literacy Innovation (DMLI) represents the platform's systemic characteristics, including its usability, accessibility, and content relevance.

Mediating Construct: Attitude (ATT) serves as the central mediating construct, reflecting the evaluative and affective responses that translate cognitive readiness and technological features into behavioral resolve.

Outcome: Behavioral Intention to Use (Beh) is hypothesized as the direct predictor of Actual Use (Use), representing the final behavioral stage of the adoption process.

Overall, the framework demonstrates both direct and indirect relationships among variables, providing a comprehensive explanation of the adoption and usage of digital media literacy platforms in contemporary learning environments.

Based on the theoretical synthesis and the proposed conceptual framework, the following hypotheses are formulated:

H1: Self-learning ability (SL) has a significant direct positive influence on behavioral intention to use (Beh) the digital media literacy innovation platform.

H2: Self-learning ability (SL) has a significant direct positive influence on attitude toward (ATT) the digital media literacy innovation platform.

H3: Digital media literacy innovation (DMLI) has a significant direct positive influence on attitude toward (ATT) the platform.

H4: Digital media literacy innovation (DMLI) has a significant direct positive influence on behavioral intention to use (Beh) the platform.

H5: Attitude toward the innovation (ATT) has a significant direct positive influence on behavioral intention to use (Beh) the digital media literacy innovation platform.

Table 3 Operational definitions of research constructs

Variable (Construct)	Operational Definition	Key Dimensions
1. Self-Learning Ability (SL)	The individual's readiness, autonomy, and capacity to initiate, manage, and sustain their own learning process within digital environments.	Basic needs; self-directed learning; self-awareness; self-development; self-worth; critical thinking.
2. Digital Media Literacy Platform Innovation (DMLI)	The technological affordances and functional features of the platform designed to facilitate user access, understanding, and media-informed engagement.	Platform registration; interface accessibility; media and information literacy (MIL) integration.
3. Attitude toward Innovation (ATT)	The user's evaluative psychological predisposition toward the platform, manifesting in cognitive belief, affective feeling, and behavioral readiness.	Cognitive (belief); Affective (feeling); Behavioral (disposition).
4. Behavioral Intention (Beh)	The extent of the user's conscious plan, trial engagement, and advocacy regarding the adoption of the innovation.	Planning to use; trial usage; willingness to recommend.
5. Innovation Acceptance (Use)	The behavioral manifestation of technology adoption, ranging from initial awareness to sustained, long-term practical application.	Awareness; interest; decision-making; continuous usage

6. Conclusion and Discussion

This study developed a conceptual framework to explain users' behavioral intention to use or actual use of a digital media literacy innovation platform by integrating self-learning ability (SL), digital media literacy platform innovation (DMLI), attitude (ATT), and behavioral intention to use (Beh). In line with the study's exploratory approach, the discussion is based on conceptual framework and literature synthesis rather than empirical model testing. The proposed framework therefore provides a theoretical explanation of how individual and technological factors may jointly shape adoption behavior in digital learning environments.

The conceptual findings suggest that self-learning ability is a foundational individual factor influencing both attitude and behavioral intention to use. Users with stronger self-directed learning, self-worth, self-awareness, self-development, and critical thinking are more likely to evaluate a digital Media Literacy platform innovation positively and demonstrate a stronger intention to use it. This highlights the importance of internal learning capability as a key driver of engagement in digital learning contexts. At the same time, digital media literacy platform innovation functions as a major technological determinant. Platform usability, accessibility,

content relevance, and user engagement are expected to strengthen users' positive attitudes and directly support their intention to adopt the platform.

Another important finding of the proposed framework is the central role of attitude as a mediating mechanism. The model suggests that self-learning ability does not only influence behavioral intention directly, but also indirectly through users' evaluative responses toward the platform. In other words, users who perceive the platform as useful, accessible, and appropriate are more likely to translate their internal learning capability into a stronger intention to use it. In addition, behavioral intention to use is positioned as the most immediate predictor of actual use, indicating that intention remains a critical pathway through which users' perceptions and evaluations are converted into real engagement with the platform.

From a theoretical perspective, this study contributes to the technology adoption literature by extending the Technology Acceptance Model (TAM) through the integration of self-learning ability and digital media literacy platform innovation within a single conceptual framework. The framework captures both direct and indirect relationships among variables and offers a more comprehensive explanation of technology adoption in digital learning environments. Importantly, it moves beyond a narrow focus on intention alone by incorporating actual use as the final outcome of the model.

From a practical perspective, the framework suggests that educational institutions, designers, and platform developers should focus on two areas simultaneously. First, they should strengthen users' self-learning ability through activities that promote self-directed learning, critical thinking, and confidence in digital learning. Second, they should improve platform quality by emphasizing user-centered design, accessibility, relevant content, and supportive learning features. Such improvements are likely to foster more positive attitudes, stronger behavioral intention, and, ultimately, greater actual use of digital media literacy innovation platforms. These implications are especially relevant for older adults and other groups who may face barriers in digital learning environments.

In conclusion, this study provides a conceptual explanation of the mechanisms underlying digital media literacy platform innovation adoption. The framework indicates that both individual learning capability and technological innovation are essential determinants of users' attitudes, behavioral intention, and actual use. By clarifying these relationships, the study offers a useful foundation for future empirical research using SEM and provides practical guidance for the design and implementation of digital learning platforms that promote engagement, effective use, and digital inclusion.

"Digital accessibility for older adults is not merely a technical challenge; it is a profound socio-economic imperative. The successful digital empowerment of Thailand's aging society requires the synergy between the innovation agility of the private sector, the structural support of the state, and the pedagogical guidance of educational institutions. Together, these stakeholders can transition the aging population from a vulnerable demographic to an empowered cohort of 'Digital Citizens', thereby securing the nation's sustainable digital future."

"This research has systematically examined the factors influencing the intention and adoption of digital media literacy platforms among Thai older adults. By departing from the conventional 'autonomy-centric' models and establishing a Socio-Technical Negotiation Paradigm, this study provides a nuanced understanding of how individual cognitive readiness, when supported by 'Social Scaffolding' and intergenerational validation, facilitates successful digital integration.

The findings underscore that for the Thai aging population, digital empowerment is not an isolated technical outcome but a collective socio-cultural achievement. By synthesizing global theoretical constructs—such as TAM, DOI, and Media Literacy frameworks—with the unique kinship dynamics of Thai society, this research offers a replicable model for other collectivist societies facing rapid digital transformation.

Looking forward, this study advocates for a strategic alignment between state policies, corporate responsibility, and pedagogical innovation. We conclude that sustainable lifelong learning for older adults requires more than accessible interfaces; it necessitates a 'Trust Ecosystem' where technology is perceived as a collaborative, defensive, and empowering tool for daily life. Future research should leverage longitudinal structural equation modeling (SEM) to further explore how this 'socio-technical negotiation' evolves over time, ensuring that the journey toward a digital-ready society remains inclusive, secure, and profoundly human-centric."

7. Suggestions

Strategic Policy Alignment: A National Collaborative Ecosystem for Digital Aging

To effectively translate research into policy, this study advocates for an integrated national strategy that transcends individual-level interventions. The successful adoption of digital media literacy platforms requires a coordinated effort among the state, the private sector, and educational institutions, framed within the national agenda for Active Aging.

7.1 State-Level Policy Transformation: From Access to Digital Resilience

Government agencies must transition from merely providing digital infrastructure to fostering "Digital Resilience." This involves:

National Digital Literacy Framework: Elevating media literacy as a national imperative for older adults, moving beyond simple usage metrics to measuring the Digital Resilience Index—a robust indicator of an older adult's ability to navigate risks safely.

Inclusive Infrastructure: Integrating "Community Digital Hubs" into existing social welfare structures, such as public health centers and community centers, ensuring that digital learning is physically and psychologically accessible to the elderly.

7.2 Corporate Digital Responsibility (CDR): Innovation for Inclusion

Private sector platform providers play a crucial role through Corporate Digital Responsibility (CDR). This goes beyond profit, focusing on:

Universal Design Standards: Implementing "Empathy-based Design" to minimize cognitive load, ensuring that platform features are intuitively usable for older adults.

Public-Private Partnerships (PPP): Collaborating with academic institutions to co-develop content that addresses real-world threats, such as AI-driven scams and deepfakes, turning platforms into defensive assets for the aging population.

7.3 A Holistic 'Trust Ecosystem' through Intergenerational Synergy

The sustainability of digital adoption depends on establishing a "Trust Ecosystem."

Intergenerational Mentorship: Policy should incentivize programs where younger generations (students) serve as "Digital Mentors," creating a symbiotic relationship that fosters social cohesion and digital inclusion.

Institutional Coordination: Educational institutions, such as KMITL, should act as the central nexus—bridging government policy, corporate technology, and community needs to ensure that digital literacy platforms are not just functionally viable, but pedagogically rigorous and socially validated.

8. Acknowledgements

The author wishes to express sincere gratitude to Associate Professor Dr. Amnuay Saengnoree, Program Chairperson and Co-Advisor, for his exceptional mentorship, profound academic guidance, and unwavering support throughout every stage of this doctoral research. His invaluable insights, dedication, and thorough reviews have been the primary and essential force behind the successful completion of this study.

Furthermore, the author is profoundly grateful to the following experts for their instrumental contribution to the Item-Objective Congruence (IOC) evaluation: Professor Dr. Paitoon Pimdee and Associate Professor Dr. Woranath Saengmanee from KMITL; Mrs.Charinya Chukkai,

Assistant Permanent Secretary of the Ministry of Culture ; Dr. Niphon Naksompop, Former Senator; and Dr. Tri Bunchua, Executive Director of Telecommunications Consumer Protection Bureau, the Office of the NBTC. Their expertise and insightful recommendations have been vital in ensuring the quality and integrity of this research.

Special thanks are also extended to Assistant Professor Dr. Wanwisa Chatchawong, Chairperson of the Human Research Ethics Committee of KMITL, for the ethics certification (EC-KMITL 69 063). Assistant Professor Dr. Toorsangrasme Tetakae is noted as research advisor for delivering documentation to internal experts at KMITL per the program's requirements.

9. References

Al-Emran, M., Mezhuyev, V., & Kamaludin, A. (2020). Technology acceptance model in m-learning context: A systematic review. *Computers & Education, 125*, 389–412.

Bond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2020). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education, 17*(1), 1–24.

Chen, K. (2021). Designing accessible digital media for older adults: A user-centered approach. *Gerontechnology, 20*(2), 1–12.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

DQ Institute. (2019). *DQ global standards report 2019: Common framework for digital literacy, skills and readiness*.

Dwivedi, Y. K., Rana, N. P., Jeyaraj, A., Clement, M., & Williams, M. D. (2020). Re-examining the unified theory of acceptance and use of technology (UTAUT): Towards a revised theoretical model. *Information Systems Frontiers, 22*(3), 719–734.

European Commission. (2020). *DigComp 2.1: The digital competence framework for citizens*. Publications Office of the European Union.

Field, J. (2019). *Lifelong learning and the new educational order* (2nd ed.). Routledge.

Gagné, R. M. (1985). *The conditions of learning and theory of instruction* (4th ed.). Holt, Rinehart and Winston.

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of artificial intelligence in education: A systematic review. *Sustainable Operations and Computers, 3*, 1–10.

Hamelink, C. J. (2008). *Human rights for communicators*. Hampton Press.

Hobbs, R. (2020). *Digital and media literacy: Connecting culture and classroom*. Corwin.

Livingstone, S., Mascheroni, G., & Staksrud, E. (2021). European research on children's internet use: Assessing the past and anticipating the future. *New Media & Society, 23*(3), 1–18.

Lu, C.-H., Ahmed, R., Lamri, A., & Anand, S. S. (2022). Use of race, ethnicity, and ancestry data in health research. *PLOS Global Public Health, 2*(9), e0001060.

Merriam, S. B., & Bierema, L. L. (2014). *Adult learning: Linking theory and practice*. Jossey-Bass.

National Statistical Office. (2025). *Report on the older adults population in Thailand*. Ministry of Digital Economy and Society.

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). AI literacy: Definition, teaching, evaluation and ethical issues. *Computers and Education: Artificial Intelligence, 2*, 100041.

Nguyen, T. X., et al. (2022). Older adults people's adaptation to the evolving digital society. *Social Sciences, 11*(8), 324.

Nikou, S. A., & Economides, A. A. (2021). Mobile-based assessment: Investigating the factors that influence behavioral intention to use. *Computers & Education, 109*, 56–73.

Piaget, J. (1972). *Psychology and pedagogy*. Viking Press.

Rasi, P., Vuojärvi, H., & Ruokamo, H. (2021). Media literacy education for older people: A review of existing research. *Educational Gerontology, 47*(6), 1–12.

Salloum, S. A., Al-Emran, M., Shaalan, K., & Tarhini, A. (2021). Factors affecting the adoption of e-learning systems in higher education: A systematic review. *Education and Information Technologies, 26*(2), 1–21.

Shen, C. W., Ho, J. T. T., & Ly, P. T. M. (2020). Digital citizenship behavior: The role of digital literacy and digital competence. *Computers in Human Behavior, 104*, 106160.

Silverblatt, A. (1995). *Media literacy: Key to interpreting media messages*. Praeger.

Spante, M., Hashemi, S. S., Lundin, M., & Algers, A. (2018). Digital competence and digital literacy in higher education research: Systematic review of concept use. *Cogent Education, 5*(1), 1519143.

United Nations. (2022). *World population prospects 2022: Summary of results*. Department of Economic and Social Affairs.

United Nations Educational, Scientific and Cultural Organization. (2023). *Media and information literacy: Policy and strategy guidelines*.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425–478.

FROM SATISFACTION TO ENGAGEMENT: A BIBLIOMETRIC ANALYSIS OF THE THEMATIC SHIFT IN GREEN TRAINING RESEARCH (2016–2026)

Xue Zhao[1]*, Anusit Anmanatarkul[2], Mongkhon Narmluk[3], Santirat Nansaarng[4], and Tanatorn Tongsumrith[5]

xue.zhao@kmutt.ac.th, anusit.anm@kmutt.ac.th, mongkhon.nar@kmutt.ac.th, santirat.nan@kmutt.ac.th, and tanatorn.ton@kmutt.ac.th

[1]Doctoral Program in Learning Innovation and Technology,
[2]Department of Mechanical Technology Education,
[3]Department of Civil Technology Education,
[4]Department of Production Technology Education,
[5]Department of Printing and Packaging Technology,
King Mongkut's University of Technology Thonburi, Bangkok 10140 Thailand

*Corresponding Author E-mail: xue.zhao@kmutt.ac.th

ABSTRACT

Green Training (GT) is a key component of Green Human Resource Management (GHRM) and one of the key drivers of industrial innovation. However, it remains unclear how to best utilize psychological mechanisms to translate environmental training into measurable organizational outcomes, particularly for SMEs subject to ESG pressures. We addressed this gap by reviewing 61 papers from 2016 to 2026 from Scopus using VOSviewer. We synthesized 25 high-impact studies to examine the link between job satisfaction and employee engagement. We found that the focus shifts from job satisfaction as the main affective outcome towards employee engagement as a motivational driver, and engagement keywords are growing sharply after 2022. We analyzed the map of the 61 papers, which shows that satisfaction models were predominant between 2016 and 2021, while engagement and green self-efficacy were more emphasized between 2024 and 2026. Qualitative evidence from the 25 papers shows that a functional hierarchy: green satisfaction provides the necessary affective baseline for organization stability and compliance and green engagement provides the energy, dedication, and focus required for complex Eco-innovation. We also showed that engagement plays a stronger role in the environmental performance of the ESG-driven industries. GHRM thus provides a road map for companies looking to transition from satisfaction-focused to engagement-focused training. The overall conclusion is that, across different industry contexts, active engagement—rather than passive satisfaction—represents a critical step toward unlocking human capital potential and fostering sustainable innovation in a carbon-neutral future.

Keywords: Bibliometric analysis, Employee engagement, Employee satisfaction, Green human resource management, Green training

1. Statement of the Problem

Global climate change and carbon neutrality targets have made sustainability of the environment a key competitive requirement for enterprises under the Environmental, Social and Governance (ESG) mandate. Green Human Resource Management (GHRM) bridges macro policies and micro behavior with Green Training (GT) being the main intervention to promote behavior in the environment. How best to translate GT to performance remains unknown.

Since the early years, GHRM has used job satisfaction (a passive affective measure) as the primary indicator of employee response to green initiatives (Bhatti et al., 2022), but passive contentment does not suffice for complex Eco-innovations. Employee engagement (vigorous and committed) has been suggested as a motivation driver (Schaufeli et al., 2002), but no systematic longitudinal analysis has measured the change from satisfaction to engagement trajectory for GT research over 2016-2026, thus practitioners are less equipped to design empowerment-oriented GT strategy. Based on the Ability-Motivation-Opportunity (AMO) framework, this study combines bibliometric mapping and qualitative analysis to explore this evolutionary trajectory, clarifying the psychological hierarchy of GHRM mediators and providing a data-driven road map for GT design.

2. Objectives

2.1 To visualize the intellectual structure and key thematic clusters of GT research (2016–2026) using bibliometric mapping.

2.2 To quantify the temporal thematic shift from job satisfaction (affective) to employee engagement (motivational).

2.3 To compare the mediating potency of satisfaction and engagement for environmental performance and provide a strategic road map for empowerment-oriented GT design.

3. Conceptual Framework

Grounded in AMO (Ramachandaran et al., 2024), GT increases employee ability (knowledge and skills to favor environmental behavior) but ability must be activated by motivation. There are two types of psychological constructs: job satisfaction (passive affective evaluation) (Bhatti et al., 2022; Pinzone et al., 2019); employee engagement (a dynamic state of enthusiasm and commitment) (Hasan & Hossain, 2025). The model posits a temporal hierarchy: early work (2016–2020) focused on satisfaction (Ari et al., 2020; Paillé et al., 2020); current research (2023–2026) employs engagement as a mediator (Al-Sabi et al., 2024), aligning with increasing ESG mandates (Efranto et al., 2026). Organizational GHRM practices influence employee psychological responses and mediate environmental performance (Sowmiya et al., 2024).

4. Research Methodology

A mixed-methods approach based on bibliometric analysis and qualitative analysis was employed (Zupic & Čater, 2015). Bibliometric analysis quantified intellectual structure, publication trends, and topical evolution of GT research. Qualitative analysis of high impact studies quantified the role played by job satisfaction and employee engagement in the GT-environmental performance relationship.

4.1 Research Procedure

This paper follows PRISMA 2020 guidelines (Page et al., 2021). The Scopus database was searched using the TITLE-ABS-KEY field: "Green Training" AND "Job Satisfaction" OR

"Employee Engagement" and filtered results from 2016 to 2026. The first search resulted in 112 records.

Inclusion criteria were: peer-reviewed journal articles or conference papers; focus on psychological outcomes (satisfaction/engagement) of GT; published between 2016 and 2026; written in English. Exclusion criteria were: non-empirical documents (editorials, notes), duplicates, thematic irrelevance, and unpublished grey literature.

After title/abstract screening and full text screening, 51 records were excluded, leaving a final core sample of 61 records for bibliometric mapping as shown in Figure 1. A subset of 25 high impact empirical studies was chosen for qualitative analysis.

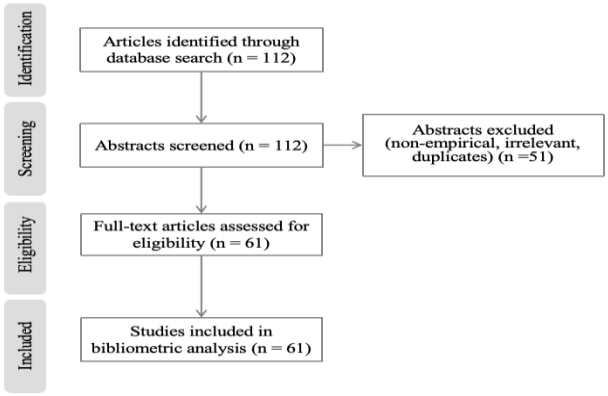

Figure 1 PRISMA 2020 Flow Diagram of the Literature Selection Process

4.2 Data Analysis

Bibliometric analysis was performed using VOSviewer (version 1.6.20) (Van Eck & Waltman, 2010). Three analytical steps were conducted:

4.2.1 Keyword Co-occurrence Analysis

By setting a minimum occurrence threshold of 2, we obtained a network visualization of 47 high-frequency keywords, which was used to identify core research clusters.

4.2.2 Density Visualization

The heat-map visualization of keyword concentration identifies research hotspots and peripheral topics, and effectively differentiates mature research domains from emerging frontiers.

4.2.3 Overlay Visualization

A time-weighted color gradient (colder colors = earlier years, warmer colors = recent years) plotted the temporal transition from job satisfaction to employee engagement. Qualitative analysis involved thematic analysis of the 25 selected empirical studies in order to extract and compare results on mediating job satisfaction and employee engagement roles. Key themes included psychological characteristics, empirical links to environmental performance, and applicability in enterprise contexts.

5. Results

5.1 Descriptive Overview of the GT Research Landscape

5.1.1 Publication Trends

Analysis of the 61 core documents revealed a steady upward trend in GT research publications from 2016 to 2026 in Figure 2, with a clear bifurcation into two phases:

5.1.1.1 Foundational Phase (2016–2021)

Low but stable publication volume (4–5 papers per year), focused on defining GHRM practices and establishing the baseline link between GT and basic employee responses.

5.1.1.2 Rapid Growth Phase (2022–2026)

A dramatic surge in scholarly interest, coinciding with the global intensification of ESG mandates and China's "Dual-Carbon" strategy implementation—with over 40% of the corpus published in 2025 alone, confirming GT as a front-line international research agenda.

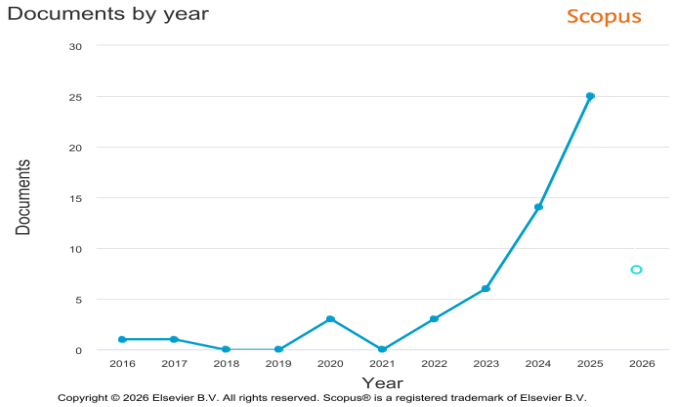

Figure 2 Annual Number of Publications on Green Training and Employee Outcomes

5.1.2 Geographic Distribution

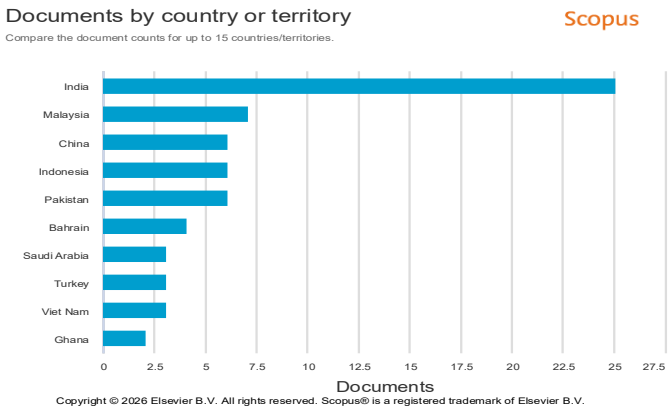

Figure 3 Top 10 Countries by Number of Publications (2016–2026, n=61)

The majority of GT research is focused on Asian emerging economies. Figure 3 illustrates that India is the most productive country (27 publications), followed by Malaysia, China, Indonesia, and Pakistan. Emerging Asian economies are particularly concerned about industrialization and sustainability and have demand for GT in manufacturing and hospitality. The remaining top 10 countries are Bahrain, Saudi Arabia, Turkey, Vietnam, and Ghana, reflecting the global relevance of GT in sustainable development.

5.2 Keyword Co-occurrence Network Analysis

Keyword co-occurrence analysis identified three distinct primary thematic clusters in GT research (2016–2026), as presented in Figure 4, confirming the conceptual distinctness of key constructs and their links to GHRM practices:

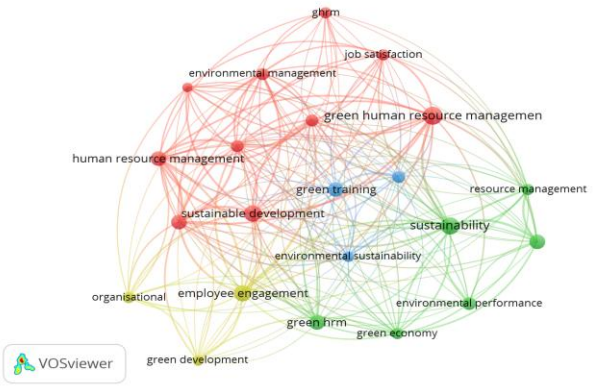

Figure 4 Keyword Co-occurrence Network of Green Training and Employee Outcomes (2016–2026, n=61)

5.2.1 Red Cluster (GHRM and Institutional Performance)

The central cluster that connects GT with macro-organizational sustainable development outcomes forms the foundation for all other research themes.

5.2.2 Green Cluster (Affective Mechanisms)

This green cluster centers on job satisfaction, which constitutes employees' passive affective response to GT initiatives, and has traditionally been the primary outcome variable in GT research.

5.2.3 Blue Cluster (Motivational Mechanisms)

Employee engagement is the strongest link to GT and to pro-environmental behavior and innovation. The red cluster correlated strongly with the green cluster (job satisfaction) (link strength: 58). This suggests that GHRM practices directly impact basic employee affective responses, with a weaker but growing link to the blue cluster (employee engagement) in recent years.

5.3 Density Visualization and Research Hotspots

Density visualization verified that GT still serves as the core hub of this research area, maintaining close dense connections with both job satisfaction and employee engagement. A very high degree of research intensity was observed. Figure 5 highlights that job satisfaction is the most mature starting point (colder density colors) for early GT research (2016–2020). Experimental studies (Amrutha & Geetha, 2021) showed that green satisfaction plays a role in GT and voluntary green behavior, but only in compliance settings. Employee engagement is the most recent high density core (warmer density colors) for the last 2024–2026 period. This density pattern reflects the increasing focus on proactive motivational mechanisms over passive affective outcomes, and confirms that employee engagement serves as a more potent mediator for environmental performance than job satisfaction.

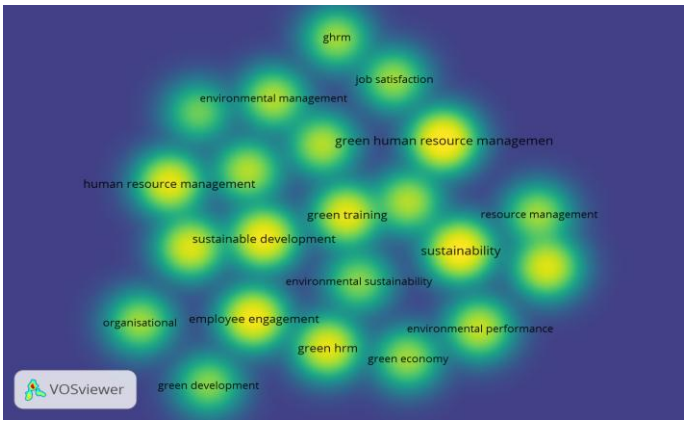

Figure 5 Density Visualization of Keyword Occurrences (2016–2026, n=61)

5.4 Overlay Visualization and Temporal Evolution

Overlay visualization with a time-weighted color gradient provided objective, data-supported evidence that GT research exhibited distinct thematic migration throughout the study period, as is illustrated in Figure 6:

5.4.1 Foundational Hotspots (2016–2020, blue/purple nodes)

Keywords such as job satisfaction and "Personnel training" dominate this period. Research is focused on the link between GT and employee affective responses. Ari et al. (2020) proposed job satisfaction as a mediator between GHRM practices (including GT) and environmental behavior, and Paillé et al. (2020) found GT improves environmental satisfaction and individual performance.

5.4.2 Emerging Frontiers (2023–2026, bright yellow nodes)

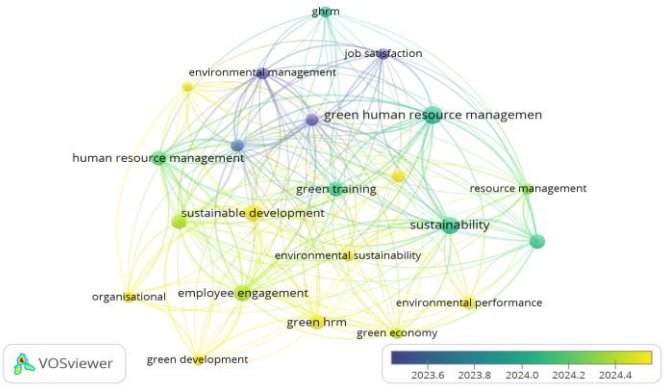

Figure 6 Overlay visualization of keyword temporal evolution (2016–2026, n=61)

Keywords such as employee engagement, green self-efficacy, and environmental passion were used. The focus was shifting from passive emotion to active motivations. Hasan and Hossain (2025) confirmed that employee engagement plays a role in interactions between GHRM (including GT) and pro-environmental behavior in hospitality, while Amiria and Suprapto (2025) confirmed that employee engagement plays a role in GT and employee performance in manufacturing.

Qualitative analysis of 25 high impact studies shows that employee engagement is more important than job satisfaction for environmental performance, especially for companies with strict ESG policies. Engaged employees align personal values with sustainability goals in an organization and contribute to green innovation.

6. Conclusion and Discussion

6.1 Core Conclusions

6.1.1 Exponential Growth

GT research has grown rapidly since 2022 due to global ESG mandates and carbon neutrality goals. More than 40% of the corpus was published in 2025 alone. In Asia, the emerging economies include India, Malaysia, China, Indonesia, and Pakistan.

6.1.2 Three Thematic Clusters

Co-occurrence analysis reveals three clusters: GHRM and institutional performance (core), job satisfaction (affective), and employee engagement (motivation). Separated clusters show job satisfaction and employee engagement are conceptually independent psychological pathways.

6.1.3 Temporal Shift from Satisfaction to Engagement

Overlay shows clear migration. Job satisfaction dominates pre-2020 studies as the main affective result (Pinzone et al., 2019; Paillé et al., 2020), and employee engagement dominates from 2023 onwards. Qualitative results show that engagement is more effective in terms of environmental performance in firms than satisfaction. Collectively, these results suggest a psychological hierarchy: Job satisfaction provides stability (passive affective response) and employee engagement provides the proactive vigour and commitment required for eco-innovation and sustainable environmental performance.

6.2 Theoretical Implications

6.2.1 Extension of the AMO Framework

This paper enhances the AMO framework by refining the motivation component of GHRM. In particular, we distinguish passive affective motivation (job satisfaction) from proactive motivational engagement (employee engagement) as separate outcomes of GT, thus providing a more detailed description of how training-induced ability is activated for environmental performance.

6.2.2 Thematic Evolution of GT Research

The study presents the first systematic decadal analysis of GT research evolution from satisfaction-focused to engagement-oriented training research, highlighting this evolution by linkage with external policy drivers like ESG mandates and carbon neutrality goals.

6.2.3 Distinctiveness of Engagement as a Mediator

We demonstrate that employee engagement is a stronger mediator than job satisfaction. Furthermore, engagement is a critical GHRM variable that captures proactive behavior required for the carbon-neutral age, beyond satisfaction measures.

6.3 Practical Implications

6.3.1 Redesign of GT toward Empowerment

Since employee engagement mediates environmental performance more effectively than job satisfaction, organizations should move beyond knowledge transfer to actively foster engagement, green self-efficacy, and psychological ownership of environmental goals. Avatar-led GT shows that such design encourages engagement through workplace spirituality, leading to greater corporate citizenship behavior for the environment.

6.3.2 Contextualization to Regional Settings

As GT research is focused on Asian emerging economies, GT training should be tailored to local sustainability demands, and address industrialization and environmental compliance. In addition, the training should be aligned with regional ESG mandates and carbon neutrality targets.

6.3.3 Adoption of Engagement Metrics in Evaluation

Organizations should supplement job satisfaction metrics with engagement indicators, such as vigour, dedication, and absorption, in their training evaluation frameworks.

6.4 Research Limitations

6.4.1 Database Scope

The sample is limited to Scopus-indexed papers. Web of Science or Google Scholar may not have been included. This may lead to generalization problems.

6.4.2 Absence of Primary Empirical Data

Without primary empirical data, causal relationships between GT, employee engagement, and environmental performance cannot be established.

6.4.3 Keyword Filter Restriction

The search focused on job satisfaction and employee engagement as psychological outcomes, other potentially relevant constructs (e.g., organizational commitment, green behavior) are not captured.

6.4.4 Lack of Cross-Cultural Comparison

While geographic concentration is found in Asian emerging economies, cross-cultural differences are not studied. How cultural or institutional factors influence the shift from satisfaction-engagement change remains unknown.

6.5 Future Research Recommendations

6.5.1 Multi-Source Bibliometric and Longitudinal Empirical Studies

Future work should include Web of Science and Google Scholar to map GT research landscape. Parallel longitudinal studies will be needed to study how GT affects employee attitudes (satisfaction, engagement, and environmental performance) over time and link causalities which bibliometric analysis alone can not provide.

6.5.2 Contextual Conditions

The relationship between satisfaction and engagement was shown hierarchically. Future research should examine whether green self-efficacy, environmental passion, and organizational commitment play mediating roles in the satisfaction-engagement hierarchy. Cross-cultural comparisons are also needed to understand how national culture, regulatory system, and institutional environment moderate the satisfaction-engagement shift, as GT research is focused on Asia and emerging economies.

6.5.3 Integration of Digital Technologies into GT

Future research should look at how digital tools and artificial intelligence can be integrated into GT programs to increase employee engagement and pro-environmental behaviour. Avatar-based training has shown promise in increasing workplace spirituality and organizational citizenship behaviour, but how these technologies scale and sustain long-term effectiveness remains unclear. Designing the best engagement in digital learning environments is a real area of research and practice.

7. Acknowledgements

The authors would like to thank the Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand, for providing the academic resources, research facilities, and institutional support that made this study possible. The authors also acknowledge the contributions of the Scopus database for providing the bibliometric data core to this research, and the developers of VOSviewer for the scientific mapping software used in the analysis.

8. References

Adeel, M., Mahmood, S., Khan, K., & Saleem, S. (2022). Green HR practices and environmental performance: The mediating mechanism of employee outcomes and moderating role of environmental values. *Frontiers in Environmental Science*, 10, 1001100. https://doi.org/10.3389/fenvs.2022.1001100

Ahmad, S., Javed, U., Sharma, C., & Siddiqui, M. S. (2025). Green human resource management: Analyzing sustainable practices and organizational impact through a Word2Vec approach. *Green Technologies and Sustainability*, 3(3), 100224. https://doi.org/10.1016/j.grets.2025.100224

Al-Sabi, S., Al-Ababneh, M. M., Al Qsssem, A. H., Afaneh, J., & Elshaer, I. (2024). Green human resource management practices and environmental performance: The mediating role of job satisfaction and pro-environmental behavior. *Cogent Business & Management*, 11(1), 2328316. https://doi.org/10.1080/23311975.2024.2328316

Alshaabani, A., Naz, F., & Rudnák, I. (2021). Impact of green human resources practices on green work engagement in the renewable energy departments. *International Business Research*, 14(6), 44–54. https://doi.org/10.5539/ibr.v14n6p44

Amiria, H. D., & Suprapto, S. (2025). Green HRM and employee engagement: Impact on employee performance in manufacturing companies. *Journal of Sustainable Economic and Business*, 1(4), 42–52. https://doi.org/10.70550/joseb.v1i4.42

Amrutha, V., & Geetha, S. (2021). Linking organizational green training and voluntary workplace green behavior: Mediating role of green supporting climate and employees' green satisfaction. *Journal of Cleaner Production,* 292, 125876. https://doi.org/10.1016/j.jclepro.2021.125876

Ari, E., Karatepe, O. M., Rezapouraghdam, H., & Avcı, T. (2020). A conceptual model for green human resource management: Indicators, differential pathways and multiple pro-environmental outcomes. *Sustainability*, 12(17), 7089. https://doi.org/10.3390/su12177089

Benn, S., Teo, S., & Martin, A. (2015). Employee participation and engagement in working for the environment. *Personnel Review*, 44(4), 492–510. https://doi.org/10.1108/PR-10-2013-0179

Bhatti, M. A., Alyahya, M., Juhari, A. S., & Alshiha, A. A. (2022). Green HRM practices and employee satisfaction in the hotel industry of Saudi Arabia. *International Journal of Operations and Quantitative Management*, 28(1), 100–120. https://doi.org/10.46970/2022.28.1.6

Dwumah, K., Sappor, P., & Sarpong, F. (2025). Navigating the green path: Strategies for enhancing organizational citizenship behavior for the environment through green HRM practices. *Business Strategy and the Environment,* 34(3), 2150–2168. https://doi.org/10.1002/bse.4149

Efranto, R. Y., Sipayung, S. N., & Amrulloh, A. B. Y. (2026). Green human resource management: A decade of evolution in practices, employee green behavior, and organizational sustainability. *Cogent Business & Management*, 13(1), 2598686. https://doi.org/10.1080/23311975.2025.2598686

Frare, A., Colombo, V. L. B., & Beuren, I. (2022). Performance measurement systems, environmental satisfaction, and green work engagement. *Revista Contabilidade & Finança*s, 33(89), 1–16. https://doi.org/10.1590/1808-057x20211503.en

Han, J. W., Kok, S. K., & McClelland, R. (2023). The impact of green training on employee turnover intention and customer satisfaction: An integrated perspective. *Corporate Social Responsibility and Environmental Managemen*t, 30(6), 3006–3019. https://doi.org/10.1002/csr.2534

Hao, F., Ng, W., Aman, A. M., & Zhang, C. (2024). Technology for sustainability: The impact of Avatar-led Green Training on OCBE and green creativity. *International Journal of Contemporary Hospitality Management*, 36(10), 3342–3360. https://doi.org/10.1108/IJCHM-12-2023-1927

Hasan, M. M., & Hossain, M. S. (2025). Leveraging green HRM for environmental sustainability: The mediating role of employee engagement in hospitality. *Tourism and Hospitality Management*, 32(1), 1–18. https://doi.org/10.20867/thm.32.1.10

Jia, S., & Shang, H. (2024). Utilizing green financing in developing green HRM resources for carbon neutrality: Presenting multidimensional perspectives of China. *Environmental Science and Pollution Research*, 31, 8798–8811. https://doi.org/10.1007/s11356-023-31479-8

Noor, J., Tunnufus, Z., Handrian, V. Y., & Yumhi, Y. (2023). Green human resources management practices, leadership style and employee engagement: Green banking context. *Heliyon*, 9(11), e22473. https://doi.org/10.1016/j.heliyon.2023.e22473

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. https://doi.org/10.1136/bmj.n71

Paillé, P., Valeau, P., & Renwick, D. (2020). Leveraging green human resource practices to achieve environmental sustainability. *Journal of Cleaner Production*, 260, 121137. https://doi.org/10.1016/j.jclepro.2020.121137

Pătraș, L., Villajos, E., Soriano, A., & Djourova, N. P. (2025). The green happy productive worker: Environmental satisfaction as mediator between green human resources practices and green extra-role behaviors in social economy organizations. *Corporate Social Responsibility and Environmental Management,* 32(4), 2150–2168. https://doi.org/10.1002/csr.3210

Paulet, R., Holland, P., & Morgan, D. (2021). A meta-review of 10 years of green human resource management: Is Green HRM headed towards a roadblock or a revitalisation? *Asia Pacific Journal of Human Resources*, 59(2), 159–183. https://doi.org/10.1111/1744-7941.12285

Pinzone, M., Guerci, M., Lettieri, E., & Huisingh, D. (2019). Effects of 'green' training on pro-environmental behaviors and job satisfaction: Evidence from the Italian healthcare sector. *Journal of Cleaner Production*, 226, 221–232. https://doi.org/10.1016/j.jclepro.2019.04.048

Ramachandaran, S. D., Vasudevan, A., Balakrishnan, R., Nagaraj, S., & Thinakaran, R. (2024). The impact of green human resource management practices on employee's job performance. *International Journal of Management and Sustainability*, 13(3), 506–522. https://doi.org/10.18488/11.v13i3.3828

Renwick, D. W., Redman, T., & Maguire, S. (2013). Green human resource management: A review and research agenda. *International Journal of Management Reviews*, 15(1), 1–14. https://doi.org/10.1111/j.1468-2370.2011.00328.x

Schaufeli, W. B., Salanova, M., González-Romá, V., & Bakker, A. B. (2002). The measurement of engagement and burnout: A two sample confirmatory factor analytic approach. *Journal of Happiness Studies*, 3(1), 71–92. https://doi.org/10.1023/A:1015630930326

Sharma, D., & Dhamija, A. (2025). A study on impact of green HRM practices on green employees engagement and employees job satisfaction in education sector. Aibi Research, *Management and Engineering Journal*, 13(1), 75–81.

Soekotjo, S., Sosidah, Kuswanto, H., Setyadi, A., & Pawirosumarto, S. (2025). A conceptual framework for sustainable human resource management: Integrating ecological and inclusive perspectives. *Sustainability,* 17(3), 1241. https://doi.org/10.3390/su17031241

Sowmiya, M., Poornima, A., Harish, M., Vaishnavi, S., Anto Pravin Singh, D., & Prakash, K. (2024). The impact of green human resource management on sustainable performance in the Indian IT sector: Exploring the mediating role of green human capital. *Pakistan Journal of Life and Social Sciences*, 22(2), 12439–12457. https://doi.org/10.57239/PJSS-2024-22.2.00890

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Wang, Y., Ummar, R., Qureshi, T. M., Ul Haq, J., & Bonn, M. A. (2025). Employee sustainability: How green practices drive employee well-being and citizenship behavior. *Sustainability*, 17(3), 936. https://doi.org/10.3390/su17030936

Yoo, D. Y. (2024). Eco-leadership in action: Integrating green HRM and the new ecological paradigm to foster organizational commitment and environmental citizenship in the hospitality industry. *Sustainability*, 16(20), 9044. https://doi.org/10.3390/su16209044

Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational Research Methods*, 18(3), 429–472. https://doi.org/10.1177/1094428114562629

DIGITAL MEDIA LITERACY AND COGNITIVE RESILIENCE AMONG OLDER ADULTS: SOCIOCULTURAL DRIVERS OF INNOVATION

Pimnatchaya Satchasin*, Toosrangrasame Tetakew, and Amnuay Saengnoree

pimnatchaya.s@gmail.com, toosrangrasame.te@kmitl.ac.th, and amnuay.sa@kmitl.ac.th

College of Innovation and Industrial Management,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: pimnatchaya.s@gmail.com

ABSTRACT

This research investigates the development of Digital Media Literacy (DML) among older adults in Thailand, focusing on the integration of cognitive frameworks and socio-cultural influences. While global DML models often emphasize individual skills and self-directed learning, this study posits that in collectivist societies like Thailand, DML must be conceptualized as a multidimensional capability shaped by both internal cognitive mechanisms and external social scaffolding.

The study addresses two primary objectives: first, to synthesize DML and epistemological beliefs into an integrated cognitive framework; and second, to examine how socio-cultural moderators, such as urban-rural disparities and relational trust, shape the application of this framework. Adopting a theory-building approach, the research utilizes a synthesis of existing literature to establish a three-level framework: the Macro-level (DML as an interpretive process), Meso-level (epistemological beliefs and AI-Risk Perception as evaluative mechanisms), and Micro-level (technology acceptance and intergenerational support as determinants of engagement).

Key findings reveal that epistemological sophistication—specifically the transition from relationship-based to evidence-based beliefs—is the primary driver of misinformation resilience. Furthermore, the research demonstrates that Intergenerational Knowledge Transfer acts as a critical moderator, effectively attenuating psychological barriers such as technophobia. The study concludes that DML interventions should move beyond top-down, skill-based training to prioritize "environmental design" and "human scaffolding." By positioning Digital Well-being as the terminal outcome, this framework offers a strategic roadmap for inclusive digital participation, ensuring that older adults can engage with Thailand's digital economy with confidence, agency, and safety.

Keywords: Digital Media Literacy (DML), Epistemological beliefs, Misinformation resilience, Older adults, Intergenerational support, Digital well-being, Thai socio-cultural context

1. Statement of the Problem

In an era of rapid digital transformation, digital media literacy (DML) has shifted from a set of technical skills to a core cognitive ability for navigating complex information environments (Livingstone, 2004). This issue is especially critical among older adults, who increasingly engage with digital content but remain more vulnerable to misinformation due to limited experience and weaker evaluative skills (Tsai et al., 2020).

Existing DML frameworks often focus on skills such as accessing, analyzing, and evaluating information. However, they pay less attention to how individuals construct and justify knowledge in everyday contexts—an essential process for distinguishing credible from misleading information (Celik et al., 2021).

Although digital literacy programs for older adults have expanded, research shows that misinformation susceptibility remains high. This is largely due to lower digital skills, limited learning opportunities, and low confidence in using technology compared to younger groups (Moore & Hancock, 2022). These findings suggest that skill-based approaches alone are not sufficient.

Recent studies emphasize the role of epistemological beliefs, which refer to individuals' assumptions about knowledge and truth, in shaping how people interpret and evaluate digital information Marlene Schommer-Aikins and Paul R. Pintrich (1997). Individuals with more advanced epistemological beliefs are generally better at critically evaluating information and are less likely to accept misinformation. This suggests that cognitive factors play a crucial role in developing effective digital media literacy (DML).

In Thailand and similar Southeast Asian contexts, socio-cultural factors further shape this dynamic. Trust is often based on relationships within family and community networks rather than solely on evidence. Older adults frequently rely on these networks to access and interpret information. While this can support access, it may also increase exposure to misinformation when trust replaces critical evaluation.

Given these challenges, a more integrated approach is needed. This study proposes that DML should be reconceptualized as a multidimensional construct that includes cognitive, socio-cultural, and behavioral dimensions. In particular, epistemological beliefs are positioned as a key mechanism linking DML to misinformation resilience.

Beyond individual skills, DML also functions as a strategic capability that supports innovation adoption and reduces misinformation risks in digital societies (Hobbs, 2020). In Thailand, strengthening DML aligns with national goals of digital inclusion and reducing inequality (Kaewthep, 2008). Therefore, improving DML among older adults is not only a social issue but also a driver of sustainable participation in the digital economy (Aufderheide, 1992).

Overall, DML should be understood as a context-sensitive and multidimensional capacity. Its connection with epistemological beliefs highlights the importance of cognitive processes in shaping digital engagement, resilience, and inclusive societal development. Accordingly, this research aims to: Synthesize digital media literacy and epistemological beliefs into an integrated cognitive framework for understanding misinformation resilience, bridging global theoretical perspectives with the Thai socio-cultural context.Examine how socio-cultural factors—specifically urban-rural disparities and trust-based information processing—shape the application and effectiveness of this framework within the Thai population, ultimately positioning DML as a strategic capability for sustainable participation in the digital economy.

2. Objectives

2.1 To synthesize digital media literacy (DML) and epistemological beliefs among older adults into an integrated cognitive framework for understanding misinformation resilience.
global perspectives with the Thai socio-cultural context.

2.2 To examine how socio-cultural context, including urban-rural differences and trust-based information processing, shapes the application of this framework in Thailand.

3. Conceptual Framework

3.1 Digital Media Literacy as a Multidimensional Capability

Digital media literacy (DML) has evolved into a core capability in the digital era, extending beyond technical skills to encompass the ability to access, analyze, evaluate, and create media content, thereby enabling individuals to navigate complex information environments and make informed decisions (Buckingham, 2019). For older adults, DML plays a critical role in promoting digital inclusion, reducing vulnerability to misinformation, and enhancing participation in the digital economy. In Thailand, the development of DML aligns with national efforts to reduce inequality and promote inclusive digital participation. As such, DML should be conceptualized as a multidimensional construct integrating cognitive, socio-cultural, and behavioral dimensions, with important implications for digital resilience and inclusive transformation.

3.2 Socio-Cultural and Contextual Influences on Digital Engagement

Digital literacy development among older adults is strongly shaped by socio-cultural and contextual factors, particularly in collectivist settings such as Thailand. Social media use and new media literacy (NML) influence how individuals engage with and process information, where interactive and information-oriented use can enhance evaluation skills, while purely social use may limit analytical processing. In addition, family-based learning and intergenerational support play a crucial role in facilitating digital engagement among older adults with limited experience. Rapid population ageing in Thailand further intensifies disparities in digital access and inclusion, especially between urban and rural areas, where structural inequalities and differences in support systems significantly influence patterns of technology use and information interpretation.

3.3 Cognitive and Behavioral Factors in Digital Media Literacy Development

The development of DML among older adults is influenced by key cognitive and behavioral factors, including perceived usefulness, ease of use, self-efficacy, and behavioral intention. Initial engagement with digital technologies is often constrained by psychological barriers such as technophobia, while continued use can enhance confidence and digital competence (Castilla et al., 2018). Variations in ICT access and usage patterns further affect individuals' ability to develop digital literacy, particularly in terms of access and comprehension. In this context, family support remains a critical mechanism in enabling learning and adaptation (Wutthirangsi, 2021), highlighting the need for adaptive learning models and community-based support systems to address structural inequalities.

3.4 Digital Media Literacy and Misinformation Resilience

Digital media literacy is closely associated with individuals' ability to identify, evaluate, and respond to misinformation. Among its core competencies, evaluative capacity plays a particularly important role in enabling individuals to assess the credibility of information before sharing or acting upon it. For older adults, higher levels of DML contribute to reduced susceptibility to misinformation, increased confidence in digital engagement, and greater participation in digital society, consistent with the concept of active ageing (WHO, 2021). This highlights the importance of strengthening evaluative and critical thinking skills as central components of digital literacy development.

3.5 Epistemological Beliefs as a Cognitive Mechanism

Epistemological beliefs represent a key cognitive mechanism that shapes how individuals understand, interpret, and evaluate knowledge. Individuals with more advanced epistemological beliefs are more likely to engage in critical evaluation and resist misinformation, whereas those who rely on authority or social trust are more vulnerable. In the Thai context, knowledge evaluation is often influenced by relationship-based trust, where information from familiar social networks is prioritized over independent verification. This

underscores the importance of integrating cognitive and socio-cultural dimensions in understanding how digital media literacy translates into misinformation resilience.

3.6 Emerging Competencies: Digital Intelligence and AI Literacy

Digital Intelligence Quotient (DQ) and AI literacy extend traditional digital literacy by incorporating ethical, social, and critical understanding of digital technologies (DQ Institute, 2023; Long & Magerko, 2020). These competencies are increasingly relevant for older adults who face growing exposure to AI-driven misinformation and digital risks. Integrating DQ and AI literacy into digital literacy frameworks can enhance critical thinking, data protection awareness, and responsible digital participation (Nguyen et al., 2022), thereby strengthening resilience in rapidly evolving digital environments.

3.7 Integrated Dynamics: Moderating and Mediating Factors

To enhance the explanatory power of this framework, it is essential to account for the dynamic interplay between individual characteristics, cognitive filters, and environmental support systems. The model incorporates the following variables to better capture the nuance of the Thai digital landscape:

Intergenerational Support as a Catalyst (Moderating Variable): Drawing upon the socio-cultural context of collectivism, intergenerational knowledge transfer acts as a critical moderator. This variable accounts for the frequent, informal support provided by younger family members, which significantly attenuates the negative impact of *technophobia* and accelerates the transition from passive technology adoption to active digital engagement. In this model, family support serves as an external resource that empowers older adults to bypass structural inequalities, effectively serving as an on-ramp to digital inclusion.

AI-Driven Risk Perception (Mediating Mechanism): With the rapid integration of artificial intelligence into information dissemination, the ability to discern AI-generated misinformation has become a necessary competency. *AI-Driven Risk Perception* is positioned as a cognitive mediator within the core mechanism of the model. It functions as an essential component of the "evaluative filter," where higher awareness of AI-driven risks directly influences an individual's critical skepticism, thereby strengthening the relationship between epistemological beliefs and overall misinformation resilience.

Digital Well-being as the Ultimate Outcome (Strategic Variable): Moving beyond mere technical proficiency, the framework adopts *Digital Well-being* as a terminal outcome. This ensures that the model aligns with modern standards of sustainable digital participation. By prioritizing well-being, the framework measures success not only by the *absence* of misinformation susceptibility but by the *presence* of positive, meaningful, and safe digital engagement. This dimension frames digital literacy as a core driver of quality-of-life improvements, fulfilling the ultimate goal of sustainable participation in Thailand's digital economy.

To establish the academic rigor and practical relevance of this model, I have anchored my design philosophy in the principle of "Synthesis and Contextualization," ensuring the framework is both theoretically robust and empirically grounded.

From Theory to Practice (Integration): My approach involves a systematic synthesis of global Digital Media Literacy (DML) frameworks with the unique socio-cultural realities of Thailand. Rather than adopting a Western-centric model, I have adapted these global perspectives to better reflect the local information landscape—specifically, the nuances of the Thai digital environment.

Unique Value Proposition (Addressing the Gap): The core innovation of this model lies in the integration of "Epistemological Beliefs" as a central mechanism. By doing so, this study addresses a significant research gap; while existing literature often focuses on technical skills, it frequently neglects the cognitive processes through which individuals construct and validate knowledge. Positioning epistemological beliefs at the center of the framework allows us to

explain why skill-based training alone is often insufficient, particularly in societies where information processing is deeply influenced by personal and communal trust.

Structural Model Visualization

To provide a clear conceptual mapping of the framework, I have organized the model into three hierarchical layers. This structure illustrates the transition from individual baseline characteristics to the ultimate societal outcomes.

Layer 1: Input & Individual Factors This layer establishes the baseline profile of the individual. It encompasses demographic variables, pre-existing digital proficiency, and psychological barriers, such as *technophobia*. Understanding these initial constraints is essential for tailoring any intervention, as these factors dictate the individual's "readiness" to engage with complex digital information.

Layer 2: The Core Mechanism (The Cognitive-Social Bridge) This is the heart of the model. It positions Epistemological Beliefs (the individual's assumptions about knowledge) as the primary cognitive filter. Critically, this filter operates in tandem with Relationship-based Social Trust Networks. In the Thai context, this dual mechanism acts as both a *vulnerability* (when relational trust overrides verification) and a *strength* (when leveraged for community-based support and peer-to-peer validation).

Layer 3: Output & Desired Outcomes The ultimate goals of this framework are twofold. First, it aims to achieve Misinformation Resilience—the capacity to critically evaluate information and resist deceptive content. Second, it promotes sustainable Digital Participation, enabling older adults to transition from passive media consumers to active, confident participants in the digital economy.

This layered approach provides a clear causal path: identifying individual entry points, navigating the cognitive-social filters, and achieving long-term societal resilience.

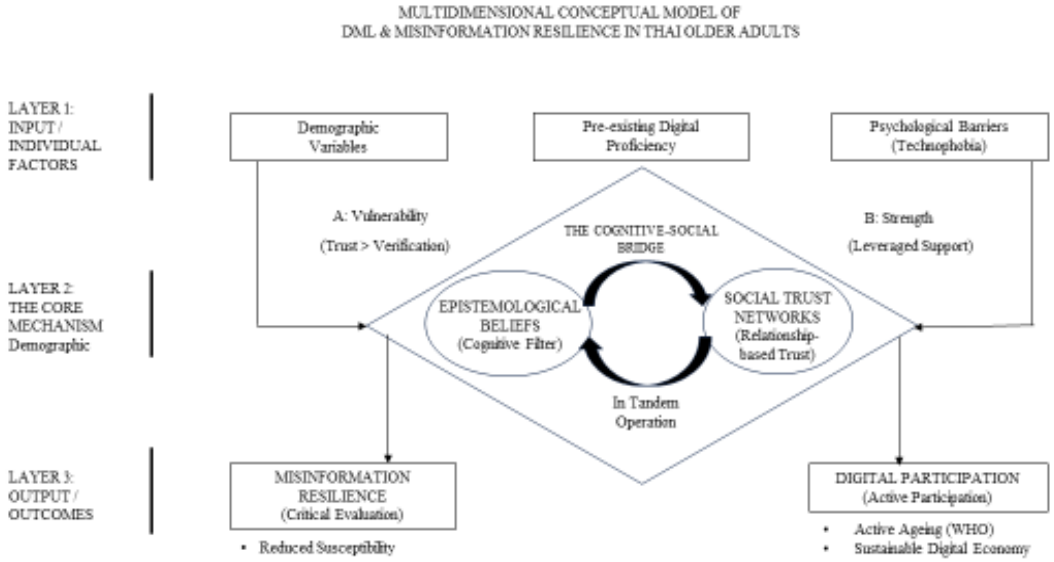

Figure 1 Conceptual of Framework

This study advances beyond existing literature by explicitly developing an integrated cognitive framework that positions epistemological beliefs as the central mechanism linking digital media literacy to misinformation resilience in a socio-cultural conte

4. Research Methodology

This study employs a qualitative research design, combining research synthesis with comparative content analysis to examine digital media literacy (DML) among older adults in both global and Thai contexts. This approach integrates diverse knowledge while capturing shared patterns and socio-cultural differences, providing a more comprehensive understanding of DML.

4.1 Data Selection and Inclusion Criteria

Studies were selected using clear inclusion criteria to ensure relevance and rigor.

First, the timeframe includes publications from 1997 to 2023, covering both foundational theories and recent developments in digital transformation. Second, data were drawn from major international databases (Scopus, Web of Science, PubMed) and national sources such as TCI Tier 1, ensuring both global coverage and contextual relevance to Thailand. Third, the scope focuses on studies related to DML, particularly cognitive aspects such as epistemological beliefs and psychological barriers (e.g., technophobia) among older adults. Both empirical and conceptual works were included to support a comprehensive analysis.

4.2 Research Instrument

A structured coding scheme was developed as the primary research instrument to guide systematic data extraction and ensure analytical consistency. The framework is aligned with the conceptual model and consists of four key dimensions: (1) spatial context (urban vs. rural), (2) core DML components (access, analysis, evaluation, creation), (3) cognitive mediators (epistemological beliefs and technophobia), and (4) policy and design implications (e.g., age-friendly interfaces and simple navigation). This multidimensional structure facilitates rigorous comparison across studies and supports the identification of underlying mechanisms influencing DML.

4.3 Data Analysis Procedures

The data were analyzed using qualitative content analysis through a three-stage process. First, thematic categorization was applied to classify studies based on key concepts and recurring patterns. Second, the constant comparative method was employed to examine similarities and differences between international and Thai contexts, particularly in relation to trust and digital behavior. Finally, an integrative synthesis was conducted to develop a unified cognitive framework, emphasizing epistemological beliefs as a central mediating construct linking DML to misinformation resilience.

4.4 Trustworthiness

To enhance the credibility and trustworthiness of the study, several methodological strategies were implemented. Methodological triangulation was applied by integrating evidence from international studies, national research, and policy documents. Additionally, peer debriefing was conducted with experts in communication and educational psychology to refine interpretations, validate analytical processes, and minimize potential researcher bias.

5. Results

5.1 Synthesis of Digital Media Literacy and Epistemological Beliefs (Objective 1)

The empirical evidence confirms that DML among older adults transcends technical utility, manifesting as a multidimensional construct encompassing functional, cognitive, affective, and social dimensions. At the center of this capability lies the role of Epistemological Beliefs, which serve as the primary cognitive mediator in how digital information is decoded, interpreted, and validated.

Individuals possessing evidence-based epistemological beliefs demonstrate a superior capacity for misinformation resilience, whereas those relying on relationship-based beliefs—where trust is anchored in the social credibility of the sender rather than empirical content—

are disproportionately susceptible to misinformation. Consequently, epistemological beliefs function as a "cognitive filter," determining whether digital content is subjected to critical scrutiny or accepted through social consensus. Furthermore, the integration of AI-Risk Perception as a secondary cognitive mediator underscores that critical skepticism is an essential, evolved competency for navigating contemporary digital risks.

5.2 Socio-Cultural and Contextual Influences (Objective 2)

The application of this framework is fundamentally moderated by spatial and relational dynamics unique to the Thai landscape. The findings highlight two critical moderating mechanisms:

Spatial Moderation (Urban–Rural Disparities): The spatial context dictates the nature of digital challenges. Urban older adults grapple with information overload and digital stress, which paradoxically constrain the depth of critical evaluation. In contrast, rural older adults experience restricted technological access but demonstrate a profound reliance on tight-knit family and community networks.

Human Scaffolding (Intergenerational Support): In the collectivist context of Thailand, Intergenerational Knowledge Transfer acts as a powerful moderating variable. Assistance from younger family members not only attenuates technophobia but serves as a crucial "on-ramp" for digital inclusion. This validates that DML development is not an isolated individual journey but a socio-cultural process; successful interventions must leverage these community-based support systems, as human scaffolding is significantly more effective than standardized, top-down training.

This comparative synthesis reveals that while global frameworks emphasize self-directed learning and evidence-based verification, the Thai context necessitates a relational approach—one that prioritizes protection and community-mediated learning to ensure sustainable Digital Well-being.

5.3 Comparative Synthesis: Global vs. Thai Perspectives

The distinction between global and Thai contexts underscores the necessity for culturally sensitive interventions.

Table 1 Comparative synthesis of digital media literacy

Aspect	Global Literature	Thai Context
Trust Mechanism	Evidence-based verification	Relationship-based trust
DML Objective	Active digital citizenship	Protection from scams and fraud
Learning Mode	Self-directed learning	Intergenerational/Community-mediated

5.4 Integrated Cognitive Framework and Research Contribution

The framework is established across three hierarchical levels:

Macro-level: DML as a holistic cognitive and interpretive process.

Meso-level: Epistemological beliefs and AI-Risk Perception as evaluative mechanisms.

Micro-level: Technology acceptance, self-efficacy, and Intergenerational Support as determinants of engagement.

5.5 Research Gaps and Conceptual Contribution

This framework addresses three critical gaps:

Integration Gap: Linking technical skills with cognitive belief systems.

Cultural Gap: Explicitly capturing relationship-based trust in non-Western contexts.

Depth Gap: Establishing a theory-building foundation for future Structural Equation Modeling (SEM).

6. Conclusion and Discussion

This research offers a nuanced analysis of how an integrated cognitive framework for Digital Media Literacy (DML) functions within the Thai socio-cultural context. By bridging global theories with local realities, the discussion highlights the study's contributions to theory, contextual understanding, and managerial practice.

6.1 Contribution to Objective 1: Framework Development

This study advances DML theory by positioning epistemological sophistication as the heartbeat of misinformation resilience. By weaving together, the four dimensions of DML—functional, cognitive, affective, and social—with an evolving cognitive belief system, we address a persistent "integration gap" in existing literature, where digital skills are often analyzed in a vacuum, separate from the cognitive frameworks that guide them.

The Trust Paradox: We identify a "trust paradox" specific to the Thai landscape, where relationship-based trust—usually a social pillar—can simultaneously act as a blind spot that leaves individuals vulnerable to misinformation.

Cognitive Resilience: By proposing the concept of cognitive resilience, this work moves beyond static skill-based models. It establishes epistemological growth as the engine of critical skepticism, especially when bolstered by AI-Risk Perception in an era of increasingly sophisticated digital threats.

6.2 Contribution to Objective 2: Socio-cultural Application

The research significantly extends DML models beyond Western-centric frameworks, which often assume that literacy is an isolated individual journey.

Human Scaffolding: Unlike global models that lean heavily on self-directed learning, the Thai experience is defined by human scaffolding. Family and community networks act as the primary conduits for digital inclusion.

Spatial Moderation: We observe that urban-rural disparities act as a crucial filter: while urban older adults navigate information overload and digital stress, their rural counterparts rely on robust social support despite technical limitations. This repositioning is vital; it highlights that in Thailand, DML must be treated as a community-mediated process rather than an exclusively individualistic endeavor.

6.3 Managerial and Practical Implications: From Training to Scaffolding

The practical implications of this study suggest a necessary shift from top-down "skill-based training" to systemic, supportive interventions.

Policy Design: For policymakers, the findings suggest that improving DML requires an "environmental design" approach—prioritizing usability and intuitive interfaces—rather than relying on the individual's effort alone.

Intergenerational Interventions: Interventions should proactively leverage Intergenerational Knowledge Transfer. Educational initiatives that empower younger family members to act as "digital scaffolds" will be significantly more effective than traditional training in lowering psychological barriers such as technophobia.

Sustainable Digital Participation: By defining Digital Well-being as the ultimate goal, this framework provides a strategic roadmap. It ensures that older adults can engage with—and benefit from—Thailand's digital economy with confidence, agency, and safety.

6.4 Limitations and Future Directions

While this research provides a robust conceptual foundation, we acknowledge that the reliance on secondary data may overlook the real-time, granular behavioral complexities of older adults. Future research should look to empirically validate these findings through longitudinal or mixed-method studies, particularly focusing on how epistemological beliefs evolve over time and how different interface designs impact digital inclusion across diverse settings.

7. Suggestions and Recommendations

7.1 Policy-Level Recommendations

At the policy level, the findings call for a transition from fragmented digital literacy initiatives toward integrated national strategies that explicitly incorporate cognitive and psychological dimensions. Rather than focusing solely on access and technical skills, policymakers should design frameworks that address how older adults interpret, evaluate, and respond to information. In addition, policy interventions should be differentiated by spatial context. Urban strategies should focus on mitigating information overload and digital fatigue through curated information environments and digital well-being programs, while rural strategies should prioritize infrastructure development alongside strengthening community-based support mechanisms. Furthermore, public communication campaigns should promote the concept of "critical trust," encouraging individuals to balance interpersonal trust with simple verification practices in everyday digital interactions.

7.2 Practical and Community-Based Recommendations

At the implementation level, digital literacy initiatives should be embedded within existing social structures rather than delivered as isolated training programs. Community-based models, where family members, peers, and local volunteers act as facilitators, can significantly enhance learning effectiveness and sustainability. Programs should also incorporate reflective learning components that gradually shift users from passive reliance on authority toward more active and analytical engagement with information. In this regard, intergenerational learning represents a particularly effective approach, as younger family members can serve as informal digital mentors, simultaneously strengthening both technical competencies and user confidence among older adults.

7.3 Design and Technology Recommendations

From a design perspective, digital platforms should move beyond general usability principles toward age-responsive design strategies that explicitly address cognitive and emotional constraints. Interfaces should adopt clear, linear navigation structures that minimize cognitive load and support step-by-step interaction. In addition, systems should integrate lightweight verification support, such as visual credibility indicators, simplified source information, and guided prompts for fact-checking, enabling users to assess information without requiring advanced analytical skills. Emotional usability should also be prioritized through reassuring feedback, consistent interaction patterns, and error-tolerant design, all of which can reduce anxiety and encourage sustained engagement.

7.4 Educational Recommendations

Educational initiatives should expand their scope to include not only digital skills, but also cognitive competencies related to information processing. Training programs should emphasize practical evaluation strategies, such as recognizing misinformation cues, comparing sources, and understanding how digital content is constructed and disseminated. Lifelong learning models should be designed with flexibility in mind, allowing older adults to progress at their own pace within supportive and low-pressure environments. Importantly, the focus of education should shift from knowledge transmission to capability building, equipping learners with the ability to make independent judgments in complex digital contexts.

8. Acknowledgements

The author wishes to express her deepest and most sincere gratitude to Associate Professor Dr. Amnuay Saengnoree, Program Chairperson, for his exceptional mentorship, profound academic guidance, and unwavering support throughout every stage of this research. His invaluable insights and dedication have been the primary inspiration and support for the completion of this study.

Special appreciation is extended to Mrs. Charinya Chukkai, Assistant Permanent Secretary of the Ministry of Culture, and Dr. Chanthapat Khamkhokkruad, Deputy Secretary-General of the NBTC, for their exceptional support, profound academic insights, and pivotal roles in providing expert guidance on Digital media literacy throughout this research.

Finally, the author acknowledges the institutional collaboration from the Ministry of Culture and the NBTC. The author also notes the appointed position of Assistant Professor Toosrangrasame Tetakew as the research advisor per the doctoral program's administrative criteria.

9. References

Aufderheide, P. (1992). *Media literacy: A report of the National Leadership Conference on Media Literacy*. Aspen Institute.

Buckingham, D. (2019). *The media education manifesto*. Polity Press.

Castilla, D., Botella, C., Miralles, I., Bretón-López, J., Dragomir-Davis, A. M., Zaragoza, I., & Garcia-Palacios, A. (2018). Teaching digital literacy skills to the elderly using a social network with linear navigation: A case study in a rural area. *International Journal of Human-Computer Studies, 118*, 24–37.

Celik, I., Muukkonen, H., & Dogan, S. (2021). A model for understanding new media literacy: Epistemological beliefs and social media use. *Library & Information Science Research, 43*(4), 101125.

DQ Institute. (2023). *Digital intelligence (DQ) framework*.

Hobbs, R. (2020). *Digital and media literacy: A plan of action* (2nd ed.). Aspen Institute.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88–140.

Kaewthep, K. (2008). *Media literacy: Concepts and applications* [in Thai]. Kasetsart University Press.

Livingstone, S. (2004). What is media literacy? *Intermedia, 32*(3), 18–20.

Long, D., & Magerko, B. (2020). What is AI literacy? Competencies and design considerations. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–16).

Moore, R. C., & Hancock, J. T. (2022). A digital media literacy intervention for older adults improves resilience to fake news. *Scientific Reports, 12*, 6008.

Nguyen, M. H., Gruber, J., Fuchs, J., Marler, W., Hargittai, E., & Hunsaker, A. (2022). Changes in digital communication during the COVID-19 global pandemic: Implications for digital inequality and future research. *Social Media + Society, 8*(1).

Rasi, P., Vuojärvi, H., & Rivinen, S. (2021). Promoting digital media literacy among older people: A systematic review. *Adult Education Quarterly, 71*(1), 37–54.

Tsai, H. S., Shillair, R., Cotten, S. R., Winstead, V., & Yost, E. (2020). Getting grandma online: Are tablets the answer for increasing digital inclusion for older adults in the U.S.? *Educational Gerontology, 46*(10), 575–586.

World Health Organization. (2021). *Global report on ageism*.

Wutthirangsi, A. (2021). Digital media literacy of older adults [in Thai]. *Sahasart Journal, 21*(1), 62–74.

DEVELOPING A PRIDE MODEL: A DIGITAL PROJECT-BASED BLENDED LEARNING APPROACH TO ENHANCE TEACHERS' RESEARCH COMPETENCY

Kemmawat Iedkhao*, Thanin Ratanaolarn, and Sirirat Petsangsri

63603009@kmitl.ac.th, thanin.ra@kmitl.ac.th, and sirirat.pe@kmitl.ac.th

Department of Industrial Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 63603009@kmitl.ac.th

ABSTRACT

Amid the challenges of digital transformation, research proficiency is no longer merely an academic skill but a vital tool for fostering "professional pride" and enhancing personnel competencies to keep pace with a dynamic world. This research aimed to develop and evaluate a blended project-based learning model delivered via a digital platform to enhance teachers' research competency. The key informants consisted of seven experts in educational technology, curriculum and instruction, educational research, measurement and evaluation, and educational administration. The research instruments included an evaluation form for the learning model and open-ended questionnaires. Data were collected through in-depth interviews and analyzed using thematic analysis, mean ($\bar{x}$), and standard deviation (S.D.).

The research findings revealed that 1) the synthesized and developed model, titled the "PRIDE Model" (Project-based Blended Learning Research in a Digital Environment), comprised three main phases: preparation, action, and evaluation. These phases encompassed six sub-steps of learning management, integrated with the Classroom Action Research cycle (PAOR). They were driven by interactions on a digital platform alongside support from mentors and Professional Learning Communities (PLC).

2) The evaluation by the seven experts indicated that the PRIDE Model achieved an overall quality at the highest level ($\bar{x}$= 4.75). Upon considering each dimension, all were rated at the highest quality level: utility had the highest mean ($\bar{x}$= 4.88), followed by appropriateness ($\bar{x}$= 4.81), congruence ($\bar{x}$= 4.75), and feasibility ($\bar{x}$= 4.55), respectively. The standard deviation (S.D.) across all dimensions remained low (0.19 - 0.42).

Furthermore, 3) the qualitative analysis confirmed that the model excelled in its clear integration of theory into practice. The use of technology served as a powerful scaffolding tool, and the emphasis on human support systems was identified as a critical factor in success.

Keywords: Blended learning, Project-based learning, Research competency,
Digital environment, PRIDE model, Supportive ecosystem

1. Statement of the Problem

Digital transformation has significantly reshaped the global educational landscape, necessitating a paradigm shift in instructional management to meet the demands of 21st-century learners (Al-Amri & Al-Badi, 2022). This evolution demands that teachers, who are the primary catalysts for educational quality, redefine their roles. They must transition from being mere transmitters of knowledge to becoming teacher-researchers capable of systematically analyzing

classroom challenges and developing evidence-based solutions through Classroom Action Research (CAR).

The concept of the "teacher-researcher" is predicated on the principle that educators possess the deepest understanding of their own classroom contexts and challenges. Fostering research competency among teachers, therefore, cultivates a data-driven culture and promotes evidence-based decision-making. These elements serve as vital mechanisms for sustainably enhancing instructional quality and student outcomes (Chow et al., 2015). In the digital era, these competencies must be integrated with technological proficiency, enabling teachers to leverage digital tools for information retrieval, data analysis, and effective collaboration within Professional Learning Communities (PLC) (Trust et al., 2021).

The Pathum Thani Primary Educational Service Area Office 2 (PTPESA 2) serves as a pivotal administrative body responsible for driving educational quality across its three constituent districts: Lam Luk Ka, Thanyaburi, and Nong Suea. The Office's core mandate involves continuous oversight, supervision, monitoring, and evaluation of educational management to ensure strict alignment with the Ministry of Education's strategies and policies. Guided by a vision to cultivate high-performance personnel whose competencies are tailored to their evolving responsibilities, PTPESA 2 strives to equip students with the global perspectives and modern skill sets required of contemporary global citizens. The model integrates research competence, digital integration, and professional values to enhance educational standards through incentivized communication systems.

Although the role of the "teacher-researcher" has gained widespread recognition, many educators continue to face substantial practical barriers in developing their research competencies. A preliminary Needs Assessment identified two critical gaps hindering the effective implementation of Classroom Action Research (CAR): methodological challenges in quantitative and statistical analysis, and deficiencies in systematic research design. Teachers reported a lack of confidence in selecting appropriate statistical methods, interpreting results, and presenting data with academic rigor (Mertler, 2019). Furthermore, educators encountered difficulties in formulating research problems aligned with authentic classroom contexts and in applying the Plan-Act-Observe-Reflect (PAOR) cycle effectively (Kemmis et al., 2020).

Despite the growing recognition of teacher-researchers and the increasing integration of digital technologies in education, existing professional development approaches remain fragmented and insufficient in addressing teachers' practical research competencies in authentic classroom contexts. Previous studies have primarily emphasized theoretical training or isolated research skills, while giving limited attention to integrating Project-Based Learning, Blended Learning, digital platforms, mentoring systems, and Professional Learning Communities (PLCs) into a unified instructional framework. Consequently, there remains a significant research gap in the development of an instructional model that holistically supports teachers' development of research competencies through practical, technology-enhanced, and collaborative learning processes. To address this gap, the present study developed the PRIDE Model, a digital, project-based, blended-learning approach designed to strengthen teachers' research competencies through systematic research practice and continuous professional support.

These preliminary survey results align closely with the findings of Kemmawat et al. (2021), whose assessment of 21st-century research competency needs revealed that teachers possess a high demand for development in digital technology integration for research, the design of high-quality research instruments, and statistical data analysis. Such findings underscore the urgent need for instructional innovations specifically tailored to these requirements—innovations that

prioritize practical, actionable skills that educators can immediately apply to their professional practice.

Instructional Innovation and the Role of Digital Platforms. To address the aforementioned competency gaps, the researcher developed an instructional model synthesized from the Project-Based Learning (PjBL) and Blended Learning frameworks, using a digital platform as the primary infrastructure to drive the learning process.

Project-Based Learning (PBL) provides educators with the opportunity to master the research process through hands-on engagement with authentic classroom challenges. By navigating the trajectory from initial inquiry to conclusion, teachers gain an immersive, meaningful learning experience (Guo et al., 2020). Concurrently, Blended Learning integrates the advantages of face-to-face instruction—which emphasizes in-depth discussion and personalized mentoring—with online learning, providing teachers with the flexibility to access resources and engage in self-paced learning at their convenience.

In this context, the digital platform serves as far more than a mere repository of content; it functions as a learning ecosystem that interconnects every element of the instructional process. It provides a collaborative workspace that supports the research trajectory at every stage—from accessing knowledge bases and utilizing data analysis tools to receiving online mentoring from experts and engaging in knowledge sharing within Professional Learning Communities (PLCs) (Zhao et al., 2021). Consequently, the integration of PjBL and Blended Learning within a digital platform represents a highly promising innovation, offering a learning experience that is flexible, structured, and effective at genuinely enhancing teachers' research competencies in the digital age.

2. Objectives

2.1 To develop a digital platform-based, project-based blended learning model designed to promote the research competencies of teachers.

2.2 To evaluate the quality of the developed model through expert review across four dimensions: Congruence, Appropriateness, Feasibility, and Utility.

3. Literature Review

The conceptualization of the Project-based Research in a Digital Environment (PRIDE) Model is firmly rooted in three foundational theoretical pillars: Project-Based Learning (PjBL), Blended Learning, and Classroom Action Research (CAR). The integration of these pedagogical frameworks constitutes the core mechanism for developing an instructional innovation that addresses the multifaceted challenges of transitioning educators into teacher-researchers, a critical professional evolution necessitated by the demands of the digital era.

3.1 Project-Based Learning (PBL)

Project-Based Learning (PBL) is an instructional approach that engages learners in the hands-on execution of complex, personally meaningful projects to address challenging, real-world questions or problems (Wurdinger & Qureshi, 2015). The essence of PBL lies in a fundamental pedagogical shift: the learner’s role transitions from a passive receiver of knowledge to an active constructor of knowledge. In contrast, the teacher’s role shifts from instructor to facilitator (Larmer, Mergendoller, & Boss, 2015).

In the context of professional development, PBL provides educators with a practical framework for refining their research proficiency through classroom action research projects. This journey encompasses the entire research cycle—from formulating inquiries and designing methodologies to data collection, analysis, and the final synthesis and presentation of findings. This approach aligns with the perspective of Guo et al. (2020), who emphasize that PBL is highly

effective in cultivating complex problem-solving and critical thinking skills—both of which are foundational to research competency. The synthesized stages of project-based learning management, derived from relevant theoretical frameworks, are presented in Table 1.

Table 1 Synthesis of Project-Based Learning (PBL) Stages from Relevant Frameworks

The Stages of Project-Based Learning (PBL)	Related Concepts and Theories														
	Wening Rahayu (2022)	Eris Nurhayati (2021).	Z. Simpson (2020)	Fendy Hardian (2019)	Littlejohn, W. N.(2019)	Nanik (2019)	Stoller, F. (2019)	Yustina (2020)	Ririn (2021)	Baron, K. (2010)	KM CHIL (2015)	Wanyan (2019)	Shelly (2016)	Frequency	Implemented Instructional Steps
1. Driving and motivating the idea	✓	✓		✓	✓	✓		✓	✓		✓		✓	9	✓
2. Formulating and understanding the concept			✓					✓				✓		3	
3. Defining and Planning the Project	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	13	✓
4. Making and doing the project proposal	✓	✓	✓					✓			✓			5	
5. Designing and Constructing the Knowledge	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	11	✓
6. Progressing and Applying the Project	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	12	✓
7. Presenting and Reflecting on the Project		✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	10	✓
8. Evaluating and Expanding the Project	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	12	✓

The researcher reviewed various academic frameworks, which offered varying stages depending on their specific contexts. These concepts were synthesized and refined to align with the principles of Constructionism and Problem-Based Learning, thereby enhancing teachers' research competencies. This synthesis resulted in **six core stages** of the project-based learning process, designed to foster research proficiency for instructional development as follows: Stage 1)Driving and Motivating the Idea 2) Defining and Planning the Project 3) Designing and Constructing Knowledge 4) Progressing and Applying the Project 5) Presenting and Reflecting on the Project and 6)Evaluating and Expanding the Project These stages serve as the primary instructional framework for the **PRIDE Model**, the details of which are illustrated in **Figure 1** below:

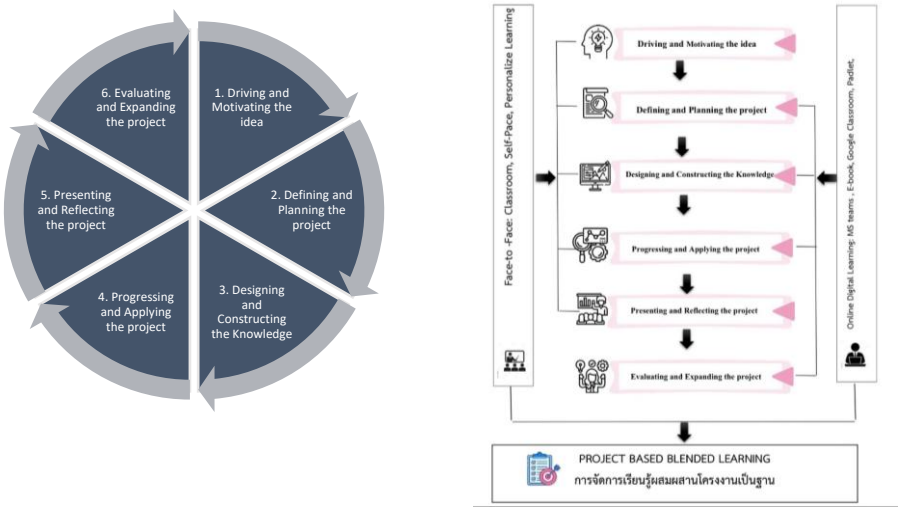

Figure 1 The Six-Stage Project-Based Blended Learning

The conceptual framework of the PRIDE Model is presented in Figure 1. The conceptual synthesis of the PRIDE Model demonstrates the dynamic interaction among Project-Based Learning (PjBL), Blended Learning, Classroom Action Research (CAR), and the digital learning ecosystem. Project-Based Learning functions as the core pedagogical mechanism that engages teachers in authentic research practices through problem-solving and reflective inquiry. Blended Learning provides flexible learning experiences by integrating face-to-face mentoring with online learning activities delivered through a digital platform, while the PAOR cycle serves as the operational process guiding systematic research practice.

Furthermore, the digital platform functions as an integrated learning ecosystem that connects learning resources, mentoring systems, collaborative workspaces, data analysis tools, and Professional Learning Communities (PLCs). The interaction among these components creates a continuous professional learning process that supports the sustainable development of teachers' research competencies in digital learning environments.

3.2 Blended Learning

Blended Learning is the systematic integration of face-to-face classroom instruction and online learning via digital technologies (Garrison & Vaughan, 2008). The primary advantage of this approach is its inherent flexibility, allowing learners to exercise control over the time, place, and pace of their learning (Horn & Staker, 2014). In developing the PRIDE Model, this framework effectively addresses the time constraints and heavy workloads educators often face.

By adopting this model, teachers can engage with research theories and principles through a digital platform at their convenience, while utilizing face-to-face sessions for in-depth consultations with experts and peers, experiential sharing, and receiving expert feedback. Research by Rasheed et al. (2020) confirms that blended learning not only broadens access to knowledge resources but also fosters the interaction and engagement essential for establishing a robust Professional Learning Community (PLC) for teacher-researchers.

3.3 Classroom Action Research (CAR)

Classroom Action Research (CAR) is a systematic inquiry conducted by educators to examine and resolve authentic challenges within their own instructional settings. Its primary objective is to enhance teaching methodologies and optimize student learning outcomes (Mills, 2018). CAR is characterized by a continuous, cyclical process comprising four key phases: Planning, Acting, Observing, and Reflecting (PAOR) (Kemmis, McTaggart, & Nixon, 2014).

Integrating CAR into the PRIDE Model ensures that teachers' research projects are not mere academic exercises but are rooted in real classroom dilemmas. This grounding makes the learning process profoundly meaningful and facilitates tangible transformation in the classroom. Research by Susilowati et al. (2021) suggests that engaging in CAR enables teachers to develop a deeper understanding of their pedagogical contexts and fosters a sense of professional ownership over their development.

3.4 Synthesis of the PRIDE Model Framework

Consequently, synthesizing these three theoretical pillars within the PRIDE Model creates a comprehensive learning ecosystem. In this system:

Project-Based Learning (PBL) serves as the primary mechanism that drives teachers toward hands-on research.

Blended Learning, supported by a Digital Platform, provides the necessary flexibility and connects educators with expert guidance and knowledge resources.

Classroom Action Research (CAR) establishes the objective and context for the projects.

This integrated approach ensures that enhancing teachers' research competencies translates into concrete, sustainable improvements in educational quality.

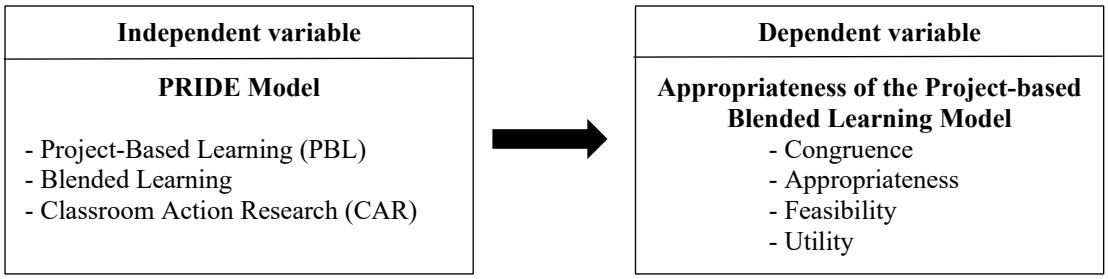

Figure 2 Conceptual Framework

4. Research Methodology

To develop the digital platform-based, project-based blended learning model to promote teacher research competencies, the researcher conducted an extensive review of domestic and international literature. Relevant concepts were synthesized to ensure the model's effectiveness. The development and evaluation process of the research instrument (the model evaluation form) is detailed below:

4.1 Research methodology

4.1.1 Key Informants

The key informants for this study consisted of seven experts selected through purposive sampling. This multidisciplinary panel included 2 experts in Educational Technology and Innovation, 2 experts in Curriculum and Instruction, 1 expert in Educational Research, 1 expert in Educational Measurement and Evaluation, and 1 expert in Educational Administration. All experts possess at least five years of professional experience in their respective fields. The selection of experts from diverse backgrounds facilitates data triangulation, thereby enhancing the validity and credibility of the evaluation results (Creswell & Creswell, 2018).

4.2.1 Research Instruments

The primary instrument used in this study was a Model Evaluation Form, structured across four core dimensions based on Stufflebeam's evaluation framework (as cited in Alkin & Christie, 2004). The instrument was designed as a 5-point Likert Scale, ranging from "Strongly Disagree" to "Strongly Agree." The criteria for interpreting the mean scores are detailed in Table 2.

Table 2 Interpretation of model evaluation form

Scale	Interpretation
5 = Strongly Agree	4.50 - 5.00 Strongly Agree
4 = Agree	3.50 - 4.49 Agree
3 = Moderate	2.50 - 3.49 Moderate
2 = Disagree	1.50 - 2.49 Disagree
1 = Strongly Disagree	1.00 - 1.49 Strongly Disagree

2) Open-ended Questions. This section allowed experts to provide qualitative feedback, justify their quantitative ratings from the first part, and offer independent suggestions. The goal was to obtain in-depth information and nuanced insights that a numerical scale might not fully capture. Key open-ended prompts included:

"What is the most significant strength of the PRIDE Model?"

"Which components should be improved or added to enhance the model's completeness?"

"What additional suggestions do you have for the practical implementation of this model in educational institutions?"

Instrument Quality Validation

Before implementation, the researcher conducted a rigorous validation process to ensure the instrument's quality. The draft evaluation form was submitted to five external experts (distinct from the key informant group) to verify content validity and linguistic clarity.

4.3 Data Collection

Data collection was designed as a constructive exchange of perspectives between the researcher and the experts to ensure a profound and comprehensive understanding of the model's quality. The researcher employed individual in-depth interviews, a flexible methodology that allows for probing into significant emerging issues (Boyce & Neale, 2006). The process was divided into three distinct phases

1. Preparation Phase

The researcher formally invited the selected experts, clarifying the research objectives and their specific roles. Upon acceptance, the following documents were provided at least one week in advance to allow for thorough review: 1) An executive summary of the research project. 2) Detailed diagrams and descriptions of the PRIDE Model components. Furthermore, 3) The finalized evaluation instrument.

2. Interview Phase

Interviews were conducted either via online conference or face-to-face, depending on the expert's convenience, with each session lasting approximately 60–90 minutes. The procedure was structured as follows: Quantitative Rating Experts first completed Part 1 (Rating Scale) of the evaluation form to establish a baseline of their assessment. Qualitative Probing The researcher used the open-ended prompts from Part 2 as a guide for the in-depth interview. This involved probing the reasoning behind specific scores and encouraging experts to elaborate on critical suggestions or innovative points. Documentation: All sessions were audio-recorded (with the experts' informed consent) and supplemented by field notes to capture nuances and contextual information.

3. Post-Interview Phase

The recorded audio data was subjected to verbatim transcription, converting the spoken dialogue into text to ensure accuracy for the subsequent data analysis stage.

4.4 Data Analysis

The data analysis process was divided into two main approaches to address both the quantitative and qualitative aspects of the research

1. Quantitative Analysis Data obtained from the 5-point Likert Scale evaluation form were analyzed to assess the quality of each model component. The statistical measures employed include Mean ($\bar{x}$): To determine the average level of agreement or suitability for each dimension. Standard Deviation (S.D.) To assess the consensus among the experts and the distribution of the scores.

2. Qualitative Analysis Data collected from the in-depth interviews and the open-ended suggestion forms were processed using Thematic Analysis. This systematic process involved interpreting and categorizing qualitative data to identify recurring patterns, core themes, and critical insights (Krippendorff, 2018).

This method ensured a rigorous transition from raw transcriptions to meaningful improvements for the PRIDE Model.

5. Results

5.1 Results of the Development of the Project-Based Blended Learning Model on a Digital Platform to Promote Teacher Research Competency (PRIDE Model)

The synthesis of theoretical frameworks and expert input resulted in the PRIDE Model, a comprehensive instructional system designed to enhance teachers' research proficiency in the digital age. The conceptual architecture and operational stages of the model are illustrated in Figure 3

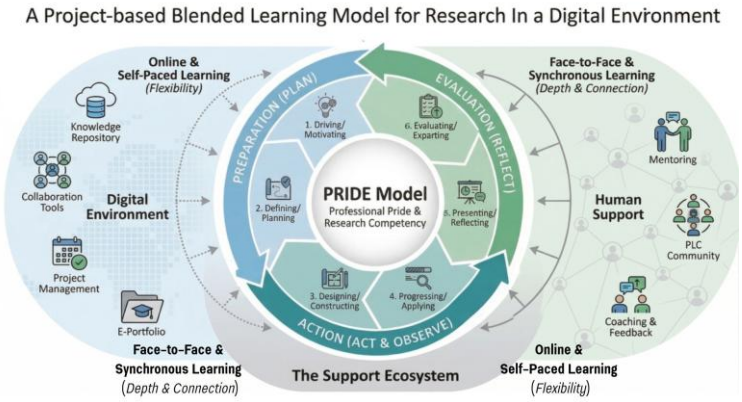

Figure 3 The Project-based Blended Learning Model (PRIDE Model)

PRIDE Model features 6 project-based learning steps: 1) Driving & Motivating, 2) Defining & Planning, 3) Designing & Constructing, 4) Progressing & Applying, 5) Presenting & Reflecting, and 6) Evaluating & Expanding. These steps are clearly directed to the subsequent stage using an arrow, driven by the PAOR cycle (Plan, Act, Observe, Reflect) within a Blended Learning ecosystem (Online & Face-to-Face). In the outer ring (Support), the model focuses on certifying the Project-Based Blended Learning Model on a digital platform to Enhance Research Competency for Teachers. The system architecture is organized into three layers. The Outer Ring represents the Blended Environment (Online + Physical Space), the Middle Ring (Cycle) represents the PAOR process for continuous learning, and the Inner Core (Process) comprises the 6 learning steps from preparation to reflection, as summarized in Table 3.

Table 3 Elements and processes of the PRIDE model

Phase / Stage	Learning Steps	Digital Platform Support
Phase 1 Preparation (P1)	Step 1: Driving & Motivating (Identifying authentic problems and stimulating inquiry)	Knowledge Repository Database for research, case studies, and educational theories.
(Aligns with PLAN)	Step 2: Defining & Planning (Developing research proposals and action plans)	Project Management Tools: Online proposal templates, mind mapping, and task tracking.
Phase 2 Action (P2)	Step 3: Designing & Constructing (Developing innovations and research instruments)	Resource & Tool Library Links to authoring tools, OERs, and collaborative feedback spaces.
(Aligns with ACT & OBSERVE)	Step 4: Progressing & Applying (Implementing innovation and systematic data collection)	Data Management System: Online surveys, digital observation logs, and E-Portfolios.
Phase 3 Evaluation & Sharing (P3)	Step 5: Presenting & Reflecting (Data analysis and collaborative reflection)	Basic Analysis Tools, Statistical calculation tools (Mean, Percentage), and PLC discussion forums.
(Aligns with REFLECT)	Step 6: Evaluating & Expanding (Final reporting and knowledge dissemination)	Showcase & Portfolio System: Digital repository for E-Research reports and video presentations.

The PRIDE Model (Project-based Blended Learning in a Digital Environment) is structured into three main phases.

Preparation Phase (P1) focuses on building a solid foundation by identifying classroom challenges and systematically planning the research.

Action Phase (P2) The core implementation stage, where teachers develop educational innovations and apply them in real classroom settings while collecting empirical data.

Evaluation & Sharing Phase (P3) Focuses on concluding the research through reflection, professional dialogue (PLC), and sharing findings with the educational community to foster a research-driven culture.

The Digital Platform serves as a Learning Ecosystem, providing the necessary technological scaffolding—from knowledge repositories to collaborative workspaces—ensuring that teachers receive continuous support throughout their research journey.

5.2 Results of Project-based Blended Learning Model appropriateness on Digital Platform to Enhance Research Competency for Teachers (PRIDE Model)

Table 4 Results of the appropriateness of the Project-based Blended Learning Model (n = 7)

Item	Description	$\bar{x}$	S.D.	interpretation
1.	Congruence	4.81	0.25	Strongly Agree
2.	Appropriateness	4.75	0.31	Strongly Agree
3.	Feasibility	4.55	0.42	Strongly Agree
4.	Utility	4.88	0.19	Strongly Agree
	Overall	4.75	0.29	Strongly Agree

According to Table 4, the overall quality of the PRIDE Model was rated at the "Strongly Agree" (Highest) level ($\bar{x}$= 4.75, S.D. = 0.29). A detailed analysis of each dimension reveals the following: Utility ($\bar{x}$ = 4.88, S.D. = 0.19). This dimension achieved the highest mean score, indicating that the experts clearly recognize the model's value in driving teachers' professional development and enhancing their learning outcomes. Congruence ($\bar{x}$ = 4.81, S.D. = 0.25). The results suggest that the model's various components are logically interconnected and mutually supportive within the instructional system. Appropriateness ($\bar{x}$ = 4.75, S.D. = 0.31). The experts agreed that the design and structure of the model are well-suited to the target users and the intended educational context. Feasibility ($\bar{x}$ = 4.55, S.D. = 0.42). This dimension also reached its highest level, confirming that the model is practical and implementable in educational institutions.

5.2.1 Qualitative Analysis Results

The Thematic Analysis of the expert interviews and open-ended feedback provided deep insights into the model's practical value. The findings are synthesized into two primary categories: Key Strengths and Recommendations for Development.

2.1) Key Strengths of the PRIDE Model

Items	Thematic Analysis	Interview Excerpts
Key Strengths of the PRIDE Model	Theme: The Seamless Integration of Theory and Practice	"This platform is not merely an online repository of theories; it is a well-designed 'Digital Research Workbench.' Once teachers learn the theory of instrument construction, they can immediately utilize system templates to develop their own questionnaires. Similarly, after studying statistical theory, they can upload data for preliminary analysis. It is a powerful mechanism for closing the 'knowing-doing gap'." — *(Educational Technology and Innovation Experts 1 & 2)* "The strength lies in transforming a teacher's 'practice' into tangible data that informs further theoretical learning. For instance, when a teacher inputs pre-test scores, the system suggests relevant instructional theories. After implementation, the platform visualizes the post-test results, allowing the theory to 'prove itself' through the reality of the teacher's own classroom." — *(Educational Administration Expert)* "…The most significant strength is the central role of PjBL, which ensures research is not a chore but a project that teachers truly own. The division into three phases and six clear stages makes the process highly accessible, effectively transforming the abstract concept of 'research' into a concrete, achievable reality." *(Curriculum and Instruction Experts 1& 2)* "This model authentically deconstructs the 'ivory tower' of research. Traditional training often teaches theory in a sterile environment, but this model compels teachers to experiment within a 'Living Laboratory'—their own classrooms. The practical challenges they encounter drive them to revisit and deepen their theoretical understanding. This is the heart of Action Research: theory must adapt to the actual context, moving beyond rote memorization for exams." — *(Educational Research Expert)*
	Theme: Cultivating a Sustainable Research	"The scope of this model exceeds simply teaching research skills; it possesses the genuine potential to cultivate a 'Teacher-Researcher Culture' within schools. Because the final stages emphasize dissemination and further development, an individual teacher's work is transformed into a collective body of knowledge for the entire institution." — *(Educational Research Expert)*

		" As multiple teachers begin conducting research within their own classrooms, their professional status evolves in the eyes of peers and administrators. They become 'context-specific experts.' This mutual professional recognition, facilitated by tangible research outputs, acts as a catalyst for a school-wide culture of continuous self-improvement." — *Educational Technology and Innovation Experts (1, 2)* "In the long term, this platform will serve as the school's 'Living Innovation Repository.' When new staff arrive or when recurring pedagogical challenges emerge, the institution can leverage the database of prior research conducted by senior colleagues. This facilitates sustainable organizational knowledge management, transforming the school into a true Learning Organization."— *Educational Measurement and Evaluation Expert.*
	Theme: The Digital Platform as an Adaptive Scaffold and Feedback Engine	"The platform transcends its role as a mere file repository; it functions as a critical Instructional Scaffold that supports teachers at every stage, from initial ideation to final presentation. The intentional alignment of the platform's functions with each specific phase of the research process is highly commendable."— *Educational Technology and Innovation Experts (1, 2)* "In my view, this platform serves as a powerful 'Feedback Loop Engine.' When teachers submit their research drafts, mentors can provide direct, contextualized comments. This is significantly more effective than verbal feedback, as it precisely identifies areas for improvement. Furthermore, the platform maintains a comprehensive developmental history for each teacher, making rigorous Formative Assessment a practical reality. We can monitor professional progress in intervals and provide targeted interventions, creating a rapid and highly efficient cycle of development."— *Educational Measurement and Evaluation Experts & Curriculum and Instruction Experts (1, 2)*
	Theme: The Synergy between Technology and Human Support Systems	" Technology alone is insufficient. This model demonstrates a deep understanding of professional development by rigorously integrating Mentors and PLCs. To truly transform a teacher's practice, a 'human-to-human' approach is essential. Having a mentor to coach and a peer group for exchange are the critical factors that will ensure the project's success and sustainability within a school."— *Educational Administration Expert.* "Classroom Action Research is highly flexible, which is both a strength and a potential weakness. Without guidance, the process can easily deviate from rigorous principles. Therefore, the role of a research expert as a Mentor is vital in 'steering the direction' of the project. They ensure that data collection remains reliable, analysis remains unbiased, and conclusions are strictly evidence-based. In essence, the Mentor serves as the Guardian of Academic Standards for the teacher's project."— *Educational Measurement and Evaluation Experts & Curriculum and Instruction Experts (1, 2)*

2.2) Recommendations for Development and Implementation

Items	Thematic Analysis	Interview Excerpts
Recommendations for Development and Implementation	Theme: Prioritizing Digital Readiness and Managing Cognitive Load	"Before implementing the model, it is essential to conduct a digital literacy assessment followed by targeted training for participating teachers. This ensures they possess the necessary skills to navigate the platform effectively, preventing technology from becoming a barrier to learning. "Educational Technology and Innovation Experts (1, 2) "I am concerned that if teachers must dedicate the majority of their mental resources to deciphering how to use the platform, they will have insufficient cognitive energy left to master the core content—the research process itself. To prevent an excessive Cognitive Load, I strongly recommend implementing a 'Module Zero.' This preparatory module should focus exclusively on platform navigation, allowing teachers to experiment in a low-stakes environment. The goal is to make platform usage 'automatic' before they encounter more complex theoretical content."— Curriculum and Instruction Experts (1, 2)
	Theme: Temporal Flexibility and the Prioritization of Deep Reflection	"The research timeline should be designed with inherent flexibility, as each teacher faces unique instructional loads and classroom variables. The platform should include features that allow teachers and mentors to adjust project milestones based on real-world constraints collaboratively."— *Educational Research Expert.* "Acquiring complex skills like research requires sufficient time for cognitive crystallization and trial and error. Overly restrictive deadlines risk transforming what should be a creative learning journey into a mere 'compliance task' aimed only at meeting deadlines. This would, unfortunately, compromise the model's core objectives. It must be clearly communicated from the outset that the 'quality of the process' takes precedence over the 'speed of completion.' The system must encourage teachers to engage deeply in reflection and critical thinking without the pressure of a ticking clock."— *Educational Technology and Innovation Experts (1, 2)*
	Theme: Establishing Robust and Actionable Feedback Mechanisms	"The system should incorporate standardized Rubrics or clear feedback criteria for mentors. This is essential to ensure that the guidance provided to teachers remains consistent and high in quality across the platform. A structured rubric prevents subjective or fragmented advice, ensuring that all participants receive a uniform standard of professional support." — Educational Technology and Innovation Experts (1, 2)

		"Quality feedback must go beyond merely stating whether a piece of work is 'good' or 'needs improvement.' It must be Actionable and Prescriptive. Mentors should be equipped with tools that help them pinpoint specific areas for growth and provide concrete suggestions on how to advance. The goal is to transform the feedback process from a simple evaluation into a strategic roadmap for the teacher's professional development."— *Educational Measurement and Evaluation Experts & Curriculum and Instruction Experts (1, 2)*
	Theme: Strategic Alignment with Professional Advancement and Multimodal Support	"A pivotal incentive for sustained engagement would be the formal recognition of research outputs generated through this model within the Professional Performance Appraisal (PA) or Academic Standing promotion systems. If this research is officially credited toward career advancement, it will serve as a powerful catalyst, encouraging teachers to commit to the continuous development of their research competencies."— *Educational Measurement and Evaluation Expert.* "I recommend enhancing the platform to support Multimodal Feedback, such as video or audio clips, which can convey instructional nuances more effectively than text alone. Furthermore, the system should include a Longitudinal Tracking feature to monitor a teacher's development over time. This would enable mentors to provide highly personalized and targeted interventions based on the specific progress and historical data of each learner."— *Curriculum and Instruction Experts (1, 2)*
In conclusion, the expert panel's evaluation results confirm that the PRIDE Model is of the highest quality. The model demonstrates exceptional congruence, appropriateness, and feasibility, serving as a highly effective framework for enhancing teacher research competencies. Furthermore, the constructive feedback and recommendations received will be meticulously integrated to refine and optimize the model's details, ensuring its comprehensive completeness for practical implementation in the subsequent phase of this study.		

6. Conclusion and Discussion

6.1 Development of the PRIDE Model

The researcher developed an innovative learning model entitled "PRIDE Model" (Project-based blended learning Research in a Digital Environment). The structural framework of the model consists of three core phases: Preparation, Implementation, and Evaluation, which are further operationalized into six specific instructional stages. A key feature of the PRIDE Model is the seamless integration of the Classroom Action Research cycle (PAOR), driven by dynamic interactions within a digital platform and bolstered by professional support from mentors and Professional Learning Communities (PLC).

6.2 Evaluation of the Model The evaluation by a panel of seven experts indicates that the PRIDE Model possesses an overall quality at the "Highest" level ($\bar{x}$ = 4.75). Detailed analysis reveals that all assessed dimensions achieved the highest rating: Utility ($\bar{x}$= 4.88), Congruence ($\bar{x}$ = 4.81), Appropriateness ($\bar{x}$ = 4.75), and Feasibility ($\bar{x}$ = 4.55)

The qualitative analysis further confirms the model's efficacy, particularly in its ability to facilitate a seamless theory-to-practice transition. Experts identified the use of technology as a robust instructional scaffold and the emphasis on human support systems as critical success factors for sustainable professional development.

The finding that the PRIDE Model received the highest level of expert validation underscores a critical insight: the model's success is not derived from any single component in isolation. Instead, it results from a strategic synergy between Project-Based Learning (PjBL) principles and a digital ecosystem specifically engineered to support the teacher-researcher's journey.

This integration aligns with the conceptual framework of Admiraal et al. (2021), who posited that effective online learning environments must transcend mere content delivery. Rather, they must be intentionally designed to facilitate activities that foster both active learning and social interaction. By blending hands-on research practice with a robust technological infrastructure, the PRIDE Model transforms the research process from an abstract requirement into a manageable, collaborative, and digitally enhanced professional experience.

The authentic enhancement of teacher research competencies within this model can be attributed to four primary operational mechanisms, each substantiated by relevant literature.

The first mechanism involves mitigating cognitive load through digital scaffolding. Research competency is inherently a high-order, complex skill set; consequently, many educators perceive the research process as daunting and procedurally opaque (Susilowati et al., 2021). The digital platform within the PRIDE Model serves as a robust scaffold to minimize teachers' cognitive load. It achieves this by systematically provisioning essential tools and resources tailored to each stage of the research cycle.

For instance, the inclusion of standardized research proposal templates in Phase 1 provides teachers with clear structural guidance, while integrated online survey instruments in Phase 2 alleviate the technical complexities of data collection. These features align with the findings of Kim and Hannafin (2011), which suggest that scaffolding within technology-enhanced environments enables learners to navigate multifaceted tasks more effectively. Therefore, the platform transcends mere data repository status; it serves as a pedagogical assistant that renders the sophisticated research process both accessible and manageable.

The second mechanism focuses on fostering a Ubiquitous Community of Practice (UCoP) and seamless mentorship. Collective learning is a cornerstone of professional teacher development (Vangrieken et al., 2020). The PRIDE Model leverages the affordances of digital technology to establish a Professional Learning Community (PLC) and a mentoring system that transcends the traditional constraints of time and physical space. Through the platform's collaborative workspaces, teachers can solicit expert guidance, share progress, and engage in peer-led brainstorming at any time. This continuous interaction, which extends beyond formal meeting rooms, cultivates a sense of interconnectedness and social support—critical factors in preventing professional isolation, which is often associated with research. As Trust and Horrocks (2019) confirm, online learning communities significantly bolster the development of pedagogical innovation. Consequently, the platform transforms research from a solitary endeavor into a shared journey within a professional community.

In the final phase, the platform serves as a dedicated Showcase area, facilitating the dissemination of teacher-discovered insights into the institution’s collective intellectual assets. This function aligns with the principles of Knowledge Management, in which information technology plays a pivotal role in capturing, organizing, and disseminating organizational knowledge (Al-Ahbabi et al., 2019).

Finally, the model serves the critical purpose of fostering ownership and professional pride. By grounding the Project-Based Learning approach in authentic classroom problems and providing a digital infrastructure that empowers teachers to navigate the entire research lifecycle independently, the model instills a profound sense of psychological ownership. The digital platform effectively functions as an E-Portfolio, archiving the teacher’s comprehensive developmental journey. Consequently, when educators witness tangible, evidence-based results from their own efforts, it bolsters their self-efficacy and professional confidence, which is the ultimate objective of the PRIDE Model. This is consistent with the research of Sari and Trisnadewi (2023), which indicates that classroom research competency is positively correlated with teaching effectiveness and overall teacher professionalism.

In summary, the expert panel’s validation of the PRIDE Model at the highest quality level is a direct result of its sophisticated utilization of digital technology. Rather than treating technology as a mere off-the-shelf tool, the model functions as a comprehensive digital ecosystem that systematically provides instructional scaffolding, facilitates interpersonal connectivity, ensures process transparency, and fosters a sense of professional ownership. These integrated mechanisms work in harmony to dismantle traditional barriers while amplifying the critical success factors necessary for teacher development. Ultimately, the PRIDE Model provides a sustainable framework for transforming educators into "teacher-researchers" who are fully equipped to thrive in the digital age.

7. Suggestions

7.1 Implementation Recommendations

Successful implementation requires enhancing digital literacy for all users while aligning research outcomes with professional appraisal systems to sustain motivation. Furthermore, schools must appoint expert mentors and provide continuous training in coaching and feedback to ensure high-quality teacher support.

7.2 Suggestions for Future Research

Educators and stakeholders should employ experimental designs and in-depth qualitative analyses to evaluate the model's efficacy and the contextual factors influencing its success. Additionally, integrating Artificial Intelligence (AI) into the platform could further optimize research workflows and enhance personalized mentorship. In addition, policy-level recommendations were added to support educational administrators and policymakers in promoting sustainable teacher research and development through digital learning ecosystems and institutional support mechanisms. Furthermore, an institutional implementation strategy was included to provide guidelines for schools and educational service areas in adopting the PRIDE Model through mentoring systems, collaborative learning structures, and continuous professional development programs.

8. Acknowledgments

This research would not be possible without Assoc. Prof. Dr. Thanin Ratanaolarn, Assoc. Prof. Dr. Sirirat Petsangsri, who provides advice, clarity, and guidelines, and encourages the publication of this research at the international academic conference, and the executives and teachers, who greatly contribute to this research, to the end. Lastly, the researchers would like to thank our parents for their good upbringing, and our dear friend who always offers encouragement and warm support throughout the course.

9. References

Admiraal, W., van Vugt, F., Kranenburg, F., Koster, B., Smit, B., Weijers, S., & Lockhorst, D. (2021). A design-based research study of a blended learning environment for professional development of university teachers. *Computers & Education*, 169, 104223. https://doi.org/10.1016/j.compedu.2021.104223

Al-Ahbabi, S. A., Singh, S. K., Gaur, S. S., & Balasubramanian, S. (2019). A knowledge management framework for enhancing public sector performance. *Journal of Knowledge Management*, 23(6), 1115–1141. https://doi.org/10.1108/JKM-08-2017-0348

Al-Amri, S. S., & Al-Badi, A. H. (2022). Digital transformation in education: A systematic literature review of the challenges and opportunities. *Education and Information Technologies*, 27(5), 6745–6770. https://doi.org/10.1007/s10639-021-10853-1

Alkin, M. C., & Christie, C. A. (2004). *Evaluation roots: Tracing theorists' views and influences*. Sage Publications.

Baron, K. (2010). "Six Steps to Planning a Project". Retrieved April 14, 2021, from http://www.edutopia.org/stw-maine-project-based-learning-six-steps-planning.

Boyce, C., & Neale, P. (2006). *Conducting in-depth interviews: A guide for designing and conducting in-depth interviews for evaluation input*. Pathfinder International.

Chow, K. C. K., Chu, S. K. W., Tavares, N., & Lee, C. W. Y. (2015). Teachers as researchers: A discovery of their emerging role and impact through school-university collaborative research. Brock Education Journal, 24(2), 20–39.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage Publications.

Eris, N. (2021). "The Effectiveness of Project-Based Learning with the Blended Learning System to Improve 21st Century Skills during the COVID-19 pandemic". *SCIENTIA Journal*, 9(2): 3.

Fendy, P. (2019). "Project-based Learning through Edmodo: improving critical thinking and histology concepts". *Biosfer: Jurnal Pendidikan Biologi*, 12(1): 58–69.

Garrison, D. R., & Vaughan, N. D. (2008). *Blended learning in higher education: Framework, principles, and guidelines*. John Wiley & Sons.

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and contributing factors. *Studies in Higher Education*, 45(3), 443–459. https://doi.org/10.1080/03075079.2018.1521722

Horn, M. B., & Staker, H. (2014). *Blended: Using disruptive innovation to improve schools*. John Wiley & Sons.

Kemmawat Iedkhao, & Krissana Kiddee. (2020). A needs assessment to enhance the research competency of teachers in the 21st century. In *The 15th National and International Sripatum University Conference (SPUCON2020)*, 18th December 2020 (pp. 85–96). Bangkok: Sripatum University.

Kemmis, S., McTaggart, R., & Nixon, R. (2014). *The action research planner: Doing critical participatory action research*. Springer.

Kim, M. C., & Hannafin, M. J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers & Education*, 56(2), 403–417. https://doi.org/10.1016/j.compedu.2010.08.024

KM. CHIL. (2015). *Project-based Learning*. Retrieved April 14, 2021, from http://www.vcharkarn.com/vcafe/202304.

Krippendorff, K. (2018). *Content analysis: An introduction to its methodology* (4th ed.). Sage Publications.

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project-based learning: A proven approach to rigorous classroom instruction*. ASCD.

Littlejohn, W. N. (2019). "The Impact of Student-Centered Coaching on the Implementation of Project-Based Learning: An Action Research Study". Doctor of Education in Curriculum and Instruction—College of Education, University of South Carolina.

Mertler, C. A. (2019). *Action research: Improving schools and empowering educators* (6th ed.). SAGE Publications.

Mills, G. E. (2018). *Action research: A guide for the teacher researcher* (6th ed.). Pearson.

Mthethwa, R. M., & Ndeya-Ndereya, C. N. (2022). Teachers' perceptions of their research skills development needs: A case of a teachers' professional development program in South Africa. *International Journal of Learning, Teaching and Educational Research*, 21(5), 238–253. https://doi.org/10.26803/ijlter.21.5.14

Nanik, I. (2019). "Developing Project-Based Learning (PBL) as a Teaching Strategy in Physical Education for Preservice Physical Education Teachers". *Advances in Social Science, Education and Humanities Research*, 335(1): 491.

Postholm, M. B. (2018). Teachers' professional development in school: A review study. *Educational Research*, 60(4), 405–429. https://doi.org/10.1080/00131881.2018.1522730

Rasheed, R. A., Kamsin, A., & Abdullah, N. A. (2020). Challenges in the online component of blended learning: A systematic review. *Computers & Education*, 144, 103701. https://doi.org/10.1016/j.compedu.2019.103701

Riana, C., Widayanti, L., & Riandi, R. (2022). Improving teachers' research skills through a project-based learning model assisted by a learning management system. *Jurnal Pendidikan IPA Indonesia*, 11(1), 12–21 . https://doi.org/10.15294/jpii.v11i1.32629

Ririn, P. (2021). "Puppet as a Medium in Project-Based Learning (PBL) to Promote English Language Competencies of EFL Students in Indonesia". *International Joint Conference on Arts and Humanities (IJCAH) Social Science, Education and Humanities Research*, 618: 195–203.

Sari, I. P., & Trisnadewi, K. (2023). The correlation between teachers' professionalism and their ability to conduct classroom action research. *Journal of Education and Teaching*, 4(1), 78–86. https://doi.org/10.51454/jet.v4i1.225

Shelly, A. (2016). "Implementing a Project-Based Learning Model in A Pre-Service Leadership Program". *National Council of Professors of Educational Administration (NCPEA)*, 11(1): University of Central Arkansas.

Simpson, Z. & Ferentinou, M. F. (2020). "Lessons learned about Engineering Reasoning through Project-Based Learning: An Ongoing Action Research Investigation Geotechnical Engineering Education (GEE)". International Conference organized by TC306, pp. 3. Athens: Greece.

Susilowati, E., Agustina, R., & Khaerunnisa, I. (2021). An analysis of teachers' difficulties in conducting classroom action research. *Journal of Physics: Conference Series*, 1779(1), 012046. https://doi.org/10.1088/1742-6596/1779/1/012046

Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2021). Understanding the link between teachers' technological and pedagogical reasoning: A meta-analytic review. *Educational Research Review*, 34, 100412. https://doi.org/10.1016/j.edurev.2021.100412

Trust, T., Carpenter, J. P., & Krutka, D. G. (2021). Shifting from professional development to professional learning: A focus on teacher agency and professional learning networks. In *Professional learning in the digital age* (pp. 1-20). Routledge.

Trust, T., & Horrocks, B. (2019). "I never feel alone": The role of social media and online communities of practice in educator professional learning. *Journal of Digital Learning in Teacher Education*, 35(4), 259–275. https://doi.org/10.1080/21532974.2019.1642822

Turner, R. C., & Carlson, L. (2003). Indexes of item-objective congruence for multidimensional items. *International Journal of Testing*, 3(2), 163–171. https://doi.org/10.1207/S15327574IJT0302_5

Vangrieken, K., AP, E., & Raes, A. (2020). Teacher professional learning in professional learning communities: A research synthesis. *Educational Research Review*, 31, 100345. https://doi.org/10.1016/j.edurev.2020.100345

Wayan, S. (2019). "Project-Based Learning and Academic Procrastination of Students in Learning Physics". *International Journal of Instruction*, 13(1): 490–580.

Wurdinger, S. D., & Qureshi, M. (2015). Enhancing college students' life skills through project-based learning. *Innovative Higher Education*, 40(3), 279–286. https://doi.org/10.1007/s10755-014-9314-3

Yustina. (2020). "The Effects of Blended Learning and Project-Based Learning on Pre-service Biology Teachers' Creative Thinking through Online Learning in the COVID-19 Pandemic". *Jurnal Pendidikan IPA Indonesia*, 9(3): 408–420.

TRANSFORMING TEACHER-RESEARCHERS IN THAILAND: A NEEDS ASSESSMENT FOR DEVELOPING RESEARCH COMPETENCIES

Kemmawat Iedkhao*, Thanin Ratanaolarn, and Sirirat Petsangsri

63603009@kmitl.ac.th, thanin.ra@kmitl.ac.th, and sirirat.pe@kmitl.ac.th

Department of Industrial Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 63603009@kmitl.ac.th

ABSTRACT

While Thai educational policies aim to transform the teaching profession into one of teacher-researchers, achieving this goal is hindered by a significant competency gap in knowledge, skills, and attitudes—an urgent obstacle requiring immediate intervention. This study aimed to 1) assess needs and 2) prioritize them to enhance teacher research competencies. The sample consisted of 334 civil service teachers under the Pathum Thani Primary Educational Service Area Office 2, selected through stratified random sampling. The research instrument was a 5-point Likert-scale needs assessment questionnaire that evaluated both current and expected states. Data were analyzed using mean, standard deviation (S.D.), and the Modified Priority Needs Index *($PNI_{modified}$)*. The results revealed that while the overall current state of teacher research competency was at a moderate level (x bar = 3.23, S.D. = 0.72), the expected state was at the highest level ($\bar{x}$= 4.63, S.D. = 0.33). The overall *($PNI_{modified}$)* was 0.43. When prioritizing urgent needs across three dimensions, the study found: 1) Research Practice *($PNI_{modified}$* = 0.46), 2) Research Knowledge *($PNI_{modified}$* = 0.45), and 3) Research Attitude *($PNI_{modified}$* = 0.39), respectively. Specifically, the most critical need in the practice dimension was the ability to construct and develop research instruments *($PNI_{modified}$*= 0.54). In contrast, the primary need in the knowledge dimension was the ability to draw conclusions and write research reports to improve learning (PNI*modified* = 0.66). These findings provide a concrete foundation for developing teacher-research competencies that align precisely with actual professional requirements.

Keywords: Needs assessment, Teacher research competency, Research knowledge, Research attitude, Research practice

1. Statement of the Problem

The global dynamics of the 21st century, propelled by digital transformation and globalization, have catalyzed a worldwide shift in educational paradigms. This shift aims primarily to equip learners with essential future-ready competencies necessary to navigate a sophisticated society. (World Economic Forum, 2020). Within this landscape, the educator has transitioned from a traditional transmitter of knowledge to a facilitator and designer of learning experiences. To fulfill this mission, the "Teacher-Researcher" concept has emerged as a cornerstone of professional development. Classroom Action Research (CAR) serves as a potent instrument, enabling educators to systematically diagnose learning impediments and innovate pedagogical strategies through evidence-based practice. In Thailand, this mandate is explicitly enshrined in the National Education Act B.E. 2542 (1999), which requires educational institutions to empower teachers to conduct research tailored to enhance student learning.

This new role demands the ability to authentically address the diverse and individualized needs of each student (Panich, 2012).

To effectively fulfill this demanding mission, the "Teacher-Researcher" concept has emerged as a cornerstone of professional development and the elevation of educational quality (Cochran-Smith & Lytle, 2009). Classroom Action Research (CAR) serves as a potent instrument in this regard, enabling educators to systematically diagnose learning impediments and innovate their pedagogical strategies through evidence-based practice. Ultimately, this approach fosters continuous, sustainable improvement in instructional management (Darling-Hammond, Hyler, & Gardner, 2017).

In the Thai context, the mandate for research-driven learning development is explicitly enshrined in the National Education Act B.E. 2542 (1999) and its subsequent amendments. Specifically, Sections 24(5) and 30 require educational institutions to empower teachers to conduct research tailored to enhance student learning (Office of the National Education Commission, 2002). These statutory provisions reflect a strategic policy intent to integrate research into the professional culture of the teaching workforce.

Despite these policy frameworks, a substantial gap persists between theoretical intent and classroom reality. A significant number of teachers still lack the necessary competencies for systematic inquiry. Existing literature consistently highlights deficiencies across three primary domains: knowledge of research methodology, practical skills in conducting research, and attitudes toward research. Many educators continue to perceive research as a burdensome administrative task that exists outside their core instructional responsibilities (Wongwanich, 2015; Mills, 2018). Furthermore, the absence of robust support systems and formal mentorship to provide guidance and foster a conducive academic environment remains a critical barrier (Iedkhao & Kiddee, 2020). Consequently, these challenges reinforce negative perceptions, leading many to view research as an inaccessible and daunting endeavor.

Given these discrepancies, traditional professional development models may be insufficient for cultivating sustainable research competencies. Therefore, to effectively promote the teacher-researcher in the digital age, it is imperative to conduct a systematic Needs Assessment. This process involves exploring and analyzing the current state versus the expected standards of teacher research competencies. This study aims to evaluate these needs and provide foundational data to prioritize urgent areas for development. Ultimately, these findings will serve as a framework for designing targeted capacity-building models that precisely address contemporary educational challenges.

2. Objectives

2.1 To assess the need to enhance teachers' research competencies

2.2 To prioritize these identified needs to establish a framework for strategic teacher development.

3. Conceptual Framework and Hypothesis

This research aims to assess the priority needs for developing teachers' research competencies, ultimately informing the design of learning models that effectively respond to the digital era. To achieve this, the researcher synthesized relevant concepts, theories, and existing literature to establish a Conceptual Framework. This framework serves as a roadmap, illustrating the logical relationships among the variables under study; details are provided below.

3.1 The Theory of Competency

The researcher adopted McClelland's (1973) conceptual framework, specifically the Iceberg Model of Competency. This model explains individual differences by comparing them to an iceberg: the visible and more easily developed components—the tip of the iceberg above the

waterline—represent an individual's Knowledge and Skills. However, the larger, more significant portion remains hidden beneath the surface, encompassing underlying Traits and Self-concept.

According to this model, an individual's professional behavior is driven by these internal characteristics. While knowledge and technical expertise reside above the surface, other attributes—such as social roles, self-image, and job-specific functional competencies—provide the foundation that enables educators to exhibit appropriate professional behaviors and excel in their duties.

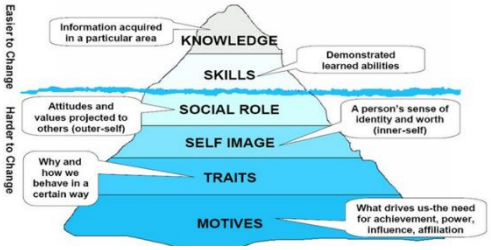

Figure 1 The Iceberg Model of Competence (McClelland, 1973).

3.1.1 Teacher Research Competency

Competency refers to a cluster of related knowledge, skills, and personal attributes (attitudes and values) that enable an individual to perform a task successfully according to established standards or beyond (Spencer & Spencer, 1993). In the context of this study, "Teacher Research Competency" is defined as the behavioral characteristics that reflect a teacher's ability to systematically and effectively apply research processes to improve instruction and resolve classroom issues.

Drawing from a synthesis of relevant literature (Mills, 2018; Office of the Teacher Civil Service and Educational Personnel Commission, 2018), the researcher has categorized research competency into three primary domains:

I. Research Knowledge (K)

This cognitive domain pertains to the understanding of research principles and methodologies. It includes:

Comprehension of the philosophy and typologies of educational research, specifically Classroom Action Research (CAR).

The ability to define research problems and conduct literature reviews.

Knowledge of research design, instrument development, and quality validation (validity and reliability).

Proficiency in selecting appropriate statistics for data analysis and adherence to research ethics.

II. Research Attitude (A)

This affective domain reflects the attitudes, values, and motivations conducive to conducting research. It encompasses:

A positive disposition toward research as a vital tool for professional development.

Open-mindedness, keen observational skills, and a commitment to seeking knowledge for problem-solving.

Professional responsibility, integrity in the research process, and a deep awareness of the importance of utilizing research findings to enhance student learning authentically.

III. Research Practice (P)

This psychomotor domain demonstrates the ability to execute the research process procedurally. It consists of:

Skills in analyzing and synthesizing data to formulate research topics.

Skills in designing pedagogical innovations to address specific challenges.

Proficiency in systematic data collection, analysis, and interpretation.

Competency in technical report writing and the presentation or dissemination of research findings.

3.1.2 Needs Assessment

To ensure that the development of research competencies is both targeted and effective, this study employs a Needs Assessment approach. This methodology facilitates the analysis of the "gap" between teachers' current research competencies (What is) and their desired or expected proficiency levels (What should be).

The data obtained will be used to prioritize these needs through the Priority Needs Index (PNI), a technique widely recognized in educational research (Wongwanich, 2015). Specifically, the Modified Priority Needs Index *($PNI_{modified}$)* formula will be applied:

Priority Needs Index (Revised) ($PNI_{modified}$)
($PNI_{modified}$) = (I-D)/D
With "I" (Importance) as the Expected Means
"D" (Degree of Success) as the Authentic Menas

In this formula, *"I"* represents the expected state (Importance/Should be) and *"D"* represents the current state (Degree of success/What is). This calculation provides a clear visualization of the gap relative to the existing baseline, thereby pinpointing which sub-competencies require the most immediate developmental intervention.

Research Hypothesis

Based on the theoretical frameworks and research objectives, the following hypothesis is proposed: Teachers under the Pathum Thani Primary Educational Service Area Office 2 exhibit a high level of need for development across all three domains of research competency (Knowledge, Attitude, and Practice), characterized by a significant gap between their current and expected performance levels.

The results of this assessment will subsequently inform the research methodology and the design of the capacity-building framework.

The following figure illustrates the relationship between the Iceberg Model (K-A-P domains) and the Gap Analysis (Current vs. Expected states), which serves as the roadmap for this study.

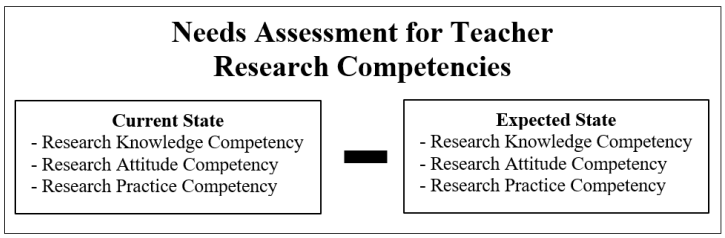

Figure 2 Conceptual Framework

The analysis framework of this study is structured to evaluate and prioritize teacher research competencies by examining the gap between current and expected states. The framework consists of three main components: input variables, the assessment process, and the prioritization output. The input involves 3 key research competency domains. The process utilizes the $PNI_{modified}$ formula to calculate the priority of needs. Finally, the output provides a prioritized roadmap that serves as a foundation for developing a Project-Based Blended Learning Model to Enhance Research competency for Teachers, ensuring a data-driven approach to teacher professional development.

4. Research Methodology

4.1 Research Design

This study employs a needs-assessment research design to systematically identify and prioritize the development of teacher research competencies. The operational process consists of the following key phases:

4.1.1 Assessment of Current and Expected States: An empirical investigation into the existing level of research competency among teachers (Current State) compared to the desired proficiency standards (Expected State).

4.1.2 Gap Analysis and Prioritization: The calculation and analysis of the Priority Needs Index (PNI) to rank the necessity of various competencies. This enables the strategic identification of critical areas for enhancing educators' professional research capabilities.

4.2 Population and Sample

The target population for this study comprises civil service teachers under the jurisdiction of Pathum Thani Primary Educational Service Area Office 2. This population includes educators from 67 schools, totaling 1,725 personnel.

Sample

The sample for this study consisted of civil service teachers under the Pathum Thani Primary Educational Service Area Office 2. To ensure statistical rigor, the sample size was determined using the standardized tables for estimating the population means developed by Kanjanawasee et al. (2004). Based on a 95% confidence level and a ±5% margin of error, a total of 334 participants were selected from the total population of 1,725.

The selection process employed a stratified random sampling technique. In this approach, the educational networks of the three designated districts served as the primary strata, with individual teachers acting as the sampling units. To ensure representative coverage, the sample was distributed across strata using proportional allocation. The distribution of the population and the corresponding sample sizes across the three districts are detailed in Table 1.

Table 1 Population and sample used in the research

District Group	No. of Teachers	No. of Sample in ratio
Lam Luk Ka District	600	116
Thanyaburi District	575	111
Nong Sua District	550	107
Total	1,725	334

(Report on Teachers and Educational Personnel in Pathum Thani Primary Educational Service Area Office 2, 2026)

4.3 Research Instruments

The primary research instrument used in this study was a Needs Assessment Questionnaire designed to evaluate teachers' research competencies. The instrument sought to elicit data regarding both the current state (actual performance) and the expected state (desired proficiency) of research competencies among civil service teachers under the Pathum Thani Primary Educational Service Area Office 2. The questionnaire was structured into two distinct sections:

Part 1: The status of the respondents. This section collected baseline data regarding the respondents' professional profiles and backgrounds.

Part 2: Research Competency Assessment. This section utilized a five-point Likert scale (Rating Scale) to assess the gap between the current and expected states across the designated competency domains.

Instrument Development and Validation

To ensure the academic rigor and quality of the instrument, the development process adhered to the following systematic phases:

Expert Review: The initial draft was reviewed by the research advisor for structural integrity. Subsequently, it was submitted to a panel of five experts for content validity evaluation. This was quantified using the Index of Item-Objective Congruence (IOC). The analysis yielded IOC values ranging from 0.60 to 1.00, indicating that all items were statistically congruent with the research objectives.

Pilot Study (Try-out): The validated questionnaire was pilot tested with a non-sample group to assess its reliability. Internal consistency was assessed using Cronbach's Alpha, yielding a high reliability coefficient of 0.94 for the entire instrument.

Finalization Following the pilot test, the questionnaire was finalized for data collection with the target sample.

4.4 Data Collection

The data collection process was carried out through a systematic, formal administrative procedure. Initially, an official request for cooperation was issued by the Faculty of Industrial Education and Technology at King Mongkut's Institute of Technology, Ladkrabang, and addressed to Pathum Thani Primary Educational Service Area Office 2.

Upon receiving authorization, the research instruments were distributed via email to the designated school networks in the sample group. A total of 334 digital questionnaires were administered through an online platform. To ensure a robust response rate and data integrity, a follow-up protocol was implemented until a 100% completion rate was achieved, resulting in 334 valid responses for subsequent analysis.

4.5 Data Analysis

4.5.1 The analysis of data regarding the enhancement of teacher research competencies was conducted using descriptive statistics. Specifically, mean ($\bar{x}$) and Standard Deviation (S.D.) were calculated to evaluate both the current and expected states of competency. To interpret the results, the mean scores were categorized according to the criteria established by Leekitchwatana (2016), as detailed in Table 2 below.

Table 2 Interpretation criteria for mean scores

Mean Range	Interpretation
4.50-5.00	Highest
3.50-4.49	High
2.50-3.49	Moderate
1.50-2.49	Low
1.00-1.49	Lowest

4.5.2 To prioritize the research competency development needs of teachers, the data obtained from the descriptive analysis were ranked using the Modified Priority Needs Index *($PNI_{modified}$)* (Wongwanich, 2015).

5. Results

The results of the needs assessment for enhancing teacher research competencies—focusing on analysis, synthesis, and research-led student development—are presented below. These competencies are categorized into three primary domains: Research Knowledge (K), Research Attitude (A), and Research Practice (P). Based on the data collected from the sample of 334 civil

service teachers under the Pathum Thani Primary Educational Service Area Office 2, the findings are structured as follows:

Table 3 Frequency and percentage of respondents'

Variable	Frequency (n=334)	Percentage (%)
Gender		
Male	194	58.08
Female	124	37.13
Non-binary/Other	16	4.79
Total	**334**	**100.00**
Academic Position		
Assistant Teacher	72	21.56
Teacher	134	40.12
Senior Professional Level Teacher	112	33.53
Expert Level Teacher	16	4.79
Total	**334**	**100.00**
Subject Area		
Thai Language	62	18.56
Mathematics	58	17.37
Foreign Languages	38	11.38
Arts	26	7.78
Occupations and Technology	24	7.19
Social Studies, Religion, and Culture	42	12.57
Science and Technology	54	16.17
Health and Physical Education	30	8.98
Total	**334**	**100.00**
District Network		
Lam Luk Ka District	116	34.73
Thanyaburi District	111	33.23
Nong Suea District	107	32.04
Total	**334**	**100.00**

Based on the data provided in Table 3, The respondents' background information of the 334 participating teachers from the Lam Luk Ka, Thanyaburi, and Nong Suea districts is summarized as follows: Regarding gender distribution, a majority of the respondents were female (n = 194, 58.08%), followed by male (n = 124, 37.13%), and LGBTQ+/alternative gender (n = 16, 4.79%). Among current academic positions, the largest group was Teachers (n = 134, 40.12%). This was followed by Senior Professional Level Teachers (n = 112, 33.53%), Assistant Teachers (n = 72, 21.56%), and Expert Level Teachers (n = 16, 4.79%). Analysis of the respondents' subject specializations revealed that the largest proportion of teachers belonged to the Thai Language department (n = 62, 18.56%), followed by Mathematics (n = 58, 17.37%). Furthermore, when classified by educational networks, the sample was distributed relatively equally across the three districts. Specifically, the Lam Luk Ka district accounted for the largest share (n = 116, 34.73%), followed by Thanyaburi (n = 111, 33.23%) and Nong Suea (n = 107, 32.04%).

Table 4 Means ($\bar{X}$) and Standard Deviation (S.D.) of the expected and the current for the enhancement of research competency in teachers

Components/Indicator of research competency	Expected			Current			PNI (I-D)/D	Priority
	$\bar{x}$	S.D.	Level	$\bar{x}$	S.D.	Level		
Knowledge: K	4.63	0.31	Highest	3.19	0.68	Moderate	0.45	2
Affective: A	4.62	0.37	Highest	3.32	0.82	Moderate	0.39	3
Practice : P	4.63	0.31	Highest	3.17	0.67	Moderate	0.46	1
Total	4.63	0.33	Highest	3.23	0.72	Moderate		

As illustrated in Table 4, the current state of teacher research competencies across all three domains was perceived as moderate ($\bar{x} = 3.23$, S.D. = 0.72). Among these, the domain with the highest score for actual performance was Research Attitude ($\bar{x}$ = 3.32, S.D. = 0.82), followed by Research Knowledge ($\bar{x}$ = 3.19, S.D. = 0.68). Conversely, the Research Practice domain received the lowest rating for its current state ($\bar{x} = 3.17$, S.D. = 0.67). Regarding the expected state, the overall research competency was rated at the highest level ($\bar{x}$ = 4.63, S.D. = 0.33), with all domains exhibiting similarly high expectations, ranging from 4.62 to 4.63. Furthermore, the analysis of the Modified Priority Needs Index ($PNI_{modified}$) revealed an overall index of 0.43. When prioritizing the domains for urgent developmental intervention, Research Practice emerged as the most critical need ($PNI_{modified}$ = 0.46). This was followed by Research Knowledge ($PNI_{modified}$= 0.45) and Research Attitude ($PNI_{modified}$= 0.39), respectively.

Table 5 Means ($\bar{X}$) and Standard Deviation (S.D.) of the expected and the current for the enhancement of research competency in teachers (**Knowledge: K)**

Components/Indicator of research competency	Expected			Current			PNI (I-D)/D	Priority
	$\bar{x}$	S.D.	Level	$\bar{x}$	S.D.	Level		
1. Classroom problem diagnosis	4.70	0.35	Highest	3.55	0.68	High	0.32	5
2. Action research design	4.65	0.35	Highest	3.10	0.82	Moderate	0.50	2
3. Research instrument development	4.60	0.38	Highest	3.30	0.75	Moderate	0.39	4
4. Literature synthesis	4.55	0.42	Highest	3.20	0.78	Moderate	0.42	3
5. Research report writing	4.65	0.42	Highest	2.80	0.95	Moderate	0.66	1
Total	4.63	0.31	Highest	3.19	0.68	Moderate	0.45	2

As illustrated in Table 5, the current state of teachers' Research Knowledge was rated as moderate overall ($\bar{x}$ = 3.19, S.D. = 0.68). Detailed analysis of individual indicators revealed that the highest mean score for actual performance was for classroom problem diagnosis (x bar = 3.55, S.D. = 0.68), followed by the development and selection of research instruments (x bar = 3.30, S.D. = 0.75). Conversely, the indicator with the lowest current state was research report writing for learning development ($\bar{x}$ = 2.80, S.D. = 0.95). Regarding the expected state, the overall requirement for Research Knowledge was perceived to be at the highest level ($\bar{x}$ = 4.63, S.D. = 0.31). The indicator with the highest expectation was classroom problem diagnosis ($\bar{x}$ =4.70, S.D. = 0.35). Furthermore, two indicators shared the second-highest mean score ($\bar{x}$ =4.65, S.D.

= 0.35): action research design and research report writing. The lowest mean score within the expected state, which remained at a high level, was for literature synthesis (x bar sis ($\bar{x}$ = 4.55, SD = 0.42). Analysis of the Modified Priority Needs Index *($PNI_{modified}$)* for this domain yielded an overall value of 0.45. When prioritizing developmental needs from highest to lowest, research report writing emerged as the most critical priority *($PNI_{modified}$* = 0.66). This was followed by action research design *($PNI_{modified}$*= 0.50), literature synthesis *($PNI_{modified}$*= 0.42), research instrument development *($PNI_{modified}$*= 0.39), and classroom problem diagnosis *($PNI_{modified}$*= 0.32), respectively.

Table 6 Means ($\bar{X}$) and Standard Deviation (S.D.) of the expected and the current for the enhancement of research competency in teachers **(Affective: A)**

Components/Indicator of research competency	Expected			Current			PNI (I-D)/D	Priority
	$\bar{x}$	S.D.	Level	$\bar{x}$	S.D.	Level		
1. Research value awareness	4.60	0.38	Highest	3.55	0.81	High	0.30	5
2. Proactive research commitment	4.55	0.35	Highest	3.25	0.84	Moderate	0.40	2
3. Openness to feedback	4.65	0.35	Highest	3.40	0.81	Moderate	0.37	4
4. Academic integrity	4.60	0.4	Highest	3.30	0.75	Moderate	0.39	3
5. Data collection resilience	4.70	0.38	Highest	3.10	0.90	Moderate	0.52	1
Total	**4.62**	**0.37**	Highest	**3.32**	**0.82**	Moderate	0.39	3

As illustrated in Table 6, the overall current state of teachers' Research Attitude was rated at a moderate level ($\bar{x}$ = 3.32, S.D. = 0.82). Upon closer examination of individual indicators, the highest mean score for actual performance was observed in the recognition of research value and its professional significance ($\bar{x}$ = 3.55, S.D. = 0.81), followed by openness to feedback ($\bar{x}$ = 3.40, S.D. = 0.81). Conversely, the indicator with the lowest rating in the current state was data collection resilience ($\bar{x}$. = 3.10, S.D. = 0.90). Regarding the expected state, the overall requirement for Research Attitude was perceived to be at the highest level ($\bar{x}$ = 4.62, S.D. = 0.37). Interestingly, the indicator with the highest expectation was data collection resilience ($\bar{x}$ = 4.70, S.D. = 0.38), followed by openness to feedback ($\bar{x}$ = 4.65, S.D. = 0.35). The lowest mean score within the expected state, although still very high, was for proactive research commitment ($\bar{x}$= 4.55, S.D. = 0.35).

Table 7 Means ($\bar{X}$) and Standard Deviation (S.D.) of the expected and the current for the enhancement of research competency in teachers **(Practice : P)**

Components/Indicator of research competency	Expected			Current			PNI (I-D)/D	Priority
	$\bar{x}$	S.D.	Level	$\bar{x}$	S.D.	Level		
1. Research problem analysis	4.65	0.35	Highest	3.45	0.83	Moderate	0.35	5
2. Information retrieval competency	4.70	0.35	Highest	3.10	0.81	Moderate	0.52	2
3. Instrument design and development	4.55	0.42	Highest	2.95	0.82	Moderate	0.54	1
4. Statistical data analysis	4.60	0.38	Highest	3.20	0.79	Moderate	0.44	4
5. Scholarly reporting and dissemination	4.65	0.42	Highest	3.15	0.85	Moderate	0.48	3
Total	4.63	0.31	Highest	3.17	0.67	Moderate	0.46	1

As illustrated in Table 7, the overall current state of teachers' Research Practice and Skills was rated as moderate ($\bar{x}$ = 3.17, S.D. = 0.67). A detailed analysis of individual indicators revealed that research problem analysis received the highest mean score for actual performance ($\bar{x}$ = 3.45, S.D. = 0.83). Conversely, the indicator with the lowest rating in the current state was instrument design and development ($\bar{x}$ = 2.95, S.D. = 0.82). Regarding the expected state, the overall requirement for research practice was perceived to be at the highest level ($\bar{x}$ = 4.63, S.D. = 0.31). When examining specific competencies, information retrieval competency exhibited the highest expected mean ($\bar{x}$ = 4.70, S.D. = 0.35). In contrast, instrument design and development were rated with the lowest expectations in this domain ($\bar{x}$ = 4.55, S.D. = 0.42), although it remained high. Furthermore, the overall Modified Priority Needs Index *($PNI_{modified}$)* for this domain was calculated at 0.46, indicating a significant gap that necessitates targeted developmental intervention.

6. Conclusion and Discussion

The findings vividly illustrate the contemporary challenges faced by Thai educators. Despite over two decades of national policy—initiated by the National Education Act B.E. 2542 (1999)—aimed at transforming teachers into classroom researchers, significant barriers persist, preventing them from reaching their full potential (Office of the National Education Commission, 2002). The wide gap between the current and expected states aligns with extensive literature indicating that heavy teaching loads, time constraints, and a lack of continuous support often render research a professional burden rather than a developmental tool (Wongwanich, 2015; Admiraal et al., 2021).

The fact that Research Practice emerged as the most critical need *($PNI_{modified}$*= 0.46), specifically regarding instrument development *($PNI_{modified}$*= 0.54), confirms that traditional lecture-based professional development is no longer sufficient. Teachers require experiential learning opportunities through Project-Based Learning (PBL) and "Learning by Doing" to construct knowledge from direct classroom problem-solving (Larmer, Mergendoller, & Boss, 2015). Without the ability to develop high-quality instruments, the credibility of gathered data is compromised, undermining the integrity of the entire research process. Furthermore, the high priority assigned to Research Knowledge *($PNI_{modified}$*= 0.45), particularly in report writing and synthesis *($PNI_{modified}$* = 0.66), is a critical concern. As the final stage of the research cycle, reporting is the gateway to dissemination and practical application. A deficiency in analytical synthesis prevents classroom-based insights from being shared or scaled, resulting in "shelf-bound" research

that fails to drive systemic change (Rust, 2017). This highlights an urgent need for Professional Learning Communities (PLCs) and mentorship programs to provide scaffolding during these complex analytical stages.

These results are best explained through the Competency Model proposed by McClelland (1973) and Spencer & Spencer (1993), which distinguishes between "visible" competencies (Knowledge and Skills) and "hidden" attributes (Attitudes and Values). The findings indicate that teachers require immediate development in the visible, more rapidly improving areas of Knowledge and Practice. Interestingly, while Research Attitude had the lowest $(PNI_{modified})$(0.39), this does not imply insignificance; rather, it suggests that teachers already possess a positive disposition toward research—as evidenced by high expected scores—but lack the technical capacity to translate that attitude into successful action.

Therefore, an effective developmental framework must integrate all three components: filling knowledge and skill gaps while sustaining positive attitudes. This holistic approach is essential for achieving a sustainable transition, enabling teachers to integrate research into their daily instruction authentically and ultimately transforming them into innovative "teacher-researchers" for the digital age.

7. Suggestions

7.1 Research should be developed for courses and activities that promote skills in Research Competency.

7.2 Curricula that can help with the development of teachers' ability in content development need to be created. Ideas are also needed to help organize teaching activities using multimedia.

7.3 The School Director or related personnel managing the curriculum in institutions can utilize the data in this research as an instrument or a guideline in developing the institution and its instructors.

7.4 Schools should implement hands-on workshops focusing on practical research tool construction and statistical software usage. These modules should prioritize active practice over theoretical lectures to directly enhance teachers' capabilities in classroom action research.

7.5 Education authorities should integrate research performance into career advancement criteria and provide dedicated research grants. Such policies will effectively transition the Expected State of Competency into sustainable classroom practices across the district.

8. Research Limitations

This study has two primary limitations. First, the scope is restricted to primary school teachers within a specific educational service area, which may limit the generalizability of the findings to different geographical or educational contexts. Second, data collection relied on self-assessment, which may have been influenced by social desirability bias. However, these findings provide a crucial empirical foundation for the next phase of the research, the development of a Project-Based Blended Learning Model to Enhance Research Competency for Teachers. This model is specifically designed to bridge the identified competency gaps through hands-on, practical inquiry, ensuring that the research moves beyond theoretical analysis toward a concrete professional development solution.

9. Acknowledgments

This research would not be possible without Assoc. Prof. Dr. Thanin Ratanaolarn, Assoc. Prof. Dr. Sirirat Petsangsri, who provides advice, clarity, and guidelines, and encourages the publication of this research at the international academic conference, and the executives and teachers, who greatly contribute to this research. Lastly, the researchers would like to thank our parents for their good upbringing, and our dear friend who always offers encouragement and warm support throughout the course.

10. References

Admiraal, W., van Vugt, F., Kranenburg, F., Koster, B., Smit, B., Weijers, S., & Lockhorst, D. (2021). A systematic literature review of teacher research in initial teacher education. Educational Research Review, 33, 100394. https://doi.org/10.1016/j.edurev.2021.100394

Cochran-Smith, M., & Lytle, S. L. (2009). Inquiry as a stance: Practitioner research for the next generation. Teachers College Press.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). Effective teacher professional development. Learning Policy Institute.

Iedkhao, K., & Kiddee, K. (2020). A needs assessment to enhance the research competency of teachers in the 21st century. In The 15th National and International Sripatum University Conference (SPUCON2020) (pp. 1–10). Sripatum University.

Kanchanawasi, S., et al. (2004). Utilizing the appropriate statistics for research. Chulalongkorn University Printing House.

Larmer, J., Mergendoller, J., & Boss, S. (2015). Setting the standard for project-based learning: A proven approach to rigorous classroom instruction. ASCD.

Leekitchwatana, P. (2016). Research methods in education (11th ed.). Meandee Graphic.

McClelland, D. C. (1973). Testing for competence rather than for "intelligence". American Psychologist, 28(1), 1–14. https://doi.org/10.1037/h0034092

Mills, G. E. (2018). Action research: A guide for the teacher researcher (6th ed.). Pearson.

Na Songkhla, J. (2017). Instructional design for distance learning in the digital age. Chulalongkorn University Press.

Office of the National Education Commission. (2002). National Education Act B.E. 2542 (1999) and its Amendments (No. 2) B.E. 2545 (2002). Prikwan Graphic.

Panich, V. (2012). Ways of building learning for students in the 21st century. Sodsri-Saritwongso Foundation.

Pathum Thani Primary Educational Service Area Office 2. (2026). Report on Teachers' Educational Personnel in Pathum.

Thani Primary Educational Service Area Office 2. Pathum Thani.

Rust, F. (2017). Teacher research: A decade of developments. Teachers College Record, 119(14), 1–22. https://www.tcrecord.org/Content.asp?ContentId=21773

Spencer, L. M., & Spencer, S. M. (1993). Competence at work: Models for superior performance. John Wiley & Sons.

Wongwanich, S. (2015). Needs assessment research. Chulalongkorn University Press.

World Economic Forum. (2020). The future of jobs report 2020. https://www.weforum.org/reports/the-future-of-jobs-report-2020

INVESTIGATING THE EFFECT OF AI INFLUENCER-GENERATED CONTENT ON CONSUMERS' PSYCHOLOGICAL WELL-BEING: A PLS-SEM ANALYSIS

Sher Singh Yadav*

drshersinghy@gmail.com

Department of Business Administration and Commerce, School of Liberal Studies,
Pandit Deendayal Energy University, Gujarat, India, 382426

*Corresponding Author E-mail: drshersinghy@gmail.com

ABSTRACT

Previous research on artificial intelligence (AI) influencers has primarily explored their commercial impact on consumer purchase behavior and engagement, overlooking critical effects on followers' information overload (IO) and psychological well-being (PWB), a gap this study aims to address. The present investigation examines how AI influencer characteristics—specifically emotional engagement, perceived enjoyment, fear of missing out, physical attractiveness, perceived anthropomorphism, parasocial attachment, and parasocial relationship—affect followers' IO and, subsequently, their PWB. Trust in AI influencers is also examined as a direct predictor of PWB. The study employs partial least squares structural equation modelling (PLS-SEM) as its analytical method, with SmartPLS 4 software on a sample of 102 respondents. A mix of purposive and snowball sampling was used to collect data from Instagram users. Findings reveal that IO significantly and positively influences PWB, while perceived anthropomorphism exhibits a significant negative effect on PWB. Other predictors did not attain significance in the direct structural model. The measurement model demonstrates satisfactory reliability and convergent validity across all constructs. These findings contribute to the emerging literature on AI influencer marketing and digital well-being, offering implications for social media platforms, marketers, and policymakers.

Keywords: Social media influencers, Artificial intelligence, Psychological well-being

1. Statement of the Problem

Influencer marketing is transforming rapidly with artificial intelligence (AI) applications creating AI influencers. Around 48.7% of marketing personnel are incorporating AI influencers into their campaigns. According to Statista data from 3,000 relevant professionals (February 2024), about 63% of marketing professionals worldwide plan to use AI and machine learning (ML) for influencer marketing in the coming years. Therefore, AI influencers will remain a fixture in marketing and user-generated content development. Well-being is part of The United Nations' (UN's) third sustainable development goal of ensuring good health. Information overload (IO) has been found to influence emotional exhaustion significantly (Sheng et al., 2023) in social media use and to influence user exhaustion and privacy invasion (Pang & Ruan, 2023). The confluence of well-being, AI-led social media influencers (SMIs), and IO is missing and understudied in fragments in existing studies. With the surge in AI-generated content and the rise of AI influencers, the impact of such content on IO and psychological well-being (PWB) needs to be investigated prominently. This study takes the initiative to research this comparatively new

domain and to stimulate academic and professional discussion on this crucial, growing phenomenon.

Influencers are popular entities on social media, whether virtual or human. They are endorsers of the new age who share posts, reels, blogs, and opinions, shaping the attitudes of their audiences. Their value is generally measured by followers, reach, impressions, likes, and comments. Scholars and marketers categorise influencers as micro, meso, or macro based on follower counts (Boerman, 2020). Micro-influencers are often considered 'everyday people' promoting products with hundreds or thousands of followers. Full-time professional meso-influencers typically have between 10,000 and one million followers (Pozharliev et al., 2022). World-renowned celebrities are macro-influencers with over one million followers (Li & Xie, 2020).

Research on influencers has focused on factors such as attractiveness, expertise, brand endorsement, and celebrity status, but there is limited research on the PWB effects of AI influencers (Janssen et al., 2022; Lou & Yuan, 2019; Masuda et al., 2022). Although AI influencers receive high engagement (Arsenyan & Mirowska, 2021), these interactions do not effectively translate into measurable well-being outcomes. This research extends the study of IO and well-being through a convergent theoretical lens and examines non-human influencers' psychological influences on followers. The study is guided by two research questions. First, how do characteristics of AI influencer content—namely emotional engagement (EE), perceived enjoyment (ENJOY), fear of missing out (FOMO), physical attractiveness (PA), perceived anthropomorphism (PAM), parasocial attachment (PSA), and parasocial relationship (PSR)—influence followers' IO and, subsequently, their PWB? Second, does trust in AI influencers directly influence followers' PWB?

2. Background Literature

2.1 Theoretical Background

Because research on social media usage, AI influencers, and well-being is still in its early stages, there is no universally accepted theoretical framework. We therefore review the major theories applied in the relevant literature: the uncanny valley theory (Mori et al., 2012), consistency theory (Bunker & Kwan, 2024), source credibility theory, parasocial relationship theory (Horton & Wohl, 1956), self-determination theory (Ryan & Deci, 2000), and cognitive load theory (Sweller, 1988). These theories were selected because they are most closely aligned with the research objectives and constructs of the study.

The uncanny valley theory explains why people react differently to digital characters that closely resemble humans (Mori et al., 2012). As AI influencers reach near-human-likeness in images and videos, the theory provides the broader conceptual framework for understanding perceived anthropomorphism and its consequences. As per the consistency theory, people find digital agents with consistent verbal and nonverbal personality cues more likeable, convincing, helpful, and enjoyable (Bunker & Kwan, 2024). It further suggests that individuals may report positive psychological outcomes when they perceive similarity between their offline and social media selves—a reasoning that grounds the perceived enjoyment and well-being relationship in this study. The source credibility theory underpins the inclusion of trust as a predictor of well-being: people are persuaded by, and feel more positively towards, sources they regard as reliable and trustworthy.

Parasocial relationship (PSR) theory, developed by Horton and Wohl (1956), explains one-way emotional bonds between media audiences and media figures that give the impression of genuine closeness. These mediated relationships are relevant to the way followers interact with

AI influencers on platforms such as Instagram. Self-determination theory (Ryan & Deci, 2000) highlights three basic psychological needs—autonomy, competence, and relatedness—that drive human motivation, growth, and well-being. When these needs are unmet through real-world interaction, individuals may turn to social media and AI influencer content to compensate, with consequences for IO and PWB. Finally, cognitive load theory (Sweller, 1988) defines the finite information-processing capacity of human working memory. When the volume of AI influencer content exceeds this capacity, users experience IO, which in turn affects their well-being.

2.2 Psychological Well-being

In positive psychology, well-being refers to the state in which happiness, contentment, and emotional balance are attained. It is studied extensively across psychology, economics, marketing, and communication (Diener et al., 2010; Iyer & Muncy, 2016; Ryan & Deci, 2000). According to Ganju et al. (2016), the use of digital technologies has become ubiquitous in society over the past two decades, and there is an unavoidable correlation between these technologies and well-being. Results from earlier research on this connection are, however, contradictory. Some studies indicate that utilising digital technologies can increase productivity, life satisfaction, enjoyment, and convenience (de Kerviler et al., 2016). Other studies link digital technology use to a rise in addiction, narcissism, interpersonal difficulties, depression, and anxiety (Chen et al., 2016). In the context of social media and influencer interaction, the psychological consequences for followers remain understudied, particularly in the newer domain of AI influencers.

2.3 Information Overload

Perceived IO is a psychological experience of feeling burdened by large amounts of information (Misra & Stokols, 2012). It is the feeling of having too much information arriving at once to process it all. When users experience cognitive overload after scrolling through social media, they feel frustrated, and their decision-making becomes impaired. In the domain of health sciences, researchers found that the perception of IO can lead to mental health problems including depression, anxiety, and anger, which in turn can alter an individual's intention to seek information online (Swar et al., 2017). Social use of smartphones has been found to positively influence perceived IO (Li & Chan, 2022), and IO has been identified as a stressor that significantly influences emotional exhaustion (Sheng et al., 2023). Furthermore, IO has been found to negatively impact the PWB of Gen Z social media users (Liu et al., 2021) and of healthcare professionals (Li & Khan, 2022). These findings motivate the present investigation of IO as a central mechanism between AI influencer engagement and follower PWB.

The present study integrates multiple complementary theories to explain how AI influencer-generated content affects followers' information overload (IO) and psychological well-being (PWB). Parasocial relationship theory explains the emotional bonds and one-sided relationships followers develop with AI influencers, while self-determination theory suggests that users engage with such content to satisfy psychological needs for relatedness, enjoyment, and social connection. Cognitive load theory provides the central mechanism linking excessive AI influencer content consumption with IO, arguing that users experience cognitive strain when information exceeds their processing capacity. Source credibility theory further explains how trust in AI influencers shapes users' psychological responses and perceptions of well-being. At the same time, uncanny valley theory explains why highly human-like AI influencers may generate discomfort and negatively influence PWB through perceived anthropomorphism. Together, these theories form an integrated framework demonstrating that emotional, cognitive, relational, and perceptual processes jointly shape followers' experiences with AI influencer content and their subsequent psychological well-being outcomes.

3. Objectives

3. 1 To examine the influence of AI influencer characteristics (emotional engagement, perceived enjoyment, FOMO, physical attractiveness, perceived anthropomorphism, parasocial attachment, and parasocial relationship) on followers' psychological well-being.

3. 2 To investigate the effect of information overload generated through AI influencer interactions on followers' psychological well-being.

3.3 To assess the role of trust in AI influencers in shaping followers' psychological well-being using PLS-SEM analysis.

4. Conceptual Framework and Hypothesis

Because research on social media usage, AI influencers, and well-being is still in its early stages, there is no universally accepted theoretical framework. We therefore review the major theories applied in the relevant literature: the uncanny valley theory (Mori et al., 2012), consistency theory (Bunker & Kwan, 2024), source credibility theory, parasocial relationship theory (Horton & Wohl, 1956), self-determination theory (Ryan & Deci, 2000), and cognitive load theory (Sweller, 1988). These theories were selected because they are most closely aligned with the research objectives and constructs of the study.

The uncanny valley theory explains why people react differently to digital characters that closely resemble humans (Mori et al., 2012). As AI influencers reach near-human-likeness in images and videos, the theory provides the broader conceptual framework for understanding perceived anthropomorphism and its consequences. As per the consistency theory, people find digital agents with consistent verbal and nonverbal personality cues more likeable, convincing, helpful, and enjoyable (Bunker & Kwan, 2024). It further suggests that individuals may report positive psychological outcomes when they perceive similarity between their offline and social media selves—a reasoning that grounds the perceived enjoyment and well-being relationship in this study. The source credibility theory underpins the inclusion of trust as a predictor of well-being: people are persuaded by, and feel more positively towards, sources they regard as reliable and trustworthy.

Parasocial relationship (PSR) theory, developed by Horton and Wohl (1956), explains one-way emotional bonds between media audiences and media figures that give the impression of genuine closeness. These mediated relationships are relevant to the way followers interact with AI influencers on platforms such as Instagram. Self-determination theory (Ryan & Deci, 2000) highlights three basic psychological needs—autonomy, competence, and relatedness—that drive human motivation, growth, and well-being. When these needs are unmet through real-world interaction, individuals may turn to social media and AI influencer content to compensate, with consequences for IO and PWB. Finally, cognitive load theory (Sweller, 1988) defines the finite information-processing capacity of human working memory. When the volume of AI influencer content exceeds this capacity, users experience IO, which in turn affects their well-being.

Psychological Well-being

In positive psychology, well-being refers to the state in which happiness, contentment, and emotional balance are attained. It is studied extensively across psychology, economics, marketing, and communication (Diener et al., 2010; Iyer & Muncy, 2016; Ryan & Deci, 2000). According to Ganju et al. (2016), the use of digital technologies has become ubiquitous in society over the past two decades, and there is an unavoidable correlation between these technologies and well-being. Results from earlier research on this connection are, however, contradictory. Some studies indicate that utilising digital technologies can increase productivity, life satisfaction, enjoyment, and

convenience (de Kerviler et al., 2016). Other studies link digital technology use to a rise in addiction, narcissism, interpersonal difficulties, depression, and anxiety (Chen et al., 2016). In the context of social media and influencer interaction, the psychological consequences for followers remain understudied, particularly in the newer domain of AI influencers.

Information Overload

Perceived IO is a psychological experience of feeling burdened by large amounts of information (Misra & Stokols, 2012). It is the feeling of having too much information arriving at once to process it all. When users experience cognitive overload after scrolling through social media, they feel frustrated, and their decision-making becomes impaired. In the domain of health sciences, researchers found that the perception of IO can lead to mental health problems including depression, anxiety, and anger, which in turn can alter an individual's intention to seek information online (Swar et al., 2017). Social use of smartphones has been found to positively influence perceived IO (Li & Chan, 2022), and IO has been identified as a stressor that significantly influences emotional exhaustion (Sheng et al., 2023). Furthermore, IO has been found to negatively impact the PWB of Gen Z social media users (Liu et al., 2021) and of healthcare professionals (Li & Khan, 2022). These findings motivate the present investigation of IO as a central mechanism between AI influencer engagement and follower PWB.

Research Framework and Hypotheses

The conceptual model positions seven AI influencer–related constructs—EE, ENJOY, FOMO, PA, PAM, PSA, and PSR—as antecedents of IO, with IO and trust in AI influencers (TRUST) as direct predictors of PWB. Mediation hypotheses further test whether IO transmits the effects of the antecedent constructs to PWB. The hypotheses and their theoretical justifications are developed below.

Emotional Engagement and Information Overload

Emotional engagement (EE) refers to followers' emotional investment and responsiveness to AI influencer content. EE of followers towards AI influencers involves frequent interactions—such as liking, commenting, and sharing—that can foster dependence on influencer content for cognitive decision-making (Cheung et al., 2022). Followers who are emotionally engaged tend to seek out more content, follow more accounts, and process greater volumes of information. One of the main goals of influencers in endorsement is to encourage EE and PSR in their audiences (Stein et al., 2024). Results by Zhou et al. (2024) showed that compared to followers of virtual influencers, those following real influencers exhibited stronger PSR and higher levels of EE. As followers of AI influencers become more emotionally invested, they are likely to consume increasing volumes of content, thereby contributing to IO. Moreover, news engagement has been found to increase IO among audiences (Aldoory & Van Dyke, 2006), and IO has been found to influence the PWB of users through stress and cognitive burden (Li & Khan, 2022). We therefore propose:

H1. Emotional engagement of followers towards AI influencers has a positive effect on information overload.

H1a. Information overload mediates the effect of emotional engagement on followers' psychological well-being.

Perceived Enjoyment

Perceived enjoyment (ENJOY) is a pleasant, intrinsic affective reaction to consuming entertainment media content (Hutter et al., 2013). On Instagram, ENJOY is one of the primary reasons why users follow and engage with AI influencers, beyond social connectivity or information-seeking. As users increasingly enjoy following AI influencer content, they tend to

spend more time on the platform, follow more accounts, and consume more posts, potentially overwhelming their cognitive processing capacity. With users having access to ever-greater amounts of AI-generated content, the significant relationship between media enjoyment and IO has received increasing attention (Kim, 2022). Media studies have found that enjoyment has a positive effect on IO, as pleasurable content motivates continued consumption beyond what individuals can efficiently process (York, 2013). Extending this finding to the AI influencer context, we therefore posit:

H2. Perceived enjoyment of AI influencer content by followers increases their information overload.

H2a. Information overload mediates the effect of perceived enjoyment on followers' psychological well-being.

Fear of Missing Out

Fear of missing out (FOMO) is a pervasive apprehension that others are having rewarding experiences that one is not participating in (Przybylski et al., 2013). FOMO typically arises when basic psychological needs—such as relatedness and belonging—are not met (Ryan & Deci, 2000), and is particularly prevalent among users with low social capital or self-esteem. FOMO is strongly tied to social media usage patterns: research shows that high levels of social media use can lead to high levels of FOMO (Buglass et al., 2017), and vice versa, creating a self-reinforcing cycle. A study by Bui et al. (2022) found that when social media users attempt to manage high FOMO by constantly checking for updates, they experience IO. Users experiencing FOMO towards AI influencer content—worrying about missing new posts, stories, or collaborations—are likely to consume content compulsively, leading to IO. IO, in turn, has been linked to impaired PWB (Liu et al., 2021). We therefore propose:

H3. Fear of missing out on AI influencer content has a positive impact on followers' information overload.

H3a. Information overload mediates the effect of fear of missing out on followers' psychological well-being.

Physical Attractiveness

Physical attractiveness (PA) is a key peripheral cue in influencer marketing, referring to the extent to which a follower perceives the influencer as visually appealing (Kim & Kim, 2021). PA has been consistently linked to positive influencer evaluation and purchase intention (Wong & Wei, 2023). In the field of influencer-based marketing, studies have shown that the physical appearance of influencers can make followers feel more connected and related to them (Ki et al., 2020). The distinctive visual aesthetics of AI influencers—who are digitally crafted for perfect proportions and visual appeal—may attract large followings and drive excessive visual consumption of their content. Visually captivating content stimulates continued browsing and following of multiple AI influencer accounts, producing a volume of content that exceeds what followers can adequately process. This cognitive strain manifests as IO. Furthermore, IO in this context is likely to affect PWB, as it becomes difficult for users to extract meaningful well-being benefits from an overwhelming stream of aesthetically compelling but cognitively taxing content. We therefore posit:

H4. The physical attractiveness of AI influencers has a positive impact on followers' information overload.

H4a. Information overload mediates the effect of physical attractiveness on followers' psychological well-being.

Perceived Anthropomorphism

Perceived anthropomorphism (PAM) refers to the attribution of human characteristics, motivations, intentions, and emotions to non-human agents (Epley et al., 2007). AI influencers are designed to appear increasingly human-like, and followers often attribute human-like feelings and personalities to them (Kim & Park, 2024). When followers perceive AI influencers as more human-like, they may be more likely to form deeper emotional connections with them and invest greater cognitive resources in processing their content, contributing to IO. Self-consistency research further suggests that in individualistic cultures, the more similar a person perceives their various selves to be, the better their PWB (Bunker & Kwan, 2024). At the same time, the uncanny valley theory (Mori et al., 2012) predicts that as AI characters approach—but do not fully reach—human-likeness, the resulting perception of slight imperfection may produce discomfort and reduce PWB, even as PAM increases IO. This dual pathway motivates the inclusion of PAM as both an antecedent of IO and a direct influence on PWB. The linkage between PAM, IO, and PWB has not previously been established in the AI influencer literature. Therefore:

H5. Perceived anthropomorphism of AI influencers has a positive effect on followers' information overload.

H5a. Information overload mediates the effect of perceived anthropomorphism on followers' psychological well-being.

Parasocial Attachment and Parasocial Relationship

Parasocial attachment (PSA) is an emotional bond that followers form with media figures in the absence of real reciprocal interaction (Bowlby, 1969; Tan, 2023). Like real-life attachments, PSA involves proximity-seeking, but closeness is achieved through media platforms rather than through direct contact. When followers form strong PSA with AI influencers, they are motivated to seek out and consume more content—checking profiles frequently, watching all posted content, and following accounts across multiple platforms. This behaviour generates a large volume of content to process, contributing to IO. Research has not previously examined how PSA towards AI influencers affects IO and the subsequent effects on mental health. We posit that PSA may lead followers to consume an overwhelming volume of content from influencers with whom they feel attached, resulting in IO and, ultimately, adverse PWB effects.

Parasocial relationship (PSR) is a broader construct describing the one-sided interpersonal connection that media audiences form with media personas (Horton & Wohl, 1956). PSR involves a sense of intimacy, familiarity, and mutual understanding, even in the absence of real interaction (Lim et al., 2020). Followers who feel a strong PSR with an AI influencer are likely to follow that influencer's content closely and accumulate a high volume of posts to review. The authors Zhou et al. (2024) argued that weaker PSR with human-like AI influencers compared to human influencers stems from a decline in EE. However, even moderately strong PSR may lead followers to demand more frequent updates, risking IO. Research into the link between PSR, IO, and PWB in the AI influencer domain remains limited. Therefore:

H6. Parasocial attachment of followers towards AI influencers directly impacts their information overload.

H6a. Information overload mediates the effect of parasocial attachment on followers' psychological well-being.

H7. The parasocial relationship of followers towards AI influencers directly impacts their information overload.

H7a. Information overload mediates the effect of parasocial relationship on followers' psychological well-being.

Information Overload and Psychological Well-being

IO is caused by both the quantity and quality of information available. The sheer volume of AI influencer content on Instagram places significant demands on followers' cognitive resources. Previous studies have shown that perceived high IO affects social networking site users' psychological and physiological well-being (Swar et al., 2017). Research on IO in social media contexts has demonstrated that IO exerts strain on users, leading to cognitive fatigue, reduced satisfaction, and diminished PWB (Liu et al., 2021). However, in some contexts, moderate IO associated with content-rich social media interactions may also reflect active engagement that users find rewarding, particularly when the content is perceived as enjoyable or socially connecting. This ambiguity in the IO–PWB relationship motivates its empirical investigation in the present study. IO has been found to influence the PWB of healthcare professionals (Li & Khan, 2022) and to negatively affect Gen Z social media users' PWB (Liu et al., 2021). Extending these findings to the AI influencer context:

H8. Information overload from following AI influencers negatively impacts followers' psychological well-being.

Trust

Trust is defined as the confidence in an exchange partner's reliability and integrity (Kim & Kim, 2021). In the social media context, trust is built through consistent, honest, and credible interactions over time. Parasocial relationships have been found to build source trustworthiness and perceived expertise, enabling influencers to persuade audiences across multiple dimensions, including endorsement evaluation, brand attitudes, and brand affection (Breves et al., 2021). In the context of AI influencers, on average 43.1% of Instagram influencers were involved in fraud worldwide in 2023 (Statista, 2023), making trust a critical concern for followers. When followers trust an AI influencer, they are more likely to regard their interactions with that influencer as positive, meaningful, and supportive—outcomes theoretically associated with enhanced PWB. Trust has been found to have a direct positive influence on the PWB of college students using social platforms (Ye & Ho, 2023). Trust also ensures positive social exchange and helps maintain relationships that contribute to well-being (Sirdeshmukh et al., 2002). Extending these findings to the AI influencer domain:

H9. Trust in AI influencers directly and positively impacts followers' psychological well-being.

Figure 1 shows the structural diagram.

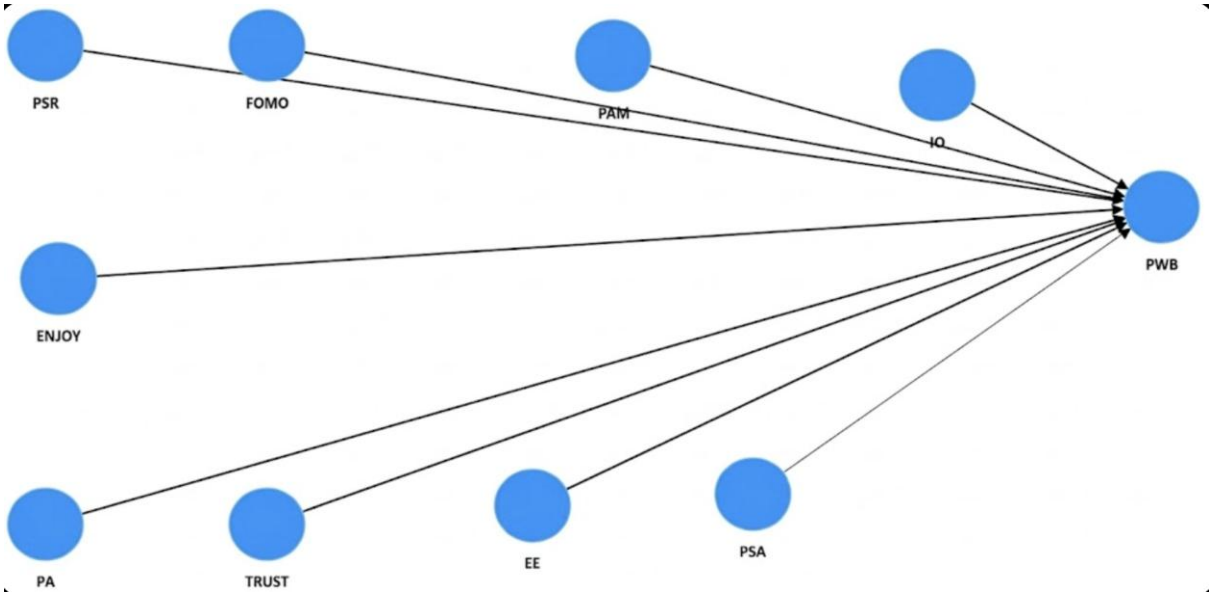

Figure 1 Conceptual diagram.

5. Research Methodology

5.1 Research Design and Operationalization

The study employed a quantitative survey design using established scales from the literature, with items adapted to the AI influencer context on Instagram. A pre-test was conducted to detect any issues with the items, and independent researchers assessed the questionnaire for robustness. Images of AI influencers with high Instagram following (in the millions) were embedded in the survey to enhance realism and to help respondents contextualise their responses, particularly for PA and PAM.

The study has seven independent constructs (EE, ENJOY, FOMO, PA, PAM, PSA, PSR) and two dependent constructs (IO, PWB). A 3-item scale for PWB (Kim & Kim, 2022) and a 6-item scale for IO (Guo et al., 2020; Lee et al., 2016; Zhang et al., 2016) were used for endogenous constructs. For exogenous constructs: a 4-item scale for EE (Lim et al., 2015; Zhou et al., 2024), a 5-item scale for ENJOY (Kim & Park, 2024), a 3-item scale for FOMO (Good & Hyman, 2020), a 3-item scale for PA (Alboqami, 2023; Kim & Kim, 2021), a 4-item scale for PAM (Kim & Park, 2024), a 3-item scale for PSA (Rubin et al., 1985; Tan, 2023), a 5-item scale for PSR (Balaban et al., 2022; Lim et al., 2020; Zhou et al., 2024), and a 4-item scale for TRUST (Alboqami, 2023). All items were measured on a five-point Likert scale.

5.2 Sample Size and Data Collection

A mix of purposive and snowball sampling was used to reach potential respondents. Only Instagram users were approached, who were then invited to forward the survey to friends who also use Instagram. The study collected 102 valid responses of Instagram users from online and offline respondents. The sample covered the millennial, Generation X, and Generation Z age cohorts. Sample size was determined using power analysis via G*Power software. With a medium effect size of 0.15, error probability of 0.05, and nine predictors, the minimum sample size was estimated at 166. The present analysis uses 102 completed responses available at this stage—a limitation addressed in Section 7. PLS-SEM is known to provide solutions with smaller samples

than covariance-based structural equation modelling (Hair et al., 2019), which supports the feasibility of the present analysis.

5.3 Analytical Approach

SmartPLS 4 software (Ringle et al., 2024) was used for hypothesis testing following PLS-SEM guidelines recommended by Hair et al. (2019). PLS-SEM was preferred over covariance-based structural equation modelling for several reasons documented by Hair et al. (2019): the research objective is prediction-oriented; the structural model includes many constructs, indicators, and model relationships; and the research involves exploring theoretical extensions in a relatively new domain. A dual-stage analysis approach was adopted (Hair et al., 2016). In the measurement model stage, scales were assessed for indicator reliability (outer loadings), internal consistency reliability (Cronbach's alpha, ρa, ρc), convergent validity (average variance extracted, AVE), and discriminant validity (heterotrait-monotrait ratio, HTMT). In the structural model stage, the coefficient of determination (R2), path coefficients, effect sizes (f2), and model fit via the Bayesian information criterion (BIC) were evaluated (Hair et al., 2019). Bootstrapping with 5,000 resamples was used to assess the statistical significance of path coefficients (Hair et al., 2019). Common method bias was assessed using a full collinearity approach following Kock (2015), and Harman's single-factor test was conducted as a supplementary check.

6. Results

6.1 Measurement Model Assessment

The measurement model was assessed following the two-step procedures outlined by Hair et al. (2019). Table 1 presents the reliability and validity statistics for all ten constructs.

Table 1 Construct reliability and validity

Construct	Cronbach's α	ρa	ρc	AVE
EE	0.887	0.892	0.922	0.748
ENJOY	0.919	0.924	0.939	0.756
FOMO	0.756	0.755	0.861	0.675
IO	0.926	0.933	0.943	0.734
PA	0.834	0.849	0.900	0.749
PAM	0.929	0.946	0.949	0.823
PSA	0.925	0.925	0.947	0.817
PSR	0.928	0.940	0.946	0.778
PWB	0.868	0.871	0.919	0.792
TRUST	0.878	0.882	0.916	0.733

Note. EE = emotional engagement; ENJOY = perceived enjoyment; FOMO = fear of missing out; IO = information overload; PA = physical attractiveness; PAM = perceived anthropomorphism; PSA = parasocial attachment; PSR = parasocial relationship; PWB = psychological well-being. ρa = composite reliability (rho_a); ρc = composite reliability (rho_c); AVE = average variance extracted. All values are from the SmartPLS 4 algorithm output (Ringle et al., 2024).

All indicator outer loadings exceed the recommended threshold of 0.708, indicating satisfactory indicator reliability (Hair et al., 2019). The lowest loading is 0.725 (IO5) and the highest is 0.945 (PSR5). Cronbach's alpha values range from 0.756 (FOMO) to 0.929 (PAM), all exceeding the minimum threshold of 0.70. ρa values range from 0.755 (FOMO) to 0.946 (PAM), and ρc values range from 0.861 (FOMO) to 0.949 (PAM), all within the recommended 0.70–0.95 range. Together, ρa and ρc bound the true reliability, with ρa typically lying between Cronbach's alpha and ρc (Hair et al., 2019). AVE values meet or exceed the 0.50 threshold for all constructs, confirming convergent validity. The lowest AVE is 0.675 (FOMO) and the highest is 0.823 (PAM). Collectively, the measurement model demonstrates satisfactory reliability and convergent validity.

Discriminant validity was assessed using the heterotrait-monotrait (HTMT) ratio of correlations (Henseler et al., 2015), as the Fornell–Larcker criterion is known to underperform when indicator loadings differ only marginally (Hair et al., 2019). Table 2 presents the HTMT matrix. Hair et al. (2019) recommend a threshold of 0.90 for conceptually similar constructs and 0.85 for conceptually distinct constructs. Several HTMT values in this study approach or exceed these thresholds: most notably FOMO–ENJOY (1.078), PA–FOMO (1.069), PA–ENJOY (1.053), PSR–EE (1.050), PSA–FOMO (1.004), TRUST–ENJOY (1.073), and TRUST–PWB (1.019). These elevated values indicate discriminant validity concerns, most likely attributable to the small sample size (n = 102) and high inter-construct correlations. Bootstrapping of HTMT values should be conducted in future work with a larger sample to formally test whether values are significantly different from 1.0 (Hair et al., 2019). These concerns are acknowledged as a study limitation.

Table 2 Heterotrait-Monotrait (HTMT) ratio of correlations

Construct	EE	ENJOY	FOMO	IO	PA	PAM	PSA	PSR
ENJOY	0.928	—	—	—	—	—	—	—
FOMO	0.973	1.078	—	—	—	—	—	—
IO	0.885	0.913	0.978	—	—	—	—	—
PA	0.875	1.053	1.069	0.887	—	—	—	—
PAM	0.922	0.908	0.939	0.703	0.921	—	—	—
PSA	0.976	0.975	1.004	0.849	0.942	1.032	—	—
PSR	1.050	0.939	1.019	0.896	0.866	0.881	0.961	—
PWB	0.941	0.962	1.009	1.078	0.916	0.760	0.911	0.944

Note. HTMT values above 0.90 indicate potential discriminant validity concerns for conceptually similar constructs; values above 0.85 are problematic for conceptually distinct constructs (Hair et al., 2019). All values from the SmartPLS 4 algorithm output (Ringle et al., 2024).

6.2 Structural Model Assessment

Prior to evaluating path coefficients, collinearity among predictor constructs was examined. Inner model VIF values ranged from 7.85 (FOMO → PWB) to 36.12 (PSA → PWB), substantially exceeding the recommended threshold of 5 for probable collinearity issues and the ideal threshold of 3 (Hair et al., 2019). This multicollinearity is consistent with the elevated HTMT values and indicates that several predictor constructs share substantial variance, which inflates standard errors and reduces the precision of path coefficient estimates.

The endogenous construct PWB achieved a coefficient of determination (R^2) of 0.953 and an adjusted R^2 of 0.948, indicating substantial in-sample explanatory power (Hair et al., 2019). The BIC value of −265.80 confirms the model's relative quality for comparison purposes. Table 3 presents the bootstrapping results for all nine direct paths from the predictors to PWB.

Table 3 Structural Model Path Coefficients and Bootstrapping Results (5,000 Resamples)

H	Relationship	β	STDEV	t	p	95% CI	Decision
H1	EE → PWB	0.151	0.128	1.175	0.240	[−0.196, 0.321]	Not Supported
H2	ENJOY → PWB	0.025	0.244	0.103	0.918	[−0.416, 0.568]	Not Supported
H3	FOMO → PWB	0.023	0.084	0.278	0.781	[−0.191, 0.148]	Not Supported
H8	IO → PWB	0.662	0.101	6.533	< 0.001	[0.430, 0.835]	Supported*
H4	PA → PWB	−0.018	0.134	0.132	0.895	[−0.234, 0.333]	Not Supported
H5	PAM → PWB	−0.351	0.165	2.125	0.034	[−0.644, −0.002]	Supported*
H6	PSA → PWB	0.393	0.210	1.869	0.062	[−0.008, 0.824]	Not Supported
H7	PSR → PWB	−0.079	0.154	0.512	0.608	[−0.260, 0.356]	Not Supported
H9	TRUST → PWB	0.167	0.225	0.744	0.457	[−0.421, 0.474]	Not Supported

Note. β = standardised path coefficient (original sample); STDEV = standard deviation of bootstrap distribution; t = |β/STDEV|; CI = 95% percentile bootstrap confidence interval. Supported* = significant at $p < 0.05$. H1–H7 were theorised as X → IO effects in the conceptual model; here they are tested as direct paths to PWB in the current model specification. Mediation hypotheses H1a–H7a are not evaluated in this output. All values from SmartPLS 4 bootstrapping output (Ringle et al., 2024).

6.3 Hypothesis Testing

Among the nine direct structural paths evaluated, two attained statistical significance. First, the path from IO to PWB (H8) yielded a standardised coefficient of 0.662 ($t = 6.533$, $p < 0.001$; 95% CI = [0.430, 0.835]), with a large f^2 effect size of 0.948. This provides strong support for H8, indicating that IO exerts a substantial positive direct effect on PWB among Instagram users following AI influencers. Second, the path from PAM to PWB (H5) yielded a standardised coefficient of −0.351 ($t = 2.125$, $p = 0.034$; 95% CI = [−0.644, −0.002]), with a medium f^2 effect size of 0.095, supporting H5 in the direct-effects model.

The remaining seven direct hypotheses were not supported. H1 (EE → PWB, p = 0.240), H2 (ENJOY → PWB, p = 0.918), H3 (FOMO → PWB, p = 0.781), H4 (PA → PWB, p = 0.895), H6 (PSA → PWB, p = 0.062), H7 (PSR → PWB, p = 0.608), and H9 (TRUST → PWB, p = 0.457) did not reach conventional levels of statistical significance. It is important to note that H1 through H7 in the original conceptual model were formulated as effects of antecedent constructs on IO (not directly on PWB), with IO subsequently mediating their effects on PWB. The current SmartPLS model specification tests all predictors as direct antecedents of PWB. Consequently, the mediation hypotheses H1a through H7a cannot be formally evaluated in the present analysis and will require a re-specified model with IO as an endogenous mediator between the antecedent constructs and PWB.

Present the results of the data analysis. This section should describe the approach to data analysis, followed by the results and interpretation. If the results are presented in the form of tables or figures, a description of the content must also be included.

7. Conclusion and Discussion

The most prominent finding of this study is the large, positive direct effect of IO on PWB ($p < 0.001$). This finding appears, at first glance, to contradict the dominant expectation in the IO literature—that IO impairs well-being by causing cognitive strain, stress, and decision fatigue (Swar et al., 2017; Liu et al., 2021). However, the positive direction of the IO–PWB relationship may be understood through several complementary explanations grounded in the social media and positive psychology literatures.

First, the present model tests a direct effect of IO on PWB without IO serving as a negative mediator between antecedent constructs and PWB. It is possible that among active Instagram users who choose to follow AI influencer content, a higher volume of information—while technically constituting IO—also carries with it a sense of connectedness, entertainment, and social belonging that contributes positively to PWB, at least in the short term. This finding is broadly consistent with evidence from self-determination theory (Ryan & Deci, 2000): when social media content satisfies needs for relatedness, competence, or enjoyment, higher engagement and even higher IO can still produce positive affective outcomes. Li and Khan (2022) similarly found context-dependent moderation in the IO–well-being relationship.

Second, it is plausible that the direction of the IO–PWB path is partially driven by the high multicollinearity in the model. VIF values between 7.85 and 36.12 indicate that the constructs share substantial variance, which inflates coefficients and may distort the sign and magnitude of individual paths. This methodological concern does not negate the finding but underscores the need for cautious interpretation and model re-estimation with a larger, cleaner sample. In future research, a mediated model in which IO is caused by the antecedent constructs and then negatively influences PWB may yield results more aligned with extant theoretical expectations (Swar et al., 2017).

The significant negative effect of PAM on PWB is theoretically coherent and empirically novel. It is consistent with the uncanny valley theory (Mori et al., 2012), which predicts that as

artificial characters approach—but do not fully achieve—human-likeness, the resulting near-human appearance can generate discomfort, unease, and eeriness in observers. When followers perceive AI influencers as highly anthropomorphic, they may simultaneously recognise the artificiality of those human-like traits, producing a cognitive dissonance that undermines PWB. This interpretation is also supported by Malhotra and Ramalingam (2023), who found that perceived anthropomorphism interacted with trust in shaping user responses to AI technology. The present finding extends this literature to the Instagram AI influencer domain, demonstrating that PAM has a measurable negative consequence for follower PWB.

These results carry important theoretical contributions. The uncanny valley effect has been documented primarily in robotics and virtual agent research; its demonstration in the social media AI influencer context enriches the understanding of how followers psychologically process increasingly human-like digital personas. Future research should explore whether the PAM–PWB relationship is moderated by user demographics (e.g., age, cultural background), platform type, or the specific design characteristics of AI influencers—such as facial realism or voice realism.

8. Suggestions

This study makes three primary theoretical contributions. First, it extends the application of cognitive load theory (Sweller, 1988) and parasocial relationship theory (Horton & Wohl, 1956) to the under-explored domain of AI influencer-generated content and its consequences for follower PWB. By positioning IO as the key mechanism between AI influencer engagement and PWB, the study provides a theoretically grounded framework for future research on the psychological consequences of AI influencer marketing. Second, the study situates PAM as a theoretically meaningful boundary condition for follower PWB in the AI influencer domain, consistent with the uncanny valley theory (Mori et al., 2012) and extending it beyond its original robotics context. Third, the study demonstrates the utility of PLS-SEM as a prediction-oriented, composite-based method (Hair et al., 2019) for modelling complex, multi-construct models in emerging digital marketing contexts where distributional assumptions and small sample sizes might otherwise preclude the use of covariance-based structural equation modelling.

9. References

Alboqami, H. (2023). Trust me, I'm an influencer! – Causal recipes for customer trust in artificial intelligence influencers in the retail industry. Journal of Retailing and Consumer Services, 72, 103242. https://doi.org/10.1016/j.jretconser.2022.103242

Aldoory, L., & Van Dyke, M. A. (2006). The roles of perceived 'shared' involvement and information overload in understanding how audiences make meaning of news about bioterrorism. Journalism & Mass Communication Quarterly, 83(2), 346–361. https://doi.org/10.1177/107769900608300208

Arsenyan, J., & Mirowska, A. (2021). Almost human? A comparative case study on the social media presence of virtual influencers. International Journal of Human-Computer Studies, 155, 102694. https://doi.org/10.1016/j.ijhcs.2021.102694

Balaban, D. C., Szambolics, J., & Chirică, M. (2022). Parasocial relations and social media influencers' persuasive power: Exploring the moderating role of product involvement. Acta Psychologica, 230, 103731. https://doi.org/10.1016/j.actpsy.2022.103731

Boerman, S. C. (2020). The effects of the standardized Instagram disclosure for micro- and meso-influencers. Computers in Human Behavior, 103, 199–207. https://doi.org/10.1016/j.chb.2019.09.015

Bowlby, J. (1969). Attachment and loss. Random House.

Breves, P., Amrehn, J., Heidenreich, A., Liebers, N., & Schramm, H. (2021). Blind trust? The importance and interplay of parasocial relationships and advertising disclosures in explaining influencers' persuasive effects on their followers. International Journal of Advertising, 40(7), 1209–1229. https://doi.org/10.1080/02650487.2021.1881237

Buglass, S. L., Binder, J. F., Betts, L. R., & Underwood, J. D. M. (2017). Motivators of online vulnerability: The impact of social network site use and FOMO. Computers in Human Behavior, 66, 248–255. https://doi.org/10.1016/j.chb.2016.09.055

Bui, M., Krishen, A. S., Anlamlier, E., & Berezan, O. (2022). Fear of missing out in the digital age: The role of social media satisfaction and advertising engagement. Psychology & Marketing, 39(4), 683–693. https://doi.org/10.1002/mar.21611

Bunker, C. J., & Kwan, V. S. Y. (2024). Similarity between perceived selves on social media and offline and its relationship with psychological well-being in early and late adulthood. Computers in Human Behavior, 152, 108025. https://doi.org/10.1016/j.chb.2023.108025

Chen, L., Yan, Z., Tang, W. J., Yang, F. Y., Xie, X. D., & He, J. C. (2016). Mobile phone addiction levels and negative emotions among Chinese young adults: The mediating role of interpersonal problems. Computers in Human Behavior, 55, 856–866. https://doi.org/10.1016/j.chb.2015.10.030

Cheung, M. L., Leung, W. K. S., Aw, E. C.-X., & Koay, K. Y. (2022). 'I follow what you post!': The role of social media influencers' content characteristics in consumers' online brand-related activities. Journal of Retailing and Consumer Services, 66, 102940. https://doi.org/10.1016/j.jretconser.2022.102940

de Kerviler, G., Demoulin, N. T. M., & Zidda, P. (2016). Adoption of in-store mobile payment: Are perceived risk and convenience the only drivers? Journal of Retailing and Consumer Services, 31, 334–344. https://doi.org/10.1016/j.jretconser.2016.04.011

Diener, E., Wirtz, D., Tov, W., Kim-Prieto, C., Choi, D. W., Oishi, S., & Biswas-Diener, R. (2010). New well-being measures: Short scales to assess flourishing and positive and negative feelings. Social Indicators Research, 97(2), 143–156. https://doi.org/10.1007/s11205-009-9493-y

Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: A three-factor theory of anthropomorphism. Psychological Review, 114(4), 864–886. https://doi.org/10.1037/0033-295X.114.4.864

Ganju, K. K., Pavlou, P. A., & Banker, R. D. (2016). Does information and communication technology lead to the well-being of nations? A country-level empirical investigation. MIS Quarterly, 40(2), 417–430. https://doi.org/10.25300/MISQ/2016/40.2.07

Good, M. C., & Hyman, M. R. (2020). 'Fear of missing out': Antecedents and influence on purchase likelihood. Journal of Marketing Theory and Practice, 28(3), 330–341. https://doi.org/10.1080/10696679.2020.1766359

Guo, Y., Lu, Z., Kuang, H., & Wang, C. (2020). Information avoidance behavior on social network sites: Information irrelevance, overload, and the moderating role of time pressure. International Journal of Information Management, 52, 102067. https://doi.org/10.1016/j.ijinfomgt.2020.102067

Hair, J. F., Hult, G. T. M., Ringle, C., & Sarstedt, M. (2016). A primer on partial least squares structural equation modeling (PLS-SEM) (2nd ed.). Sage Publications.

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. European Business Review, 31(1), 2–24. https://doi.org/10.1108/EBR-11-2018-0203

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. Journal of the Academy of Marketing Science, 43(1), 115–135.

Horton, D., & Wohl, R. R. (1956). Mass communication and para-social interaction. Psychiatry, 19(3), 215–229. https://doi.org/10.1080/00332747.1956.11023049

Hutter, K., Hautz, J., Dennhardt, S., & Füller, J. (2013). The impact of user interactions in social media on brand awareness and purchase intention: The case of MINI on Facebook. Journal of Product & Brand Management, 22(5/6), 342–351. https://doi.org/10.1108/JPBM-05-2013-0299

Iyer, R., & Muncy, J. A. (2016). Attitude toward consumption and subjective well-being. Journal of Consumer Affairs, 50(1), 48–67. https://doi.org/10.1111/joca.12079

Janssen, L., Schouten, A. P., & Croes, E. A. J. (2022). Influencer advertising on Instagram: Product-influencer fit and number of followers affect advertising outcomes and influencer evaluations via credibility and identification. International Journal of Advertising, 41(1), 101–127. https://doi.org/10.1080/02650487.2021.1994205

Ki, C.-W., Cuevas, L. M., Chong, S. M., & Lim, H. (2020). Influencer marketing: Social media influencers as human brands attaching to followers and yielding positive marketing results by fulfilling needs. Journal of Retailing and Consumer Services, 55, 102133. https://doi.org/10.1016/j.jretconser.2020.102133

Kim, D. Y., & Kim, H.-Y. (2021). Trust me, trust me not: A nuanced view of influencer marketing on social media. Journal of Business Research, 134, 223–232. https://doi.org/10.1016/j.jbusres.2021.05.024

Kim, H., & Park, M. (2024). When digital celebrity talks to you: How human-like virtual influencers satisfy consumer's experience through social presence on social media endorsements. Journal of Retailing and Consumer Services, 76, 103581. https://doi.org/10.1016/j.jretconser.2023.103581

Kim, M. (2022). How can I be as attractive as a fitness YouTuber in the era of COVID-19? The impact of digital attributes on flow experience, satisfaction, and behavioral intention. Journal of Retailing and Consumer Services, 64, 102778. https://doi.org/10.1016/j.jretconser.2021.102778

Kim, M., & Kim, H.-M. (2022). What online game spectators want from their Twitch streamers: Flow and well-being perspectives. Journal of Retailing and Consumer Services, 66, 102951. https://doi.org/10.1016/j.jretconser.2022.102951

Kock, N. (2015). Common method bias in PLS-SEM: A full collinearity assessment approach. International Journal of E-Collaboration, 11(4), 1–10. https://doi.org/10.4018/ijec.2015100101

Lee, A. R., Son, S.-M., & Kim, K. K. (2016). Information and communication technology overload and social networking service fatigue: A stress perspective. Computers in Human Behavior, 55, 51–61. https://doi.org/10.1016/j.chb.2015.08.011

Li, W., & Khan, A. N. (2022). Investigating the impacts of information overload on psychological well-being of healthcare professionals: Role of COVID-19 stressor. INQUIRY: The Journal of Health Care Organization, Provision, and Financing, 59. https://doi.org/10.1177/00469580221109677

Li, X., & Chan, M. (2022). Smartphone uses and emotional and psychological well-being in China: The attenuating role of perceived information overload. Behaviour & Information Technology, 41(11), 2427–2437. https://doi.org/10.1080/0144929X.2021.1929489

Li, Y., & Xie, Y. (2020). Is a picture worth a thousand words? An empirical study of image content and social media engagement. Journal of Marketing Research, 57(1), 1–19. https://doi.org/10.1177/0022243719881113

Lim, J. S., Choe, M.-J., Zhang, J., & Noh, G.-Y. (2020). The role of wishful identification, emotional engagement, and parasocial relationships in repeated viewing of live-streaming games. Computers in Human Behavior, 108, 106327. https://doi.org/10.1016/j.chb.2020.106327

Lim, J. S., Hwang, Y., Kim, S., & Biocca, F. A. (2015). How social media engagement leads to sports channel loyalty: Mediating roles of social presence and channel commitment. Computers in Human Behavior, 46, 158–167. https://doi.org/10.1016/j.chb.2015.01.013

Liu, H., Liu, W., Yoganathan, V., & Osburg, V.-S. (2021). COVID-19 information overload and generation Z's social media discontinuance intention during the pandemic lockdown. Technological Forecasting and Social Change, 166, 120600. https://doi.org/10.1016/j.techfore.2021.120600

Lou, C., & Yuan, S. (2019). Influencer marketing: How message value and credibility affect consumer trust of branded content on social media. Journal of Interactive Advertising, 19(1), 58–73. https://doi.org/10.1080/15252019.2018.1533501

Malhotra, G., & Ramalingam, M. (2023). Perceived anthropomorphism and purchase intention using artificial intelligence technology: Examining the moderated effect of trust. Journal of Enterprise Information Management. https://doi.org/10.1108/JEIM-09-2022-0316

Masuda, H., Han, S. H., & Lee, J. (2022). Impacts of influencer attributes on purchase intentions in social media influencer marketing: Mediating roles of characterizations. Technological Forecasting and Social Change, 174, 121246. https://doi.org/10.1016/j.techfore.2021.121246

Misra, S., & Stokols, D. (2012). Psychological and health outcomes of perceived information overload. Environment and Behavior, 44(6), 737–759. https://doi.org/10.1177/0013916511404408

Mori, M., MacDorman, K., & Kageki, N. (2012). The uncanny valley. IEEE Robotics & Automation Magazine, 19(2), 98–100. https://doi.org/10.1109/MRA.2012.2192811

Pang, H., & Ruan, Y. (2023). Can information and communication overload influence smartphone app users' social network exhaustion, privacy invasion and discontinuance intention? Journal of Retailing and Consumer Services, 73, 103378. https://doi.org/10.1016/j.jretconser.2023.103378

Pozharliev, R., Rossi, D., & De Angelis, M. (2022). A picture says more than a thousand words: Using consumer neuroscience to study Instagram users' responses to influencer advertising. Psychology & Marketing, 39(7), 1336–1349. https://doi.org/10.1002/mar.21659

Przybylski, A. K., Murayama, K., DeHaan, C. R., & Gladwell, V. (2013). Motivational, emotional, and behavioral correlates of fear of missing out. Computers in Human Behavior, 29(4), 1841–1848. https://doi.org/10.1016/j.chb.2013.02.014

Ringle, C. M., Wende, S., & Becker, J.-M. (2024). SmartPLS 4. SmartPLS. https://www.smartpls.com

Rubin, A. M., Perse, E. M., & Powell, R. A. (1985). Loneliness, parasocial interaction, and local television news viewing. Human Communication Research, 12(2), 155–180. https://doi.org/10.1111/j.1468-2958.1985.tb00071.x

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. American Psychologist, 55(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Sheng, N., Yang, C., Han, L., & Jou, M. (2023). Too much overload and concerns: Antecedents of social media fatigue and the mediating role of emotional exhaustion. Computers in Human Behavior, 139, 107500. https://doi.org/10.1016/j.chb.2022.107500

Shmueli, G., Sarstedt, M., Hair, J. F., Cheah, J.-H., Ting, H., Vaithilingam, S., & Ringle, C. M. (2019). Predictive model assessment in PLS-SEM: Guidelines for using PLSpredict. Working Paper.

Sirdeshmukh, D., Singh, J., & Sabol, B. (2002). Consumer trust, value, and loyalty in relational exchanges. Journal of Marketing, 66(1), 15–37. https://doi.org/10.1509/jmkg.66.1.15.18449

Statista. (2023). Share of Instagram influencers involved in fraud worldwide from 2022–2023, by number of followers. Statista. https://www.statista.com/statistics/1250681/share-of-instagram-influencers-involved-in-fraud-worldwide/

Stein, J.-P., Linda Breves, P., & Anders, N. (2024). Parasocial interactions with real and virtual influencers: The role of perceived similarity and human-likeness. New Media & Society, 26(6), 3433–3453. https://doi.org/10.1177/14614448221102900

Swar, B., Hameed, T., & Reychav, I. (2017). Information overload, psychological ill-being, and behavioral intention to continue online healthcare information search. Computers in Human Behavior, 70, 416–425. https://doi.org/10.1016/j.chb.2016.12.068

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Tan, Y. (2023). More attached, less stressed: Viewers' parasocial attachment to virtual YouTubers and its influence on the stress of viewers during the COVID-19 pandemic. SHS Web of Conferences, 155, 03012. https://doi.org/10.1051/shsconf/202315503012

Wong, A., & Wei, J. (2023). Persuasive cues and reciprocal behaviors in influencer-follower relationships: The mediating role of influencer defense. Journal of Retailing and Consumer Services, 75, 103507. https://doi.org/10.1016/j.jretconser.2023.103507

Ye, S., & Ho, K. K. W. (2023). College students' Twitter usage and psychological well-being from the perspective of generalised trust. Library Hi Tech, 41(1), 152–173. https://doi.org/10.1108/LHT-06-2021-0178

York, C. (2013). Overloaded by the news: Effects of news exposure and enjoyment on reporting information overload. Communication Research Reports, 30(4), 282–292. https://doi.org/10.1080/08824096.2013.836628

Zhang, S., Zhao, L., Lu, Y., & Yang, J. (2016). Do you get tired of socializing? An empirical explanation of discontinuous usage behaviour in social network services. Information & Management, 53(7), 904–914. https://doi.org/10.1016/j.im.2016.03.006

Zhou, Q., Li, B., Li, H., & Lei, Y. (2024). Mere copycat? The effects of human versus human-like virtual influencers on brand endorsement effectiveness: A moderated serial-mediation model. Journal of Retailing and Consumer Services, 76. https://doi.org/10.1016/j.jretconser.2023.103610

STRATEGIC ACADEMIC MANAGEMENT APPROACHES IN THE DIGITAL ERA FOR ENHANCING STUDENT QUALITY AT WATYANNARANGSARAM SCHOOL

Daoprakai Nanthaprom*

drdaoprakai.r@gmail.com

Watyannarangsaram School, Chachoengsao Primary Educational Service Area Office 1,
Office of the Basic Education Commission

*Corresponding Author E-mail: drdaoprakai.r@gmail.com

ABSTRACT

This research aimed to study strategic academic administration approaches based on the concept of strategic management in the digital era to enhance student quality at Watyanrangsanaram School. The key informants consisted of six participants, including school administrators and heads of academic affairs from three schools under the Chachoengsao Primary Educational Service Area Office 1, selected through purposive sampling. These schools were identified as successful in academic administration based on the Ordinary National Educational Test (O-NET) results of Grade 6 students in the 2024 academic year, with at least eight students and an average score of 50 percent or higher. Data were collected through semi-structured interviews, and content analysis was employed for data analysis.

The findings revealed that academic administration based on strategic management in the digital era was successfully implemented across five key dimensions. First, curriculum development was driven by data and learner context, incorporating participation through Professional Learning Communities (PLC) and systematic management using the PDCA cycle, resulting in flexible and up-to-date curricula aligned with learners' needs. Second, learning management emphasized student-centered approaches, with clear learning objectives, the use of Active Learning, and continuous teacher development through PLC and classroom research, supported by coaching-based supervision. Third, assessment and evaluation employed authentic and diverse methods, focusing on formative assessment and continuous feedback, alongside the use of technology and data analytics to support individualized learner development. Fourth, research for educational quality improvement was promoted through classroom research, supported by clear policies and resources, with research findings applied to curriculum and instructional development, fostering a research-oriented school culture. Finally, educational supervision was conducted through a developmental and collaborative approach, emphasizing evidence-based practices, classroom-based supervision, PLC processes, and the expansion of best practices through professional networks, leading to continuous improvement in student quality.

Keywords: Academic administration, Strategic Management, Digital era

1. Statement of the Problem

Academic management is a crucial mechanism for driving educational quality and enhancing learners' competencies in alignment with the demands of the 21st century. It encompasses curriculum development, instructional management, assessment and evaluation, as well as teacher development, all of which directly influence school effectiveness. In Thailand, national education

policy identifies academic management as a core mission for improving student quality (Ministry of Education, 2023, pp. 12–15).

In the digital era, technology and artificial intelligence (AI) play a significant role in education, particularly in learning management, assessment processes, and data utilization. These technologies contribute to increased efficiency and support evidence-based decision-making at both institutional and policy levels (OECD, 2023, pp. 24–30).

However, basic education institutions—especially small-sized schools—continue to face several challenges in academic management. These include teacher-centered instructional practices, underutilization of technology, lack of effective data use, and unsystematic internal supervision systems. Such issues hinder the achievement of expected educational standards. This is consistent with findings from the Chachoengsao Primary Educational Service Area Office 1 (2022, pp. 12–18) and the Office of the Basic Education Commission (2023, pp. 25–30), which indicate that educational inequality in small schools remains a critical issue, largely due to limitations in resources, access to technology, and the strength of management systems.

Watyannarangsaram School, a small-sized school located in a semi-rural context under the Chachoengsao Primary Educational Service Area Office 1, faces similar challenges. These include limitations in implementing active learning approaches, integrating technology into instruction, utilizing student data, and establishing an effective internal supervision system. As a result, students' academic achievement has not met the expected standards.

Therefore, it is necessary to develop strategic academic management approaches in the digital era. Such approaches would enable schools to set clear developmental directions, utilize data for informed decision-making, and effectively integrate technology into academic administration. Ultimately, this would lead to sustainable improvement in student quality. Hence, this study aims to explore such approaches in order to support school development in alignment with its context and the ongoing changes in the digital age.

2. Objectives

This study aims to explore strategic academic management approaches in the digital era to enhance student quality at Watyannarangsaram School under the Chachoengsao Primary Educational Service Area Office 1.

3. Conceptual Framework and Hypothesis

The researcher reviewed academic management concepts from both Thai and international scholars, including the Office of the Basic Education Commission (2018, p. 114), Chamchoy (2019, pp. 73–82), Chaiprom (2022, pp. 114–118), Dechakup (2021, pp. 45–60), Wongyai (2020, pp. 97–110), Hallinger (2020, pp. 25–32), Robinson (2017, pp. 94–101), Fullan (2021, pp. 54–66), Leithwood (2020, pp. 18–29), and Darling-Hammond (2022, pp. 121–135). The researcher established criteria for variable synthesis by selecting only variables with a frequency of 50 percent or higher to develop new variables for the study.

The synthesis of these studies indicates that academic management at Watyannarangsaram School, under the Chachoengsao Primary Educational Service Area Office 1, comprises five key components:

1. Curriculum development
2. Learning management
3. Measurement and evaluation
4. Research for educational quality development
5. Educational supervision

As shown in figure 1. Model of academic management: Five key components

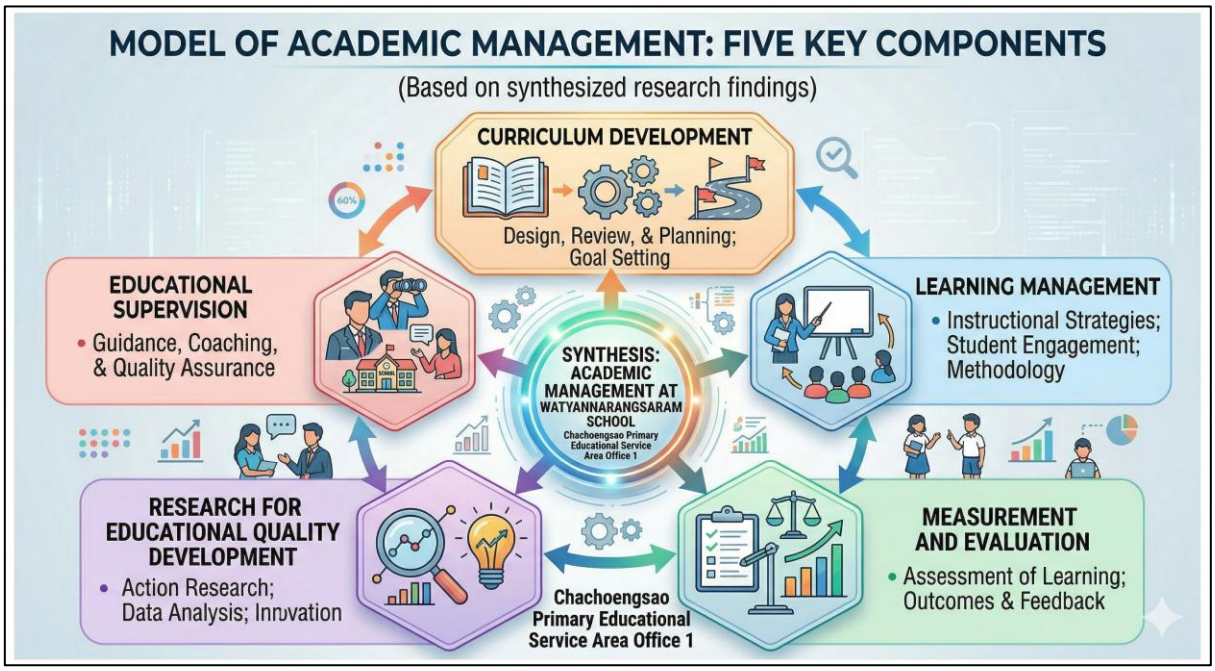

Figure 1 Model of academic management: Five key components

4. Research Methodology

4.1 Key Informants

The key informants consisted of six participants, including school administrators and heads of academic affairs from three schools under the Chachoengsao Primary Educational Service Area Office 1. These schools were purposively selected as information-rich cases, as they demonstrated successful academic management based on the Ordinary National Educational Test (O-NET) results of Grade 6 students in the 2024 academic year. The selection criteria required schools to have at least eight students and an average score of 50 percent or higher, ensuring the inclusion of schools with stable and credible performance outcomes.

Purposive sampling was employed to allow for an in-depth exploration of best practices and strategic processes within high-performing contexts. The sample size of six participants was considered appropriate for qualitative research, as it enabled rich, detailed data collection from key stakeholders directly involved in academic management. (Educational Measurement and Evaluation Division, Supervision, Monitoring, and Evaluation Division, Chachoengsao Primary Educational Service Area Office 1, 2025, pp. 19–24)

The three selected schools, all operating under the jurisdiction of the Chachoengsao Primary Educational Service Area Office 1, share comparable contextual conditions and are guided by the same policy framework and their average scores were as follows:

1. Anuban Wat Pitulathiratrangsarit School (62.02%)
2. Wat Donthong School (56.68%)
3. Ban Bangkaew School (50.66%)

4.2 Research Instrument

The research instrument was a semi-structured interview designed to explore strategic academic management approaches in the digital era. The instrument consisted of two parts:

Part 1: General information of the informants (name, position, and workplace)

Part 2: Interview questions related to successful academic management practices

The interview questions covered five aspects:
1. Curriculum development
2. Learning management)
3. Measurement and evaluation
4. Research for educational quality development
5. Educational supervision

The instrument was validated by five experts using the Index of Item-Objective Congruence (IOC), with values ranging from 0.60 to 1.00.

4.3 Data Collection

Official permission letters were sent to the school administrators and heads of academic affairs of the three selected schools. Data were collected through interviews conducted between January 28 and February 20, 2026. All interviews were completed on February 20, 2026.

4.4 Data Analysis

The qualitative data were analyzed systematically following the approach proposed by Photisita (2019, pp. 185–192), as follows:

1. Data verification: Checking completeness, clarity, and accuracy of interview data from audio recordings and field notes

2. Transcription: Verbatim transcription and validation against original audio files

3. Data organization: Categorizing and coding data based on research questions and conceptual framework

4. Content analysis: Repeated reading to identify key concepts and patterns, and interpret meanings

5. Thematic analysis: Grouping data into themes and sub-themes aligned with research objectives

6. Trustworthiness: Ensuring data credibility through consistency checks and validation procedures

7. Synthesis and presentation: Presenting findings through descriptive analysis, linking with theories and related studies, and including direct quotes to enhance credibility

5. Results

The study on strategic academic management approaches in the digital era for enhancing student quality at Watyannarangsaram School revealed the following findings:

1. Curriculum Development: Successful curriculum development was characterized by:

1.1 Data-driven and context-based curriculum design: Schools analyzed student data, including past academic performance (e.g., O-NET results), as well as community and local contexts to revise course structures and learning units, ensuring relevance to learners' needs.

1.2 Stakeholder participation: Curriculum development involved administrators, teachers, experts, and community representatives, with collaboration through Professional Learning Communities (PLC), fostering shared ownership and systematic development.

1.3 PDCA-based management: The Plan-Do-Check-Act (PDCA) cycle was applied to continuously improve curriculum design, instruction, and evaluation processes.

1.4 Active learning and learner-centered approach: Instruction emphasized hands-on learning, 21st-century skills, digital competencies, and desirable characteristics alongside moral development.

1.5 Authentic and standards-aligned assessment: Assessment methods were aligned with learning indicators and outcomes, using diverse authentic approaches to reflect students' actual competencies.

1.6 Continuous supervision and evaluation: Ongoing monitoring and annual evaluation ensured curriculum relevance and responsiveness to societal changes.

2. Learning Management: Effective learning management included:

2.1 Clear outcome-based learning goals: Schools defined explicit academic and competency-based goals to guide instructional planning and evaluation.

2.2 Active learning implementation: Learners engaged in participatory, experiential, and problem-solving activities, including project-based learning.

2.3 Teacher development through PLC and classroom research: Teachers collaboratively designed lessons, shared practices, and conducted classroom action research for continuous improvement.

2.4 Coaching and feedback supervision: Internal supervision emphasized guidance, reflection, and professional support rather than inspection.

2.5 Assessment for learning: Formative assessment and feedback were used to improve both teaching and individual student learning.

2.6 Supportive learning environment and innovation: Schools promoted the use of technology, learning resources, and instructional innovations to enhance student achievement and higher-order thinking skills.

3. Measurement and Evaluation: Successful assessment practices included:

3.1 Clear alignment with curriculum standards: Learning objectives, criteria, and tools were aligned with standards and competencies.

3.2 Authentic assessment: Evaluation reflected students' real abilities in knowledge, skills, and behaviors.

3.3 Use of diverse assessment tools: Methods included tests, projects, portfolios, observations, and presentations.

3.4 Assessment for learning: Continuous feedback supported student development and instructional adjustment.

3.5 Data analysis and information systems: Student data were analyzed to support decision-making and individualized development plans (IDPs).

3.6 Remedial and support systems with parental involvement: Immediate interventions and collaboration with parents ensured holistic student development.

4. Research for Educational Quality Development: Key success factors included:

4.1 Clear research policy aligned with school goals: Research initiatives were linked to improving student outcomes and academic achievement.

4.2 Teacher research competency through PLC: Teachers developed research skills collaboratively.

4.3 Support systems and academic mentoring: Schools provided resources, expert support, and consultation systems.

4.4 Promotion of classroom action research: Teachers conducted research to solve real classroom problems.

4.5 Utilization of research findings: Results were applied to improve curriculum, instruction, and academic management.

4.6 Research culture and dissemination: Schools promoted sharing of research and innovation, fostering a sustainable research-based organizational culture.

5. Educational Supervision: Effective supervision practices included:

5.1 Clear supervision policies and plans aligned with school goals and student achievement targets.

5.2 Coaching and mentoring approach: Emphasis on support, trust-building, and constructive feedback.

5.3 Systematic six-step supervision process: Needs assessment, analysis, planning, implementation, evaluation, and reporting.

5.4 Classroom coaching integrated with PLC: Real classroom observation linked with collaborative reflection.

5.5 Evidence-based improvement: Use of supervision and student data to guide teacher development.

5.6 Networking and scaling best practices: Collaboration with external supervisors and dissemination of best practices to enhance academic standards.

6. Conclusion and Discussion

The findings indicate that successful academic management can be characterized as a "strategic integrated system", in which all academic functions are holistically interconnected. The key findings can be summarized into five dimensions as follows:

1. Curriculum Development

The study found that successful curriculum development is grounded in data-driven decision-making and contextual analysis of learners and communities. This approach ensures that the curriculum aligns with actual needs. Active participation from all stakeholders through Professional Learning Communities (PLC) fosters collaboration and shared ownership. Additionally, the implementation of the PDCA cycle supports systematic and continuous improvement. The integration of active learning, authentic assessment, and continuous supervision further enhances curriculum flexibility and relevance.

This may be attributed to the increasing importance of evidence-based curriculum development and stakeholder engagement in modern education, which enhance instructional effectiveness and student learning outcomes.

These findings are consistent with Tyler (2021, pp. 1–5), who emphasized that curriculum development should be based on learners' needs and societal context using data as a foundation. They also align with Zhang et al. (2022, pp. 3–5), who found that PLC combined with action research significantly enhances teacher learning and instructional improvement, leading to improved student outcomes.

2. Learning Management

Effective learning management emphasizes clear outcome-based goals and learner-centered approaches through active learning strategies. These approaches promote critical thinking and problem-solving skills. Teacher development through PLC and classroom action research contributes to continuous instructional improvement. Furthermore, coaching and feedback-based supervision, along with assessment for learning, enables teachers to refine their instructional practices effectively. A supportive learning environment and the integration of innovation and technology further enhance student achievement.

These findings may be explained by the shift toward competency-based education, where active engagement and clear learning goals promote higher-order thinking and real-world application. Continuous teacher development through collaborative and reflective practices plays a crucial role in improving instructional quality.

The results are consistent with Bonwell and Eison (2021, pp. 2–4), who highlighted that active learning promotes student engagement and higher-order thinking skills. They also align

with Darling-Hammond et al. (2020, pp. 5–8), who found that active learning and collaborative teacher development significantly enhance student competencies and learning outcomes.

3. Measurement and Evaluation

The study revealed that effective assessment practices involve clearly defined objectives aligned with curriculum standards, along with the use of authentic and diverse assessment methods. Emphasis on assessment for learning and continuous feedback supports student development. The use of technology and information systems for data analysis enables personalized learning plans and informed decision-making. Additionally, systematic remedial support with parental involvement ensures comprehensive student development.

This may be due to the growing emphasis on data-driven and individualized learning approaches in contemporary education. Diverse and authentic assessment methods provide a more accurate reflection of students' abilities, while feedback and data analytics support continuous improvement.

These findings are consistent with Black and Wiliam (2018, pp. 7–9), who emphasized the importance of formative assessment and feedback in enhancing student learning. They also align with Gulikers et al. (2022, pp. 70–73), who found that authentic assessment effectively reflects real-world competencies and promotes meaningful learning.

4. Research for Educational Quality Development

The success of research management is attributed to clear policies aligned with school goals and the development of teachers' research competencies through PLC. Support systems, including budget allocation, expert guidance, and mentoring, facilitate effective research implementation. Classroom action research serves as a key mechanism for solving instructional problems and improving learning outcomes. Furthermore, the application and dissemination of research findings contribute to a sustainable research-based organizational culture.

This may be explained by the role of action research as a reflective and systematic process that enables teachers to improve their practices. Institutional support and collaborative learning further strengthen academic capacity and continuous development.

These findings are consistent with Kemmis and McTaggart (2018, pp. 6–8), who described action research as a cyclical process of planning, acting, observing, and reflecting. They also align with Kraft et al. (2018, pp. 547–550), who found that coaching and collaborative professional learning significantly improve teaching quality and student achievement.

5. Educational Supervision

Effective supervision is characterized by a developmental approach, with clear policies aligned with school goals. It emphasizes coaching and mentoring rather than inspection, fostering trust and professional growth. A systematic supervision process and classroom-based coaching integrated with PLC enhance instructional improvement. The use of empirical data and the establishment of professional networks further support continuous development and the dissemination of best practices.

This may be due to the shift from control-oriented supervision to teacher empowerment. Developmental supervision, supported by evidence-based practices and collaborative reflection, enables teachers to continuously improve their instructional practices.

These findings are consistent with Glickman et al. (2018, pp. 8–10), who emphasized that developmental supervision should focus on teacher support and professional growth. They also align with Kraft et al. (2018, pp. 547–549), who found that coaching with continuous feedback significantly improves teaching effectiveness and student outcomes.

The findings of this study revealed that effective academic management could be conceptualized as a "strategic integrated system," in which five key dimensions—curriculum development, learning management, measurement and evaluation, research development, and educational supervision—were holistically interconnected. Building upon these empirical findings, this study advanced beyond a set of best practices toward a system-level innovation by integrating artificial intelligence (AI) and data analytics as core driving mechanisms for continuous improvement and informed decision-making.

The integration of AI across the five dimensions was concretely described as follows.

First, in curriculum development, AI was utilized to analyze learners' needs and community contexts, enabling the design of a dynamic curriculum that could be continuously adapted based on real-time data.

Second, in learning management, AI supported personalized active learning by recommending individualized learning activities, while AI tutors or chatbots facilitated continuous learning support.

Third, in measurement and evaluation, AI enabled learning analytics for individual learners, supported automated test generation, and provided immediate feedback to enhance learning outcomes.

Fourth, in research development, AI was applied to analyze classroom research data and generated actionable insights for solving learning-related problems.

Finally, in educational supervision, intelligent dashboards were employed to support administrators, while AI assisted in analyzing teaching quality and provided coaching-oriented feedback for teacher development.

As shown in Figure 2. Innovation-Oriented Extension: An AI-Driven Academic Management System

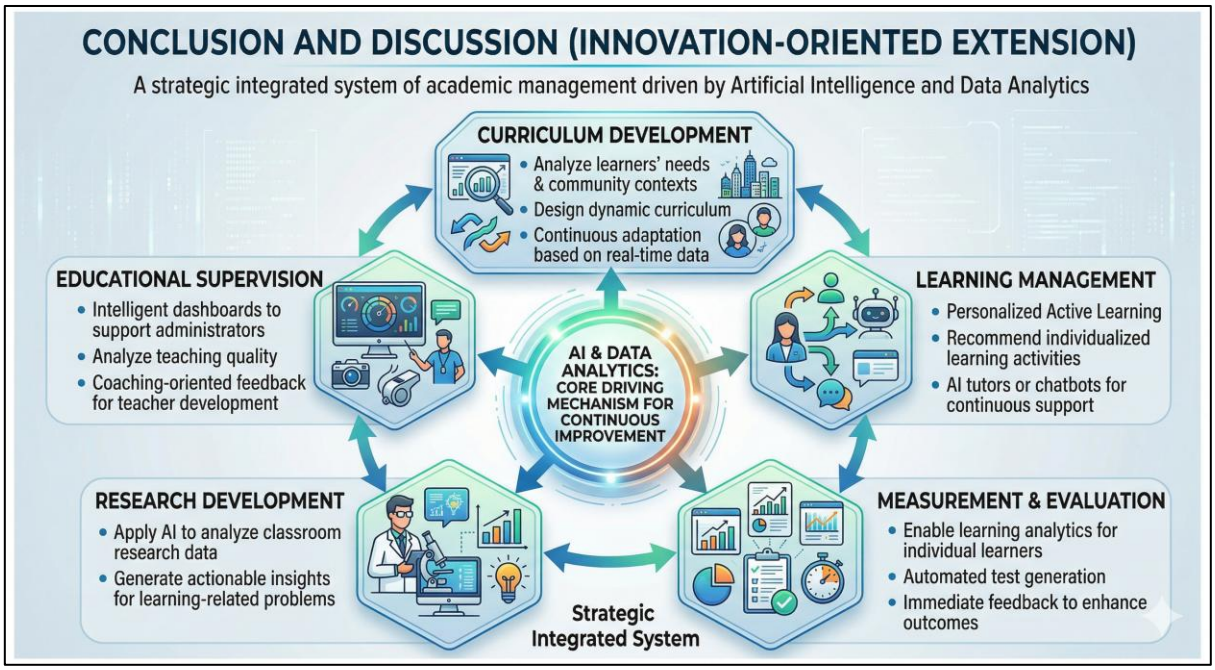

Figure 2 Innovation-Oriented Extension: An AI-Driven Academic Management System

However, some scholars argue that an overemphasis on data-driven approaches may oversimplify the complexity of education and neglect its humanistic dimensions (Biesta, 2010, pp. 18–25; Selwyn, 2019, pp. 47–52). In addition, although PLC and coaching are identified as key mechanisms, their effectiveness depends heavily on organizational culture and leadership capacity, and may not be fully realized without strong structural support (Hargreaves & Fullan, 2012, pp. 3–7; Robinson, 2011, pp. 89–95).

7. Suggestions

7.1 Recommendations Derived from the Study

7.1.1 Educational institutions should implement academic management based on data-driven decision-making, integrated with the PDCA cycle and Professional Learning Communities (PLC) to ensure systematic and continuous improvement.

7.1.2 Schools should promote active learning approaches and enhance teacher professional development through classroom action research and coaching-based supervision.

7.1.3 Assessment systems should be developed to support learning improvement by utilizing technology for data analysis and enabling personalized learning management.

7.2. Recommendations for Future Research

7.2.1 Future studies should focus on research and development (R&D) to design and implement academic management models in the digital era, in order to examine their effectiveness in real-world contexts.

7.2.2 Further research should be extended to schools with diverse contexts to enable comparative analysis and enhance the generalizability of findings.

7.2.3 Future studies should investigate the role of digital leadership and the application of artificial intelligence in academic management.

8. Acknowledgements

The researcher would like to express profound gratitude to the executives of the Chachoengsao Primary Educational Service Area Office 1 for their continuous support and guidance throughout this study. Special thanks are extended to the five esteemed experts who dedicated their time and valuable insights to validate the research instruments.

Furthermore, the researcher is deeply indebted to the school administrators and heads of academic affairs from Anuban Watpitulathirachrangsarit School, Wat Donthong School, and Ban Bang Kaeo School. Their willingness to participate in the interviews and share their profound practical experiences provided invaluable data that significantly contributed to the completion and success of this research.

9. References

Biesta, G. (2010). *Good education in an age of measurement: Ethics, politics, democracy*. Boulder, CO: Paradigm Publishers.

Black, P., & Wiliam, D. (2018). Assessment and classroom learning. *Assessment in Education, 5*(1), 7–74. https://www.tandfonline.com/doi/pdf/10.1080/0969595980050102

Bonwell, C. C., & Eison, J. A. (2021). *Active learning: Creating excitement in the classroom*. ASHE-ERIC Higher Education Report. https://files.eric.ed.gov/fulltext/ED336049.pdf

Chachoengsao Primary Educational Service Area Office 1. (2025). *Annual action plan for fiscal year B.E. 2568 (2025)*. Chachoengsao.

Phothisita, C. (2019). *Science and art of qualitative research* (8th ed.). Bangkok: Amarin Printing and Publishing.

Darling-Hammond, L. (2022). *Effective teacher professional development*. Learning Policy Institute.

Fullan, M. (2021). *The new meaning of educational change*. Teachers College Press.

Gulikers, J. T. M., Bastiaens, T. J., & Kirschner, P. A. (2022). A five-dimensional framework for authentic assessment. *Educational Technology Research and Development, 52*(3), 67–86. https://link.springer.com/article/10.1007/BF02504676

Hallinger, P. (2020). Instructional leadership and school improvement. *Educational Management Administration & Leadership, 48*(4), 563–589. https://doi.org/10.1177/1741143220935436

Hargreaves, A., & Fullan, M. (2012). *Professional capital: Transforming teaching in every school*. New York, NY: Teachers College Press.

Kemmis, S., & McTaggart, R. (2018). *The action research planner*. Springer. https://link.springer.com/book/10.1007/978-981-10-1645-5

Kraft, M. A., Blazar, D., & Hogan, D. (2018). The effect of teacher coaching on instruction and achievement: A meta-analysis of the causal evidence. *Review of Educational Research, 88*(4), 547–588. https://journals.sagepub.com/doi/full/10.3102/0034654318759268

Leithwood, K., Seashore Louis, K., Anderson, S., & Wahlstrom, K. (2020). *How leadership influences student learning*. The Wallace Foundation.

Ministry of Education. (2023). *National education development plan B.E. 2566–2570 (2023–2027)*. Bangkok: Office of the Education Council.

Napatsakorn Chaiprom. (2022). *Academic administration of Wat Benchamabophit Secondary School* (Master's thesis, Sukhothai Thammathirat Open University).

OECD. (2023). *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing. https://doi.org/10.1787/c74f03de-en

Office of the Basic Education Commission. (2018). *School administrator's operational manual*. Bangkok.

Pimphan Dechakup. (2021). *Competency-based learning*. Bangkok: Chulalongkorn University Press.

Robinson, V. (2017). *Student-centered leadership*. Jossey-Bass.

Selwyn, N. (2019). *Should robots replace teachers? AI and the future of education*. Cambridge, UK: Polity Press.

Sukanya Chamchoy. (2019). *Academic administration for enhancing student quality*. Bangkok: Chulalongkorn University Press.

Tyler, R. W. (2021). *Basic principles of curriculum and instruction*. University of Chicago Press. https://archive.org/details/basicprincipleso0000tyle

Wichai Wongyai. (2020). *Competency-based curriculum*. Bangkok: Textbook Center.

Zhang, X., et al. (2023). Facilitating teacher learning in professional learning communities through action research: A qualitative case study in China. *Teaching and Teacher Education, 119*, 103875. https://www.sciencedirect.com/science/article/pii/S0742051X22002505

A STUDY OF NEEDS FOR STRATEGIC DIGITAL LEADERSHIP DEVELOPMENT IN THE AI ERA UNDER THE SECONDARY EDUCATIONAL SERVICE AREA OFFICE CHONBURI RAYONG

Jakkarin Jamsai

jamsai.jakkarin@gmail.com

The Secondary Educational Service Area Office Chonburi Rayong,
Office of the Basic Education Commission,
Chonburi 20000 Thailand

*Corresponding Author E-mail: jamsai.jakkarin@gmail.com

ABSTRACT

This study aimed to explore the developmental needs of school administrators regarding strategic digital leadership in the era of artificial intelligence (AI) under the Chonburi-Rayong Secondary Educational Service Area Office. The Informants consisted of five school directors serving as chairpersons of school networks, selected through purposive sampling. A qualitative research methodology was employed using in-depth interviews to collect data.

Findings revealed five key areas of need: (1) formulating a clear digital vision by integrating AI, big data, and digital technologies to align with regional development, (2) managing digital and AI innovations, including change management, organizational culture, staff engagement, and technological risk, (3) supporting digital learning for teachers and students through AI integration, professional learning communities, and future skills development, (4) developing competencies in AI policy and governance to ensure ethical and effective use in schools, and (5) implementing data-driven leadership to monitor, evaluate, and inform strategic decision-making.

Keywords: Strategic digital leadership, Artificial Intelligence (AI), School administration

1. Statement of the Problem

In the contemporary context of the global digital era, advanced technologies particularly Artificial Intelligence (AI) have played a pivotal role in national development across all dimensions, including the economy, society, and education. International organizations, such as UNESCO, have emphasized that integrating AI into educational systems necessitates appropriate governance and policy measures. These should be grounded in a human-centered approach to ensure that technology is utilized ethically, safely, and equitably (UNESCO, 2023, p. 18). Concurrently, the OECD highlights that national digital education strategies aim to enhance learners' digital skills and bridge the digital divide. However, some forward-looking nations have set more ambitious targets: systematically integrating digital technology into pedagogy and school management, employing data analytics to enhance learning outcomes, and supporting teachers in designing efficient learning systems that cater to individual student needs (OECD, 2023, p. 361). In this digital age, Information and Communication Technology (ICT) has become indispensable to educational management, encompassing instruction, communication, and institutional data administration. Such advancements compel educational institutions to adapt and promote technology usage to elevate learning quality in alignment with 21st-century skills (Demuyakor et al., 2024, p. 2).

Thailand has established a clear national development framework through the 20-Year National Strategy (2018–2037), which aims for security, prosperity, and sustainability by prioritizing human capital development. The strategy identifies human resources as a critical factor in advancing the country across all sectors, aiming to equip Thais with essential 21st-century skills and fostering lifelong learning to withstand rapid socio-economic and technological shifts (Office of the National Strategy Secretariat, 2018, pp. 30–31). This is complemented by the National Scheme of Education, which sets goals for developing citizens with the knowledge, attributes, and learning skills necessary for the 21st century (Office of the Education Council, 2017, p. 79). Furthermore, Thailand emphasizes the application of AI to drive national progress, aiming to create an integrated AI ecosystem that enhances the economy and long-term quality of life (Digital Economy Promotion Agency, 2024, pp. 15–17).

Digital leadership has emerged as a crucial concept in educational administration during this period of technological transition. Leaders must redefine their roles to effectively leverage digital technology and information systems to enhance learning and school management. This aligns with the notion that technological and digital shifts require educational systems to prepare learners for the Fourth Industrial Revolution, emphasizing data-driven decision-making and innovation to improve educational quality (Sheninger, 2019, pp. 2–3). This perspective is consistent with Bass & Riggio (2006, pp. 1–2) transformational leadership theory, which posits that leadership is a vital determinant of organizational success. Amidst rapid environmental changes, organizations require leaders who can inspire change and adapt to new contexts. Transformational leadership serves as a foundation for digital leadership by stimulating inspiration and developing personnel potential. Similarly, Pholmun and Kanjanapun (2023, p. 136) conclude that rapid technological innovation increases the complexity and uncertainty of school management. Consequently, school administrators must act as key drivers of change, adopting new mindsets, embracing innovation, and utilizing technology to achieve organizational goals efficiently.

The Secondary Educational Service Area Office Chonburi Rayong has defined its vision to become a "Quality Organization, Elevating Education in the Eastern Economic Corridor (EEC) toward Excellence and Cultivating Happy, Virtuous Citizens." Its mission includes supporting schools in the EEC to achieve educational excellence by integrating digital technology to ensure students are digitally literate, capable of career planning, and able to thrive in modern society. However, current observations reveal that despite the growth of this special economic zone, some administrators remain tethered to traditional management styles that do not align with the digital era. Specifically, there is a lack of promotion for digital media, innovation, and advanced measurement and evaluation processes (Secondary Educational Service Area Office Chonburi Rayong, 2025, p. 10).

Previous research by Phonman and Kanchanaphan (2024, p. 131) on innovative leadership among school administrators in this jurisdiction found that such leadership was overall at a high level. This is supported by Singphu et al. (2023, p. 32), who found that technological leadership significantly influences the efficiency of academic administration in extra-large secondary schools within the same area. Given their location in the EEC, administrators in the Chonburi-Rayong area face an urgent need to develop strategic digital leadership to keep pace with educational and economic shifts. Administrators must possess a forward-looking vision, utilize digital data for precise strategic planning, leverage social media for organizational branding, and lead the adoption of quality educational innovations to transform organizational culture into a digital learning society. These factors are essential for enhancing teacher competency and student skills to meet the sustainable development goals of the EEC.

Despite the increasing attention given to digital leadership in education, most existing studies have primarily focused on general digital competencies and leadership characteristics. There remains a limitation in examining the concrete integration of artificial intelligence (AI) into strategic leadership practices. Much of the existing research addresses digital leadership within broad contexts, leaving a gap regarding the specific demands placed on administrators in rapidly developing zones like Thailand's Eastern Economic Corridor (EEC).

Consequently, the researcher was interested in investigating the needs for developing strategic digital leadership in the era of artificial intelligence within the Secondary Educational Service Area Offices of Chonburi and Rayong. This study aimed to examine the needs for developing strategic digital leadership among school administrators. The findings served as a foundational database for formulating a developmental model to enhance digital competencies, drive educational organizations toward excellence, and align with the future development context of the Eastern Economic Corridor (EEC).

2. Objectives

This study aimed to investigate the needs for developing strategic digital leadership in the era of artificial intelligence among administrators under the Secondary Educational Service Area Offices of Chonburi and Rayong.

3. Conceptual Framework and Hypothesis

The researcher studied strategic digital leadership in the era of artificial intelligence in school administration based on the works of the following scholars and researchers: Office of the Basic Education Commission (OBEC, 2023, pp. 15–22), Sukanya Chaemchoi (2019b, pp. 167–175), Wiroj Sararatna (2018, pp. 45–52) , Charinee Triwaranyu (2022, pp. 88–94) ,Zeng, Cheah, & Abdullah (2025, pp. 112–115) , Sheninger (2019, pp. 34–36) , Pietsch & Mah (2024, pp. 6–10) , Pongsak Pakamach (2023, pp. 45–50) , Bulsathaporn Kannika (2025, pp. 366) ,Phra Maha Apipong Khamhonsa (2025, pp. 14) ,Siemens (2013, pp. 1382–1387) ,Anannawee & Prawatrungruang (2023, pp. 87–92). Based on a synthesis of both Thai and international studies, the researcher established criteria for variable synthesis by selecting only variables with a frequency of 50 percent or higher to develop new variables for the study. The strategic digital leadership in the era of artificial intelligence among administrators under the Secondary Educational Service Area Offices of Chonburi and Rayong can be described in the following five dimensions:

1. Digital vision setting serves as the fundamental driving mechanism that determines the direction and priorities of digital transformation within educational institutions.
2. Innovation management functions as a mechanism for translating strategic goals into concrete practices, particularly through the application and adaptation of artificial intelligence technologies in alignment with the school context.
3. Promotion of digital learning is supported by innovation management, enabling the development of teacher competencies, the establishment of professional learning communities, and the integration of digital technologies into instructional practices.
4. Application of AI in learning management acts as a key operational component, supporting personalized learning, intelligent content delivery, and the use of data to enhance instructional strategies.
5. Digital monitoring and evaluation serves as a feedback mechanism, utilizing data and AI-driven analytics to assess performance, support decision-making, and continuously improve both strategic directions and implementation practices.

From the detail above can create the conceptual framework as the figure 1:

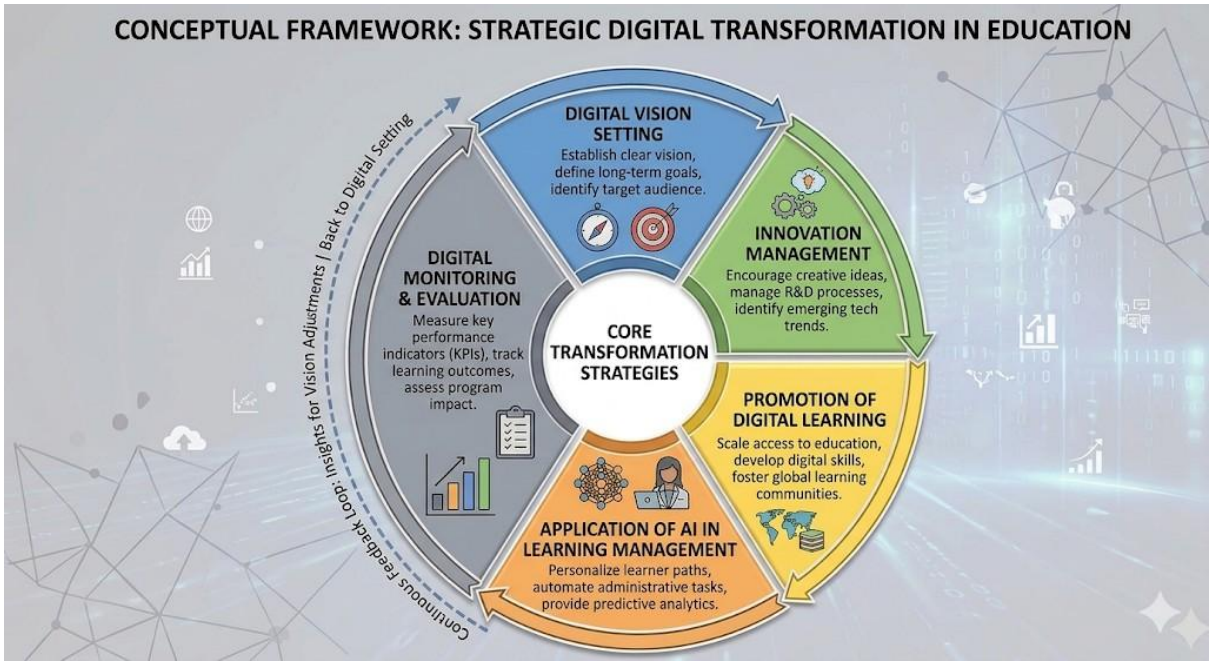

Figure 1 The Conceptual Framework of Strategic Digital Transformation in Education

4. Research Methodology

4.1 Research Design

This study adopted a qualitative research approach, employing in-depth interviews to investigate the developmental needs of school administrators in relation to strategic digital leadership within the context of the artificial intelligence (AI) era. The qualitative design was chosen to capture rich, detailed insights and to explore complex phenomena associated with digital leadership practices and competencies.

4.2 Population and Sample

The Secondary Educational Service Area Offices of Chonburi Rayong had a total of 51 schools, which were administratively organized into five school clusters: Chonburi Cluster 1, Chonburi Cluster 2, Chonburi Cluster 3, Rayong Cluster 1, and Rayong Cluster 2. Each cluster was led by a chairperson who served as the representative of the schools within that network.

Accordingly, the study involved five school principals who served as chairpersons of these school clusters. They were selected through purposive sampling based on their leadership roles and extensive experience in school administration, innovation management, and AI-related educational practices. Importantly, each chairperson functioned as a representative of a specific group of schools, reflecting shared contexts, challenges, and management practices within their respective clusters. This approach ensured that the informants were information-rich and capable of providing in-depth and meaningful insights relevant to the research objectives.

4.3 Research Procedures

The researcher was conducted the research interview as below:

4.3.1 Literature Review

The researcher conducted a comprehensive review of both national and international literature to develop an in-depth understanding of concepts, theories, and frameworks related to strategic digital leadership in the era of artificial intelligence (AI).

4.3.2 Development of the Research Framework

Based on the literature review, a conceptual framework for strategic digital leadership in school administration was developed. The framework consisted of five key dimensions: digital vision setting, innovation management, promotion of digital learning, application of artificial intelligence in learning management, and digital-based monitoring and evaluation.

4.3.3 Research Instrument Development

A semi-structured interview protocol was designed to cover all five dimensions, ensuring alignment with the research objectives and the established conceptual framework.

4.3.4 Instrument Validation and Pilot Testing

The semi-structured interview protocol was reviewed by five experts to assess its content validity. The Index of Item-Objective Congruence (IOC) ranged from 0.66 to 1.00. The instrument was revised based on expert feedback to improve clarity, appropriateness, and comprehensiveness.

A pilot test was conducted with three individuals who were not part of the study sample to evaluate the suitability and effectiveness of the interview protocol. Minor revisions were made prior to actual implementation.

4.3.5 Structure of the Final Interview Protocol

The finalized semi-structured interview consisted of three parts:

Part 1: General information of the informants and the interviewer

Part 2: Questions regarding the developmental needs of school administrators in strategic digital leadership in the AI era, covering five dimensions:

Knowledge, skills, and approaches for establishing a digital vision aligned with digital transformation and AI integration.

Roles and competencies required for managing digital innovation and AI within educational institutions.

Capacity to promote digital learning among teachers and students, including the integration of AI in learning management.

Knowledge and skills in formulating policies and supporting the implementation of AI in educational management.

Competencies in utilizing digital technologies and AI for monitoring, evaluation, and data-driven decision-making.

Part 3: Additional comments and suggestions from informants regarding their developmental needs

4.3.6 Data Collection and Trustworthiness

Data were collected through semi-structured, in-depth interviews conducted individually with key informants. Prior to the interviews, appointments were arranged, and the research objectives were clearly explained. Informed consent was obtained, including permission for audio recording. During the interviews, the researcher followed a set of guiding questions while also taking field notes to capture additional contextual information.

All interviews were transcribed verbatim to ensure accuracy. The data were then analyzed using content analysis. The researcher repeatedly reviewed the transcripts to gain familiarity with the data, followed by coding, categorization, and thematic synthesis based on the research framework.

To ensure the trustworthiness of the study, the following strategies were employed:

1) Credibility: Member checking was conducted by returning the transcribed data and interpretations to the informants for verification.

2) Dependability: An audit trail was maintained to systematically document the research procedures, allowing for transparency and replicability.

3) Confirmability: Reflective notes were used to minimize researcher bias, and peer debriefing with experts or colleagues was conducted to validate the data analysis process.

4) Transferability: Thick description of the research context and Informant was provided to enable readers to assess the applicability of the findings to other settings.

5) Triangulation: Data from multiple informants were compared and cross-checked with the research framework to enhance the consistency and credibility of the findings.

4.4 Data Collection

Data were collected through in-depth interviews with the five selected school principals serving as chairpersons of school networks under the Secondary Educational Service Area Offices of Chonburi Rayong. The interviews were conducted between February 18 and 27, 2026, using both face-to-face and online formats via Microsoft Teams (Meeting link: https://teams.live.com/meet/9375224424913?p=MDhua7y3m7QSmu5EdD).

Prior to data collection, the researcher obtained formal permission from the relevant Secondary Educational Service Area Offices and informed consent from all informants. The interview schedule and consent forms were provided to the informants in advance. Each interview lasted approximately one hour and was audio-recorded, with supplementary notes taken to ensure accuracy. The informants were given the opportunity to review and confirm the transcripts for validation purposes.

4.5 Data Analysis

Data analysis followed a systematic qualitative approach using content analysis, as outlined below:

4.5.1 Transcription: All interviews were transcribed verbatim to ensure the accuracy of informants' responses.

4.5.2 Content Analysis: The transcribed data were categorized, coded, and thematically analyzed to identify key patterns, concepts, and insights related to the developmental needs in strategic digital leadership.

4.5.3 Credibility Verification: Cross-verification was conducted across responses from multiple informants to enhance the reliability and trustworthiness of the findings.

Following content analysis, the research findings were synthesized and compiled into a comprehensive report for presentation. The results provide in-depth insights into the specific areas of professional development required for strategic digital leadership in the AI era.

5. Results

The study findings were derived from in-depth interviews with five school principals who served as chairpersons of school networks under the Secondary Educational Service Area Offices of Chonburi and Rayong. The results revealed the developmental needs of school administrators regarding strategic digital leadership in the AI era, which were organized into five key dimensions.

Importantly, the findings also reflected how these leadership practices were enacted in real-life educational settings. For instance, school administrators demonstrated the application of digital vision through the integration of AI-supported learning platforms in classrooms, the promotion of digital learning through teacher professional development and collaborative learning communities, and the use of data-driven decision-making in monitoring student progress and instructional outcomes.

5.1 Development Needs in Digital Vision Setting

1. Contextual Analysis for Digital Vision Development

The analysis indicated that administrators required systematic skills to analyze school contexts, integrating information on students, teachers, community, infrastructure, and regional development trends in the Eastern Economic Corridor (EEC). This competency was essential for formulating a clear digital vision aligned with AI integration across both management and instructional dimensions.

2. AI and Big Data Skills for Strategic Planning

Administrators continuously sought to strengthen their capabilities in applying AI and

Big Data analytics, recognizing these tools as crucial for accurately forecasting educational trends and evaluating strategic initiatives. These skills were viewed as critical to evidence-based decision-making and improving the efficiency of traditional administrative processes.

3. Intelligent Management Approaches

Administrators emphasized the importance of adopting "smart management" strategies to reduce administrative workload, enabling teachers to focus on student learning, particularly in coding and programming, thus supporting the development of logical thinking and AI application skills among students.

4. Translating Vision into Practice

Informants reported the need for enhanced competencies in translating digital vision into operational strategies, performance indicators, and actionable plans. Administrators also highlighted the importance of concrete KPIs from central authorities to ensure alignment with organizational objectives and regional development in the EEC.

5.2 Development Needs in Innovation Management

1. Systematic Digital Innovation Management

Interviewees expressed a need to systematically manage digital innovations, including the ability to search for, select, and adapt best practices using AI. Such skills were deemed necessary to move beyond traditional administrative models and to optimize strategic decision-making and project oversight.

2. Change Management and Innovative Leadership

Findings indicated a desire among administrators to strengthen their change management and leadership competencies, including motivating staff, recognizing achievements, and fostering an organizational culture conducive to digital innovation.

3. Facilitating Participation and Professional Learning Communities

The data showed administrators wanted to shift from directive roles to facilitative ones, promoting safe, open environments that encourage experimentation and the formation of professional learning communities (PLCs) focused on digital innovation.

4. Capacity Building and Knowledge Management in AI

Administrators highlighted the need to support continuous teacher professional development in AI application and coding, through peer mentoring, external expert workshops, and systematic digital resource management, ensuring sustained organizational learning.

5. Resource Allocation and Innovation Ecosystem Development

Informants emphasized the necessity of aligning resources—budget, personnel, and time—with digital vision priorities, investing in AI infrastructure, creating safe innovation spaces, and establishing partnerships with universities and industry.

6. Risk Management and Sustainable Value Assessment

Interviews reflected a focus on developing competencies in technology risk management, pilot project implementation, data privacy compliance, and evaluating quality outcomes to ensure digital innovation initiatives are secure, cost-effective, and sustainable.

5.3 Development Needs in Promoting Digital Learning

1. AI-Enhanced Assessment

Administrators highlighted the need to develop AI-based assessment tools capable of measuring individual student competencies, supporting formative, personalized, and adaptive learning approaches rather than comparative evaluation methods.

2. AI Literacy for Learning System Design

The findings revealed that administrators required a deeper understanding of AI literacy

to guide, supervise, and design AI-integrated learning systems, both at the classroom and policy levels.

3. Teacher Capacity Building in Digital and AI-Based Learning

Data indicated that administrators sought to enhance teachers' roles as "learning coaches," facilitating proactive learning experiences and fostering critical thinking and problem-solving through AI integration, supported by professional learning communities and upskilling initiatives.

4. Developing 21st Century Skills in Students

Administrators emphasized promoting computational thinking and programming skills among students, connecting learning with industry experiences to prepare learners for future challenges.

5. Designing Digital Learning Environments and Platforms

Informants reported the need to develop flexible digital learning environments, integrating infrastructure, technology, and learning management systems (LMS) to support a Smart Campus approach.

6. Equity, Responsibility, and Digital Citizenship

The study revealed a strong need to utilize AI and digital technologies to ensure equitable learning opportunities, foster ethical use of AI, and cultivate responsible digital citizenship among students.

5.4 Development Needs in Policy Formulation and AI Integration

1. Systematic AI Policy Development

Administrators expressed the need to develop comprehensive AI policies covering academic, administrative, and governance dimensions to ensure clarity, transparency, and practical application in classrooms.

2. Supporting Teacher Professional Development via AI

Findings indicated that administrators sought to support teachers' AI use within PLCs to analyze learning challenges, access emerging research, and continuously improve instructional practices.

3. Facilitating Personalized Learning through AI

Interview data suggested administrators aimed to enable AI-supported personalized learning, automating administrative tasks and maximizing teachers' ability to coach students effectively.

4. Data-Driven Management and AI for Decision-Making

Administrators emphasized the importance of using AI for data-driven decision-making, analyzing individual and group learning behaviors to inform curriculum design and teaching strategies.

5. Ethical and Legal Compliance in AI Usage

Informants highlighted the need to develop knowledge of digital ethics, data privacy, and regulatory compliance to prevent algorithmic bias and ensure AI supports rather than replaces human decision-making.

6. Creating a Responsible AI Culture

The study found administrators desired to foster participatory mechanisms involving teachers, students, and parents, promoting responsible, ethical AI use while balancing technological integration with human values.

5.5 Development Needs in Digital Monitoring and Evaluation

1. Data-Driven Leadership

Administrators expressed a need to enhance data-driven leadership, using AI to monitor, evaluate, and make timely, transparent strategic decisions.

2. AI for Monitoring, Evaluation, and Quality Assurance

Interview findings indicated the need for AI skills to process operational data, performance indicators, and project outcomes, enabling evidence-based decisions and continuous quality improvement.

3. Integrated Information Systems

Informants highlighted the desire for a centralized platform that integrates plans, budgets, personnel, and student data, replacing fragmented systems and improving organizational efficiency.

4. AI-Enhanced LMS and Executive Dashboards

The data suggested a need for AI-integrated LMS and dashboards to track individual competencies, learning patterns, and provide real-time feedback for organizational decision-making.

5. Data Analysis and Interpretation Skills

Administrators reported the need to develop data analysis and interpretation skills, using AI to predict trends, identify risks, and implement targeted interventions for evidence-based management.

6. Continuous Improvement through Data Integration

The study revealed that administrators sought to integrate AI-driven data insights into the PDCA cycle, creating a culture of "using data for development" to enhance systematic improvement at policy and classroom levels.

The findings of this study can be systematically categorized into two major components: driving factors and outcomes, reflecting a causal relationship in which strategic inputs and enabling conditions lead to observable transformations in educational practices and organizational performance.

1. Driving Factors

The driving factors represent foundational elements that shape strategic direction, enable implementation, and facilitate digital transformation in educational management.

1.1 Digital Vision Setting

Informants highlighted that administrators required competencies in analyzing school contexts, including learners, teachers, community, and regional development trends. This was followed by the ability to apply AI and Big Data for strategic planning and forecasting. Administrators also emphasized the adoption of intelligent management approaches to enhance efficiency and reduce administrative workload. Finally, the ability to translate digital vision into actionable strategies, performance indicators, and implementation plans was identified as a critical component.

1.2 Innovation Management

The results revealed that administrators needed systematic approaches to managing digital innovation, including identifying and adapting best practices through AI. This was supported by competencies in change management and innovative leadership, particularly in fostering an organizational culture conducive to innovation. Facilitating participation through Professional Learning Communities (PLCs) was also highlighted as essential. In addition, capacity building in AI and knowledge management, strategic resource allocation, and the development of an innovation ecosystem were identified as key factors. Risk management and the evaluation of sustainability and value were also emphasized to ensure long-term effectiveness.

1.3 Policy Formulation and AI Integration

The findings showed that administrators required the development of systematic AI policies that align with academic, administrative, and governance dimensions. Supporting teacher professional development through AI within PLCs was identified as a key mechanism for improving instructional practices. The ability to facilitate personalized learning through AI was also highlighted. Furthermore, data-driven management and AI-supported decision-making were considered essential competencies. Ethical and legal compliance in AI usage, along with the creation of a responsible AI culture involving stakeholders, were identified as critical factors for sustainable implementation.

2. Outcomes

The outcomes reflect the transformation resulting from the driving factors, particularly in teaching, learning, and organizational management.

2.1 Digital Learning Development

Interview data showed that the integration of AI contributed to the development of advanced assessment practices, including AI-enhanced and personalized assessment systems. Administrators also emphasized the importance of AI literacy for designing effective learning systems. Teacher capacity development shifted toward roles as facilitators or learning coaches, supporting student-centered learning. This transformation led to the development of 21st-century skills among students, particularly in computational thinking and problem-solving. In addition, the design of flexible digital learning environments and platforms supported the implementation of Smart Campus concepts. The promotion of equity, ethical responsibility, and digital citizenship was also identified as a key outcome.

2.2 Digital Monitoring and Evaluation

Most administrators emphasized that data-driven leadership emerged as a key outcome, enabling administrators to make informed and timely decisions. The use of AI in monitoring, evaluation, and quality assurance supported evidence-based management. Integrated information systems were developed to enhance organizational efficiency and reduce fragmentation. AI-enhanced learning management systems (LMS) and executive dashboards enabled real-time tracking of performance and learning outcomes. Administrators also developed competencies in data analysis and interpretation, allowing for predictive insights and targeted interventions. Ultimately, the integration of data into continuous improvement processes, particularly through the PDCA cycle, contributed to sustainable organizational development.

Ultimately, clear vision, effective innovation management, and robust policies serve as the foundational drivers for digital transformation. When these elements are in place, schools experience tangible improvements in both student learning processes and data-driven management practices. As shown in figure 2:

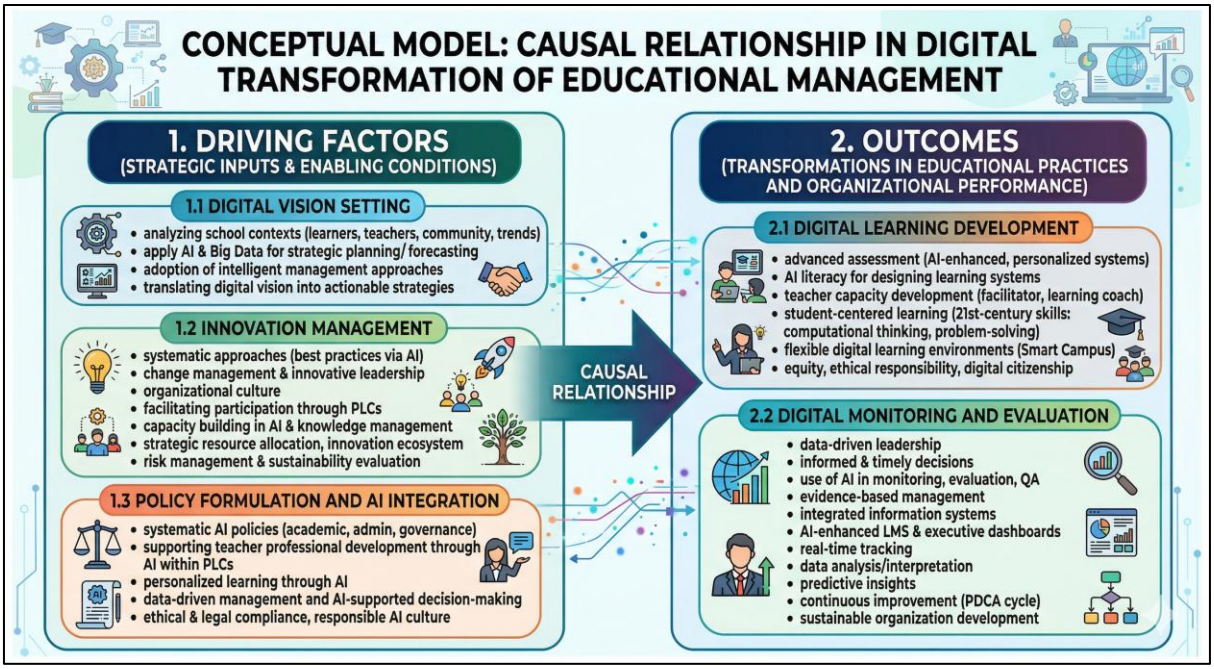

Figure 2 Conceptual Model: Causal Relationship in Digital Transformation of Educational Management

6. Conclusion and Discussion

1. Digital Vision Knowledge and Skills Development

Interview data showed that school administrators required the development of digital vision knowledge and skills, which could be interpreted as a response to the increasing uncertainty and complexity of the digital era. This suggested that administrators were expected to move beyond traditional management roles toward strategic and anticipatory leadership. The integration of artificial intelligence (AI) and Big Data into vision formulation reflected a shift from experience-based decision-making to data-informed and predictive leadership.

Building upon Sheninger's (2014, p. 1) emphasis on technological vision in digital leadership, the current findings rev Overall, the findings demonstrate that driving factors related to vision eal a broader scope. Specifically, effective digital vision in this context requires not only technology adoption but also direct alignment with macro-level policies like Thailand 4.0 and the EEC. This was aligned with Suksai, Suanpang, and Thangchitcharoenkhul (2021, p. 16), who highlighted visionary leadership as a key component in aligning educational institutions with the digital transformation context.

2. Digital Innovation and AI Management Competency Development

Most administrators emphasized that administrators needed competencies in managing digital innovation and AI systematically, which could be explained by the increasing demand for organizational adaptability in the digital age. The integration of AI in schools was not merely a technical issue but involved organizational change, cultural transformation, and human resource development.

This was consistent with Chaemchoi (2018, p. 120), who described technology leadership as the ability to apply technology for improving both learning and management. However, the present study further extended this perspective by indicating that AI management also required competencies in ethical considerations and technological risk management. This aligned with Prasanchip and Sriputtarin (2023, p. 104), who emphasized the importance of comprehensive

technology management skills. Therefore, digital innovation management in this context could be conceptualized as a socio-technical process rather than a purely technical function.

3. Development of Digital Learning Competency for Teachers and Students

The findings showed that administrators emphasized the development of digital learning competencies for both teachers and students. This could be interpreted as a response to the transition toward a knowledge-based and skills-oriented society, where learning was increasingly personalized and learner-centered. The integration of AI into learning processes functioned not only as a support tool but also as a transformative mechanism for enhancing instructional practices.

This finding was consistent with Kulchalee (2022), who highlighted the importance of teachers' ability to select appropriate technologies for learners. Moreover, the study extended this perspective by demonstrating that digital competency development was not solely an individual capability but required systemic support, including professional learning communities (PLC) and digital learning environments. This was aligned with Saengsawang and Piamphuechna (2024, p. 268), who emphasized the importance of collaborative technological environments in educational settings.

4. Policy and AI Utilization Competency Development

Most Informants emphasized that competencies in policy development and AI utilization, which reflected the critical role of governance in digital transformation. This could be explained by the increasing importance of ethical considerations, data governance, and systematic implementation of AI in education. Without clear policies, AI integration might remain fragmented and ineffective.

This finding was consistent with Luckin and Griffiths (2016, p. 24), who emphasized the importance of governance frameworks in supporting effective AI implementation. However, the present study extended this view by suggesting that policy competency at the school level was crucial for translating national policies into practice. This was aligned with Noiwong (2022, p. 66), who highlighted the role of policy management in enhancing learning in the digital era.

5. Data-Driven Leadership Development

The findings revealed that administrators needed to strengthen data-driven leadership, which could be interpreted as a paradigm shift from experience-based to evidence-based decision-making. The increasing availability of digital technologies and information systems enabled administrators to utilize data not only for monitoring and evaluation but also for strategic planning and continuous improvement.

This was consistent with Sinlarat (2017, pp. 213–215), who emphasized evidence-based management for effective administration. Similarly, Sirikorn (2024, pp. 114–115) highlighted the role of information systems in supporting educational quality improvement. However, the present study extended these perspectives by proposing that leadership in the AI era should evolve into "intelligent leadership," where human decision-making was enhanced by AI and advanced data analytics.

From the detail above can create the integrated model as the figure 3:

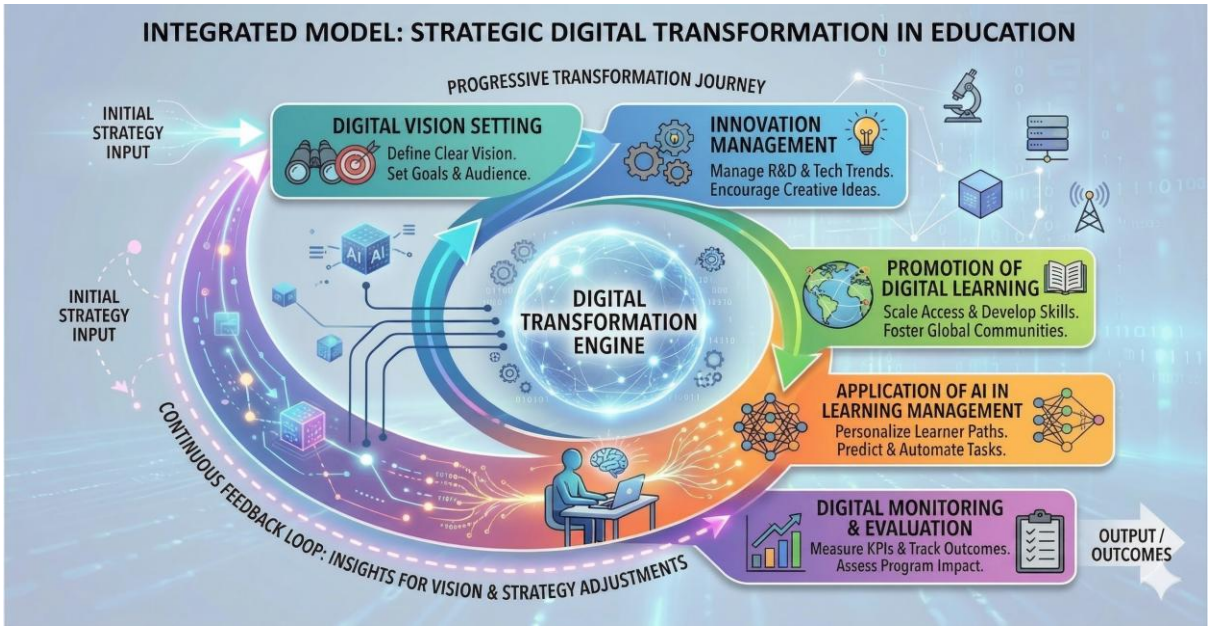

Figure 3 Integrated Model: Strategic Digital Transformation in Education

Overall, the findings reflected a transformation of educational administration in the digital era driven by AI and data. This perspective differed from traditional views that emphasized isolated managerial competencies. The study extended the concept toward a socio-technical system that integrates people, technology, and policy. It also highlighted the critical tension between human decision-making and AI-driven decision-making. Finally, it proposed a dynamic leadership model that continuously adapts to changing contexts and data-driven environments.

7. Suggestions

7.1 Suggestions for Practical Application

7.1.1 Educational authorities should use the findings of this study as guidelines to develop the capacity of school administrators, enhancing their competencies in digital vision, innovation management, and data-driven strategic decision-making.

7.1.2 Schools should apply digital technologies and AI to reduce administrative workload, support teaching and learning processes, and improve overall management efficiency.

7.1.3 Relevant agencies should support the development of digital infrastructure, integrated information systems, and teacher development in AI literacy to enhance the quality of education.

7.2 Suggestions for Improving the Implementation Process

7.2.1 Develop integrated information systems to support data-driven school management.

7.2.2 Promote the competencies of administrators and teachers in digital technology use, data analysis, and AI applications.

7.2.3 Establish clear governance guidelines for AI utilization in schools, ensuring alignment with digital ethics and relevant legislation.

8. Acknowledgements

The researcher would like to express sincere gratitude to Dr. Nisa Banjongkan, Director of the Secondary Educational Service Area Office Chonburi-Rayong, for her valuable support and facilitation throughout this study. The researcher also wishes to extend heartfelt appreciation to Dr. Daoprakai Nanthaporm for her guidance, encouragement, and invaluable support, which greatly contributed to the successful completion of this research.

9. References

Anannawee, A., & Prawatrungruang, P. (2023). Digital leadership of school administrators in the era of artificial intelligence. *Journal of Educational Administration Innovation, 9*(2), 80–100.

Bass, B. M., & Riggio, R. E. (2006). *Transformational leadership* (2nd ed.). Lawrence Erlbaum Associates.

Bulsataporn, K. (2025). Digital school management in the AI era: Decoding AI toward future skills. *Journal of Buddhist Education and Research, 11*(4).

Chaemchoi, S. (2018). *School management in the digital era.* Bangkok: Chulalongkorn University Press.

Chaemchoi, S. (2019). *Digital educational leadership.* Bangkok: Chulalongkorn University Press.

Demuyakor, J., Doe, V. A., Tachie-Djan, C., Bhatti, M. A., & Avenyo, S. J. (2024). Predicting university teachers' behaviour intentions toward digital technologies: An extension of the unified theory of acceptance and use of technology model (UTAUT). *Journal of Intelligent Communication, 3*(2).

Digital Economy Promotion Agency. (2024). *Thailand National AI Strategy Annual Report 2024.* Bangkok: Ministry of Digital Economy and Society.

Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education.* London: Pearson.

Noiwong, W. (2022). Learning management to promote students' critical thinking and problem-solving skills in the 21st century. *Journal of Research for Learning Reform, 5*(2), 54–69.

OECD (2023), OECD Digital Education Outlook 2023: Towards an Effective Digital Education Ecosystem, OECD Publishing, Paris, https://doi.org/10.1787/c74f03de-en.

Office of the Basic Education Commission. (2023). *Guidelines for developing school administrators in the digital era for 21st century learning.* Bangkok: Ministry of Education.

Office of the Education Council. (2017). *National Education Plan 2017–2036.* Bangkok: Ministry of Education.

Office of the National Strategy Committee. (2018). *National strategy 2018–2037.* Bangkok: Office of the National Economic and Social Development Council.

Pholmun, A., & Kanjanapun, R. (2023). Innovation leadership of school administrators under the Chonburi-Rayong Secondary Educational Service Area Office, Chonburi Province. *MCU Buddhist Studies Review.*

Pietsch, M., & Mah, D. K. (Phonman and Kanchanaphan 2024). Leading the AI transformation in schools: It starts with a digital mindset. Educational Technology Research and Development, 6–10.

Prasanchip, P., & Sriputtarin, S. (2023). Digital competencies of school administrators in the digital era under the Nakhon Phanom Secondary Educational Service Area Office. *Journal of Educational Administration and Innovation, 5*(2), 98–107.

Saengsawang, D., & Piamphuechna, N. (2024). Components of digital leadership of school administrators in special education centers in Northeastern Thailand. *Academic and Research Journal, Northeastern University, 14*(3), 258–273.

Sarratana, W. (2018). *School management in the 21st century: Theories, concepts, and case studies for school development.* Bangkok: Thippayavisut.

Sheninger, E. C. (2014). *Pillars of digital leadership.* International Center for Leadership in Education. Retrieved March 9, 2026, from https://pdf4pro.com/view/pillars-of-digital-leadership-58ce50.html

Sheninger, E. C. (2019). *Digital leadership: Changing paradigms for changing times* (2nd ed.). Corwin.

Siemens, G. (2013). Learning analytics: The emergence of a discipline. *American Behavioral Scientist, 57*(10), 1380–1400.

Singphu, T., Saengsawang, C., Prajongjit, S., & Buakhao, J. (2023). Technology leadership of school administrators affecting academic administration in large special secondary schools under the Secondary Educational Service Area Office, Chonburi-Rayong.

Sinlarat, P. (2017). Education 4.0: Philosophy of Education for Thailand's Future Bangkok: Chulalongkorn University Press.

Suksai, T., Suanpang, P., & Thangchitcharoenkhul, R. (2021). A digital leadership development model for school administrators in basic education to fulfill the Thailand 4.0 policy. *Asian Interdisciplinary and Sustainability Review, 10*(2), 11–20.

Triwaranyu, C. (2017). Developing teaching and learning processes to enhance pre-service teachers' innovative teaching abilities using collaborative lesson development combined with sufficiency economy philosophy-based thinking practices. *Journal of Education, Chulalongkorn University, 45*(2), 21–40.

Triwaranyu, C. (2022). Developing digital competencies and future skills for teachers and school administrators in a disruptive era. Bangkok: Faculty of Education, Chulalongkorn University.

UNESCO. (2023). *Guidance for generative AI in education and research.* Paris: UNESCO.

Chonburi-Rayong Secondary Educational Service Area Office. (2025). *Annual report 2025.* Policy and Planning Division, Chonburi-Rayong Secondary Educational Service Area Office.

Zeng, M., Cheah, J. H., & Abdullah, A. (2025). The role of artificial intelligence in enhancing educational management: Integrating UTAUT and leadership perspectives. *Journal of Educational Technology & Management, 12*(2), 105–128.

A STUDY OF SKILL COMPONENTS OF ADMINISTRATORS IN THE DISRUPTIVE ERA OF PRIVATE HIGHER EDUCATION IN THAILAND

Totsaporn Lertpichate*, Pariyaporn Tungkunanan, and Boonchan Sisan

totsabhorn@gmail.com, pariyaporn.tu@kmitl.ac.th, and boonchan.si@kmitl.ac.th

Department of Industrial Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang Bangkok 10520 Thailand

*Corresponding Author E-mail: Totsabhorn@gmail.com

ABSTRACT

In the disruptive era of the 21st century, higher education systems are undergoing rapid transformation driven by globalization, digital technologies, artificial intelligence, and increasing uncertainty. These changes have significantly challenged the roles and management practices of higher education institutions, particularly private institutions, which face intensified competition, declining enrollment, and evolving stakeholder expectations. Despite growing recognition of the importance of administrative competencies, existing studies remain fragmented and lack an integrated theoretical framework that systematically explains the multidimensional nature of administrative skills. This study aimed to classify and categorize the components of administrative skills in the disruptive era within the context of private higher education institutions in Thailand. A qualitative research design was employed, integrating documentary analysis and in-depth interviews with seven experts to ensure methodological triangulation. Research instruments included a checklist for validating 56 synthesized skill indicators and a semi-structured interview protocol for exploring their classification. Data were analyzed using content analysis and thematic analysis. The findings revealed that all 56 skill indicators were rated at a high level of appropriateness and could be systematically classified into five major skill clusters: personal skills, interpersonal skills, digital skills, organizational empowerment development skills, and strategic management skills. These clusters form an integrated and multidimensional framework, demonstrating that administrative competencies are interrelated and collectively contribute to effective leadership and organizational performance. Digital and strategic skills were identified as critical drivers of adaptability and organizational transformation.

The study concludes that administrative skills in the disruptive era constitute a coherent and integrated system rather than isolated competencies. This research contributes theoretically by addressing the fragmentation of prior studies and practically by providing a structured framework to support administrator development, policy formulation, and institutional management, thereby enhancing the adaptability and sustainable competitiveness of private higher education institutions in Thailand.

Keywords: Administrative skills, Disruptive era, Private higher education, Skill management, Leadership

1. Statement of the Problem

In the context of the 21st century, higher education systems worldwide are undergoing rapid transformations driven by globalization, advancements in digital technologies, artificial intelligence (AI), and increasing economic and social uncertainties. These forces have given rise to what is commonly referred to as the "Disruptive Era." Such transformations have exerted direct impacts on the roles, structures, and management practices of higher education institutions, particularly private higher education institutions, which are confronted with intensified competition, declining student enrollment, and evolving stakeholder expectations.

Under these circumstances, administrators in higher education institutions can no longer rely on traditional management approaches. Instead, they are required to develop "new skill sets" that enable flexible responses to change, including systems thinking, strategic management capabilities, technological proficiency, and innovation-driven competencies to enhance educational quality. The perspectives of Whetten (2016) and OECD (2017) emphasize that modern administrative skills must be integrative, encompassing personal, social, and organizational dimensions. Similarly, Sousa (2017), Thompson (2018), Dodgson (2019), and Balyer (2020) highlight the critical importance of innovation, adaptability, and transformational leadership skills in highly uncertain environments. However, while prior studies have acknowledged the importance of these competencies, the existing body of literature remains predominantly fragmented and lacks a clearly articulated theoretical structure that explains how diverse administrative skills are conceptually integrated within a unified framework. This indicates a critical conceptual limitation, as current approaches tend to examine administrative skills in isolation or within specific domains, without systematically synthesizing them into a multidimensional construct that reflects the complexity of administrative roles in the disruptive era. Moreover, although integrative perspectives have been suggested, there is still an absence of a comprehensive structural model that clearly categorizes and operationalizes administrative skill components in a manner that is both theoretically grounded and practically applicable. This limitation is particularly evident in the context of private higher education institutions in Thailand, which operate under unique administrative structures, resource constraints, and policy conditions distinct from public institutions. Consequently, the research gap extends beyond the lack of empirical classification of administrative skills to include the absence of a systematically developed and contextually relevant structural framework that can support both theoretical advancement and practical implementation. By addressing these conceptual and structural limitations, this study provides a more analytically grounded understanding of administrative competencies, thereby strengthening the theoretical foundation and supporting more effective administrative development practices.

Therefore, this research focuses on examining administrative skills in the disruptive era, classifying and categorizing their components, and developing a structural framework aligned with the context of private higher education institutions in Thailand. The findings are expected to contribute both theoretically and practically to advancing the adaptability and sustainable competitiveness of the higher education system.

2. Objectives

2.1 To classify and categorize the skill components of administrators in the disruptive era of private higher education institutions in Thailand.

3. Conceptual Framework

Conceptual Framework of Administrative Skills in the Disruptive Era of Private Higher Education Institutions in Thailand

The researcher employed a conceptual framework related to administrative skills in the disruptive era, derived from an extensive review of relevant literature, including the works of David A. Whetten (2016), OECD (2017), Maria José Sousa (2017), Sarah A. Thompson (2018), Mark Dodgson (2019), Aydin Balyer (2020), Pimolphan (2017), and Paradee (2022). Rather than treating these skills as isolated attributes, the present study conceptually positions administrative skills as an integrated and multidimensional construct, in which individual competencies are interrelated and collectively contribute to effective management in highly dynamic and uncertain environments. Drawing upon integrative perspectives from the reviewed literature, the identified skills are theoretically organized into a coherent structure that reflects the interaction between personal, interpersonal, technological, and strategic dimensions of administrative performance. This conceptual structuring enables the transformation of a broad set of individual skills into a systematically synthesized framework, thereby addressing the limitation of prior studies that primarily present fragmented or domain-specific skill classifications. Based on these sources, a total of 56 administrative skills were synthesized. These skills were systematically organized and prioritized to establish the conceptual framework for this study in the context of disruption, as follows: (1) communication speaking skills; (2) listening skills; (3) time management; (4) stress management; (5) decision-making; (6) creativity; (7) problem-solving; (8) use of innovative media for learning; (9) motivation; (10) delegation; (11) teamwork; (12) strategy formulation; (13) vision creation; (14) application of work techniques; (15) planning; (16) self-management; (17) team building; (18) conflict management; (19) information technology utilization; (20) learning; (21) coaching; (22) people management; (23) collaboration; (24) diagnostic skills; (25) recruitment; (26) work flexibility; (27) business planning; (28) marketing; (29) innovation; (30) project management; (31) administrative performance evaluation; (32) risk management; (33) resource management; (34) networking; (35) management of high-skilled personnel; (36) career development; (37) cross-cultural management; (38) development of new work models; (39) big data analytics; (40) holistic thinking; (41) organizational development; (42) strategic management; (43) knowledge management; (44) understanding others; (45) agility; (46) results orientation; (47) managerial expertise; (48) relationship building; (49) emotional management; (50) task prioritization; (51) adaptability; (52) inspirational leadership; (53) systems thinking; (54) experimentation; (55) regulatory enforcement; and (56) accountability.

Accordingly, this study conceptualizes administrative skills not merely as a list of competencies, but as a structured system of interrelated components, which provides the foundation for subsequent classification and empirical validation through a confirmatory factor analysis (CFA) approach.

4. Research Methodology

4.1 Research Design

The study entitled “A Study of Administrative Skill Components in the Disruptive Era of Private Higher Education Institutions in Thailand” employed a qualitative research approach, focusing on the systematic synthesis of knowledge and the classification of administrative skill components in the disruptive era. The integration of documentary analysis and in-depth interviews enabled methodological triangulation, enhancing the depth and robustness of the findings through the combination of theoretical evidence and expert perspectives.

4.2 Key Informants

The selection of seven experts was considered appropriate for qualitative inquiry, as it allows for in-depth, information-rich data while ensuring that each informant possesses substantial expertise relevant to the research objectives. Moreover, the diversity of roles among the informants contributed to a comprehensive understanding of administrative skills from multiple perspectives within higher education institutions.

4.3 Research Instruments

The research instruments developed by the researcher comprised two types:

4.3.1 a checklist, used to collect and validate the appropriateness of the 56 administrative skill variables synthesized from document analysis; and

4.3.2 an in-depth interview protocol, used to obtain qualitative insights into the grouping, classification, and justification of administrative skill components.

These instruments were designed to ensure consistency and rigor in data collection, supporting both the validation of variables and the in-depth exploration of expert perspectives.

4.4 Data Collection

Data were collected by the researcher through the following procedures:

(1) administering the checklist to experts to assess the appropriateness of the identified variables;

(2) conducting in-depth interviews to obtain qualitative data on the classification of skill components; and

(3) recording and verifying the accuracy of the data with the informants.

To ensure qualitative rigor, the study emphasized credibility through data verification with informants, dependability through systematic data collection procedures, and confirmability through the use of multiple data sources. In addition, ethical considerations were strictly observed, including obtaining informed consent from all participants, ensuring confidentiality of responses, and using the data solely for research purposes.

5. Results

Results of the Analysis of Administrative Skills in the Disruptive Era

In addition, quantitative results obtained from the checklist indicated that all 56 skill indicators were rated by the seven experts as appropriate at a high level, thereby providing empirical support for the inclusion of these variables in the subsequent classification process.

The process of classifying the 56 skill indicators was conducted systematically through the application of content analysis and thematic analysis. In the first stage, content analysis was used to code and group similar skill indicators into preliminary categories based on conceptual similarity. In the second stage, thematic analysis was employed to synthesize these categories into broader themes by identifying patterns, relationships, and functional roles of the skills. Subsequently, the researcher analyzed the data using content analysis and thematic analysis to systematically classify the skill components. The results indicated that the administrative skills could be grouped into five major skill clusters, as follows:

Table 1 Skill clusters

Skill Clusters	Skill Items
Personal Skill	Verbal Communication Skills, Listening Skills, Stress Management Skills, Creative Thinking Skills, Self-Management Skills, Lifelong Learning Skills, Adaptive Work Skills, Cross-Cultural Management Skills, Agility Skills, Emotional Intelligence Skills, Accountability Skills
Interpersonal skill	Motivation Skills, Conflict Management Skills, Networking Skills, Empathy Skills, Relationship-Building Skills Adaptability Skills, Inspirational Leadership Skills, Teamwork Skills, Team-Building Skills, Collaboration Skills
Digital Skill	Innovative Media Utilization for Learning Skills, Information Technology Utilization Skills, Innovation Skills, Big Data Analytics Skills
Develop Empowerment Skill	Managerial Expertise Skills, Delegation Skills, Coaching Skills, Recruitment Skills, High-Skilled Talent Management Skills, Task Prioritization Skills, Regulatory Enforcement Skills, People Management Skills, Administrative, Performance Evaluation Skills, Career Development Skills, Organizational Development Skills, Results-Oriented Skills
Strategic management skill	Time Management Skills, Strategy Formulation Skills, Vision Development Skills, Planning Skills, Business Planning Skills Marketing Skills, Project Management Skills, Risk, Management Skills, Resource Management Skills, Strategic Management Skills, Knowledge Management Skills, Decision-Making Skills, Problem-Solving Skills, Diagnostic Skills
Adaptability management skill	Technical Work Method Skills, Innovative Work Design Skills, Holistic Thinking Skills, Systems Thinking Skills, Experimental Skills

The emergence of these skill clusters reflects a logically organized and conceptually consistent structure, in which individual skills are grouped according to their functional roles and underlying competencies in administrative practice. The classification demonstrates that administrative skills in the disruptive era are not isolated competencies, but rather interconnected domains that collectively support effective leadership and organizational management. Specifically, personal and interpersonal skills form the foundational layer of administrative effectiveness, enabling communication, self-regulation, and collaboration, while digital and strategic management skills represent advanced capabilities required to address technological change and organizational complexity. Furthermore, the inclusion of organizational empowerment and adaptability-related skill clusters highlights the critical role of flexibility, innovation, and organizational development in responding to rapidly changing environments.

Research Summary

The findings consistently indicate that the identified components are aligned with the conceptual framework proposed in the study, thereby ensuring coherence between the theoretical structure and empirical results.

This structural classification provides a deeper understanding of how and why these components emerge, as they reflect the multidimensional nature of administrative roles in dynamic and uncertain environments.

Overall, the findings move beyond descriptive reporting by offering an analytical explanation of the interrelationships among skill domains, thereby strengthening the rigor and credibility of the study.

Furthermore, the findings provide practical implications for administrator development, policy formulation, and institutional management, as well as recommendations for future research directions in enhancing administrative competencies within higher education systems.

6. Discussion

6.1 Integrated Skill Framework

Beyond confirming prior perspectives, this finding refines existing frameworks by empirically demonstrating how administrative competencies can be structured into an integrated and hierarchical system, by Whetten (2016), and OECD (2017) thereby offering a more explicit conceptualization of multidimensional administrative capability in the disruptive era.

6.2 Significance of Digital Skills and Adaptability

However, the findings extend beyond simple alignment by indicating that digital competencies are not merely supportive skills, of Sousa (2017) and Dodgson (2019) but function as central mechanisms that enable organizational responsiveness and strategic transformation in uncertain environments.

6.3 Role of Organizational Empowerment Skills

This finding provides a more nuanced interpretation by highlighting the shift from control-oriented management toward empowerment-based leadership, Balyer (2020), thereby reinforcing the role of administrators as facilitators of organizational capability rather than merely decision-makers.

6.4 Importance of Strategic Capability

Importantly, the results suggest that strategic capability serves as a unifying dimension that integrates other skill domains, enabling administrators to align operational, Thompson (2018), technological, and human resource functions within a coherent strategic direction.

6.5 Linking the Thai Context with Global Perspectives

Furthermore, the findings offer deeper contextual implications by demonstrating how global competency frameworks are interpreted and operationalized within the specific constraints of Thai private higher education institutions, thereby highlighting the importance of contextual adaptation in competency development.

7. Conclusion

This study makes a clear theoretical contribution by advancing an integrated conceptual framework of administrative skills, in which competencies are systematically structured into five interrelated components, thereby addressing the limitation of fragmented approaches in prior research. In addition, the study contributes to practice by providing a structured and contextually relevant model that can be applied to administrator development, policy formulation, and institutional management within private higher education institutions in Thailand. The findings effectively summarize that administrative skills in the disruptive era constitute an integrated, multidimensional system encompassing personal, interpersonal, organizational, technological, and strategic dimensions. Overall, the study extends existing knowledge by offering both a

theoretically grounded and practically applicable framework, which enhances the understanding of administrative competencies and supports sustainable organizational development in dynamic and uncertain environments.

8. Suggestions

Based on the findings of the study entitled "A Study of Administrative Skill Components in the Disruptive Era of Private Higher Education Institutions in Thailand," which identified five core components of administrative skills—namely personal skills, interpersonal skills, digital skills, organizational empowerment development skills, and strategic management skills—the following recommendations are proposed:

8.1 Policy Implications

This framework should explicitly define competency indicators, assessment criteria, and performance benchmarks for each skill component to ensure clarity and consistency in implementation. Priority should be given to digital and strategic competencies, as these skills play a central role in enabling institutional adaptability in the disruptive era. Such a system should incorporate structured training pathways, periodic competency evaluation, and continuous feedback mechanisms to ensure long-term development effectiveness.

8.2 Practical Implications

Specifically, institutions should operationalize the model by developing competency-based assessment tools, such as structured evaluation forms and performance indicators aligned with each skill component. These programs should be prioritized based on institutional needs, with a particular focus on enhancing digital and strategic management skills as high-impact competencies. Clear implementation guidelines, including mentor selection, program structure, and evaluation criteria, should be established to ensure the effectiveness of these systems. These technologies should be systematically integrated into administrative processes to enable real-time data analysis and evidence-based decision-making.

8.3 Future Research Directions

8.3.1 Such studies should prioritize model validation and comparison across different institutional contexts to strengthen generalizability.

8.3.2 The instrument should include clearly defined indicators, validated scales, and standardized scoring criteria aligned with the five-component framework.

8.3.3 Comparative analysis should focus on identifying contextual differences in skill prioritization and structural variation across institutional settings.

8.3.4 Future studies should also incorporate measurable outcome indicators to establish causal or predictive relationships between administrative competencies and institutional effectiveness.

9. Acknowledgements

The author would like to express sincere and profound gratitude to Pariyaporn Tungkunana and Boonchan Sisan for their invaluable guidance and unwavering support throughout the entire research process. Their expertise, mentorship, and insightful feedback played a crucial role in shaping the direction and outcomes of this study. Their extensive academic knowledge greatly contributed to rigorous critical analysis, the refinement of research methodologies, and the provision of constructive recommendations, all of which significantly enhanced the quality and robustness of this research.

The author feels deeply honored and privileged to have been under their supervision and to have benefited from their invaluable experience. Their dedication, patience, and encouragement have profoundly influenced the author's academic journey and served as a continuous source of inspiration toward achieving academic excellence.

10. References

Altbach, P. G., Reisberg, L., & Rumbley, L. E. (2019). *Trends in global higher education: Tracking an academic revolution*. UNESCO.

Balyer, A. (2020). Transformational leadership behaviors of school principals: A qualitative research based on teachers' perceptions. *International Online Journal of Education and Teaching, 7*(1), 59–75.

Christensen, C. M., & Eyring, H. J. (2011). *The innovative university: Changing the DNA of higher education from the inside out*. Jossey-Bass.

Dodgson, M. (2019). *Innovation management: A research overview*. Routledge.

Fullan, M. (2020). *Leading in a culture of change* (2nd ed.). Jossey-Bass.

Marginson, S. (2016). *The dream is over: The crisis of Clark Kerr's California idea of higher education*. University of California Press.

Organisation for Economic Co-operation and Development. (2017). *OECD skills outlook 2017: Skills and global value chains*. OECD Publishing. https://doi.org/10.1787/9789264273351-en

Organisation for Economic Co-operation and Development. (2019). *OECD skills outlook 2019: Thriving in a digital world*. OECD Publishing. https://doi.org/10.1787/df80bc12-en

Paradee, C. (2022). *Educational leadership in the digital era* [in Thai]. Chulalongkorn University Press.

Pimolphan, P. (2017). *Educational administration in the 21st century* [in Thai]. Ramkhamhaeng University Press.

Sousa, M. J. (2017). Skills for disruptive innovation: Implications for higher education. *Journal of Business Research, 79*, 1–8.

Thompson, S. A. (2018). Strategic leadership in disruptive environments. *Journal of Leadership Studies, 12*(3), 96–102. https://doi.org/10.1002/jls.21590

UNESCO. (2015). *Education 2030: Incheon declaration and framework for action*. UNESCO.

Whetten, D. A., & Cameron, K. S. (2016). *Developing management skills* (9th ed.). Pearson.

World Economic Forum. (2020). *The future of jobs report 2020*. https://www.weforum.org

SERVANT LEADERSHIP OF EDUCATIONAL ADMINISTRATORS UNDER THE OFFICE OF THE BASIC EDUCATION COMMISSION

Sanguthai Moto* and Boonchan Sisan
sanguthai.mo@kmitl.ac.th and boonchan.si@kmitl.ac.th

Department of Industrial education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author Email: sanguthai.mo@kmitl.ac.th

ABSTRACT

The objective of this study was to examine the servant leadership of educational administrators under the Office of Basic Education Commission using empirical data. The key informants consisted of 15 educational administrators under the Office of Basic Education Commission, selected using purposive sampling. The research instrument was a semi-structured interview questionnaire with an Index of Content Validity (IOC) ranging from .80 to 1.00. Data were analyzed using content analysis.

The research findings revealed that servant leadership among educational administrators under the Office of the Basic Education Commission comprises six components:

1) Valuing others: This behavior demonstrates acceptance and affirmation of the dignity, perspectives, abilities, and decision-making rights of each individual within the framework of equality and mutual respect.

2) Developing others: This is a deliberate and systematic process of promoting the holistic growth of individuals through providing opportunities, professional guidance, and constructive feedback to ensure sustainable progress.

3) Building community: This involves cultivating trust, collaborative relationships, and stakeholder participation to promote unity, shared responsibility, and organizational sustainability.

4) Moral expression: This involves consistently adhering to ethical and moral principles through honesty, transparency, respect, and moral courage in professional practice.

5) Promoting leadership... It is the development and enhancement of individual leadership potential and intrinsic motivation, along with the promotion of shared responsibility and continuous improvement within the organization.

6) Co-leadership is a collaborative work approach characterized by decentralization, participatory decision-making, mutual trust, and shared responsibility to achieve organizational effectiveness.

Keywords: Servant leadership, Valuing others, Developing others, Community building, Moral expression

1. Statement of the Problem

Servant leadership is from English word "Servant Leadership" In this research, the word "servant leader" is generally used. It found that servant leader is accepted to be an efficient tool to get the organization and society strong. Servant leader is center or model of people in the organization. The people will follow the servant leader automatically. It is not necessary to force or control them to serve. Servant leader is good model in morality and service mind.

As servant leader is good model and kind, the followers or the people in the organization will have good relationship. Therefore, working atmosphere in the organization will be nice and support team working, participation in making decisions based on morality, to pay attention to other people and support other people to improve themselves (Wong et al., 2007) Hence, it is necessary to develop the leader to be servant leader. There are many researches, which studied for servant leader. Each researcher defined qualification of servant leader differently. Some researchers defined the meaning from many documents synthesis and then defined special qualification in their researches. Some researchers remain the concept or definition of experts or academician, who defined the meaning or qualification of servant leader for study; such as Thompson, (Thompson., 2005) who studied school director of public school and servant leadership. This research studied ten factors of servant leader, which are being good listener, sympathy, maintenance, awareness, cogency, concept, vision, taking care, human development, and community development. Additionally, the research studied six factors of servant leader, which is concept of Laub (Laub.,2004); the six factors consist of appreciating of the others, developing others, developing community, moral expressions, supporting leadership, and using leadership together.

2. Objectives

The objective of this study was to examine the servant leadership of educational administrators under the Office of the Basic Education Commission.

3. Conceptual Framework and Hypothesis

This research examines the concept of servant leadership from Laub (2004), which states that a servant leader is a leader with a sense of service, vision and work goals, understanding and guidelines for work. In addition, a servant leader is a good role model that supports and develops followers and the organization more than themselves. Laub's concept states that servant leadership consists of 6 components: valuing others, developing others, developing communities, demonstrating virtue, supporting leadership, and exercising shared leadership. In addition, a study of the confirmatory factor analysis model of servant leadership of school directors under the Office of the Vocational Education Commission by Boonchan Sisan (2017) used all 6 components in this study. Therefore, in this study, the researcher used the conceptual framework of development of trait indicators for servant leadership of teacher in Basic Education school and Vocational School under the Ministry of Education servant leadership, which consists of 6 components: 1) valuing others, 2) developing others, 3) developing communities, 4) demonstrating virtue, 5) supporting leadership, and 6) exercising shared leadership. Although rooted in a Western organizational context, Laub's framework is adopted here as an analytical lens for contextual reinterpretation, recognizing that servant leadership in Thai vocational institutions is culturally mediated by hierarchical deference and collectivist values.

4. Research Methodology

4.1 Scope of the Study

4.1.1 Key Informants

The key informants in this study consisted of 15 educational administrators under the Office of the Basic Education Commission. Participants were selected through purposive sampling based on their experience in adminitration at least 3 years, professional roles, and relevance to the research objectives.

4.1.2 Variables of the Study

The primary variable examined in this study was servant leadership. This construct comprised six components: (1) valuing others, (2) developing others, (3) community building,

(4) moral expression, (5) leadership promotion, and (6) shared leadership. These components served as the analytical framework guiding data collection and interpretation.

4.2 Research Instrument

The primary research instrument employed in this study was a semi-structured interview protocol. The instrument was divided into two parts. Part I elicited information regarding the general characteristics of the respondents. Part II focused on servant leadership characteristics, encompassing six core components: (1) valuing others, (2) developing others, (3) community building, (4) moral expression, (5) leadership promotion, and (6) shared leadership.

The content validity of the instrument was examined by experts, yielding an Index of Item–Objective Congruence (IOC) ranging from .80 to 1.00, indicating a high level of consistency between the interview items and the research objectives.

4.3 Data Collection

The researcher collected the data by formally requesting permission and cooperation from the experts, followed by scheduling interview appointments. All interviews were conducted personally by the researcher. The interview protocol included questions related to the six components of servant leadership characteristics.

After each interview, the researcher reviewed and verified the completeness and comprehensiveness of the information obtained. The interview process was concluded once the data were deemed sufficiently comprehensive. This procedure was carried out with all 15 key informants to ensure the accuracy and thoroughness of the data collected.

4.4 Data Analysis

Data were analyzed using content analysis. The information obtained from interviews with all 15 experts was systematically examined, synthesized, and summarized to generate findings consistent with the research objectives.

5. Results

The findings derived from the synthesis of in-depth interviews with 15 subject-matter experts revealed that servant leadership among educational administrators under the Office of the Basic Education Commission consists of six principal components: (1) valuing others, (2) developing others, (3) community building, (4) moral expression, (5) leadership promotion, and (6) shared leadership. These components, while consistent with Laub's (2004) framework, reflect a contextually situated understanding of servant leadership as shaped by the hierarchical and collectivist nature of Thai vocational educational institutions. Each component is described as follows.

Valuing others encompasses the recognition and affirmation of individuals' dignity, perspectives, capabilities, and decision-making rights. This component is manifested through respectful interaction, active listening, inclusive participation, and genuine acknowledgment grounded in principles of equality and mutual understanding.

Developing others refers to a systematic and intentional process aimed at fostering individuals' holistic growth across knowledge, competencies, professional skills, personality, and moral character. This development is facilitated through the provision of opportunities, mentoring, guidance, and constructive feedback to promote continuous personal and professional advancement.

Community building involves the deliberate strengthening of relationships, trust, and collaboration among individuals and organizational stakeholders. It is characterized by transparency, fairness, participatory engagement, and effective network coordination to cultivate unity, shared responsibility, and sustainable institutional resilience.

Moral expression reflects a steadfast commitment to ethical principles and moral values in both personal conduct and professional practice. It is demonstrated through integrity,

transparency, selflessness, respect for others, exemplary role modeling, and moral courage in upholding what is right for the common good.

Leadership promotion denotes the structured effort to enhance individuals' leadership capacity and intrinsic motivation. This includes fostering positive attitudes, self-confidence, responsible decision-making, and risk management competencies, while nurturing a culture of shared responsibility and ongoing leadership development within the organization.

Shared leadership represents a collaborative leadership approach in which authority and responsibility are distributed among members. It emphasizes participatory decision-making, situational flexibility in assuming leader and follower roles, and the cultivation of trust, mutual respect, and collective accountability to strengthen team effectiveness and ensure sustainable organizational success.

6. Conclusion and Discussion

The findings indicate that servant leadership among educational administrators under the Office of the Basic Education Commission consists of six interrelated components. The discussion of each component is presented as follows:

1) Valuing Others The finding that valuing others constitutes a core component of servant leadership is consistent with the foundational theory of Robert K. Greenleaf, who emphasized that authentic leadership begins with a genuine concern for the growth and well-being of others. This result also aligns with James A. Laub (1999, 2004), who identified valuing people as central to servant leadership organizations. In educational settings, recognizing individuals' dignity and decision-making rights fosters trust and psychological safety, which are critical for collaborative governance and participatory management. The present findings reinforce the view that servant leadership in basic education is grounded in relational ethics and respect-based leadership practices.

2) Developing Others The emphasis on developing others reflects the growth-oriented nature of servant leadership. According to Larry C. Spears (1998), one of the defining characteristics of servant leadership is a commitment to the growth of people. Similarly, Laub (2004) highlighted the leader's responsibility to intentionally nurture professional and personal development. In the vocational education context, where institutional effectiveness depends on teacher capacity and administrative competence, systematic mentoring and constructive feedback are essential mechanisms for sustainable advancement. The findings suggest that servant leadership promotes long-term human capital development rather than short-term performance outcomes.

3) Community Building The identification of community building as a major component aligns with Greenleaf's proposition that servant leaders are builders of community. Laub (1999) likewise conceptualized community development as integral to servant leadership. Educational institutions function as social systems; therefore, cultivating trust, collaboration, and shared responsibility strengthens institutional resilience. This finding supports prior research indicating that servant leadership positively influences organizational culture, teamwork, and stakeholder engagement (Wong & Davey, 2007). In the context of basic education, community building enhances institutional coherence and sustainable organizational development.

4) Moral Expression The moral dimension of leadership is strongly embedded in servant leadership theory. Greenleaf asserted that servant leadership is fundamentally ethical in orientation. Moral expression in this study reflects integrity, transparency, and moral courage—attributes consistent with ethical leadership frameworks. Laub (2004) emphasized that servant leadership requires value-driven conduct and principled decision-making. In educational administration, moral leadership strengthens institutional credibility and public

trust. The present findings confirm that ethical consistency is not peripheral but foundational to servant leadership practice.

5) Leadership Promotion The component of leadership promotion corresponds with contemporary perspectives on distributed and capacity-building leadership. Servant leaders are not authority-centered but empowerment-oriented. Spears (1998) argued that servant leaders prepare others to lead. This aligns with modern educational leadership theories emphasizing leadership sustainability through succession and shared responsibility. Within basic education institutions, cultivating leadership capacity among staff ensures organizational continuity and adaptive capability. Thus, the findings suggest that servant leadership operates as a catalyst for leadership multiplication rather than leadership concentration.

6) Shared Leadership hared leadership as identified in this study reflects a collaborative paradigm in which authority and responsibility are distributed. This finding resonates with Laub's (1999) concept of shared leadership and contemporary distributed leadership theory. Research in educational administration indicates that participatory decision-making enhances organizational commitment and effectiveness. Servant leadership, therefore, provides a moral and relational foundation for shared governance structures. In vocational education settings, shared leadership promotes innovation, collective accountability, and institutional adaptability.

7. References

Diamantopoulos, A., & Siguaw, J. A. (2000). *Introducing LISREL: A guide for the uninitiated*. Sage Publications.

Laub, J. A. (1999). *Defining servant leadership: A recommended typology for servant leadership studies*. Servant Leadership Research Roundtable, Regent University. https://www.regent.edu

Laub, J. A. (2003). *From paternalism to the servant organization: Expanding the Organizational Leadership Assessment (OLA) model*. Servant Leadership Research Roundtable, Regent University. https://www.regent.edu

Meesuk, P. (2016). Structural validity analysis of selected indicators related to vocational education. *Journal of Industrial Education, 15*(2), 86–93. (in Thai)

Thompson, C. H. (2005). *The public school superintendent and servant leadership* (Doctoral dissertation, Edgewood College). ProQuest Dissertations & Theses Global. (UMI No. 3190501)

Viratchai, N. (1999). *LISREL model: Statistical analysis for research*. Chulalongkorn University Press. (in Thai)

Wong, P. T. P., & Davey, D. (2007). Best practices in servant leadership. In *Servant Leadership Research Roundtable*. Regent University. https://www.regent.edu

Angsuchoti, S., Wichitwanna, S., & Pinyophanawat, R. (2009). *Statistical analysis for social and behavioral science research: LISREL techniques* (2nd ed.). Charoen Munkong Printing. (in Thai)

EFFECT OF AIR SUPPLY DUCT CONFIGURATIONS ON TEMPERATURE DISTRIBUTION IN OPEN PLUG-IN REFRIGERATED DISPLAY CABINETS

Nutthakit Hanboonyanon*, Songwut Egwutvongsa, and Thanate Piromgarn

66036076@kmitl.ac.th, momojojo108@gmail.com, and thanate.pi@kmitl.ac.th

Department of Architectural and Design Education,
School of Industrial Education and Technology
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 66036076@kmitl.ac.th

ABSTRACT

This study investigates the influence of air discharge slot configurations on the thermal and humidity distribution performance in an open refrigerated display cabinet, using a 90-cm plug-in type unit as a case study. Three slot sizes (6 mm, 3.5 mm, and 2.5 mm) were experimentally evaluated under identical operating conditions. Key performance indicators included air velocity, temperature, relative humidity, and vertical temperature distribution within the cabinet. The results demonstrate that the 6 mm slot configuration achieved the highest average air velocity (0.562 m/s), leading to the formation of a more stable air curtain. Consequently, this configuration yielded the lowest average temperature (≈4.01°C) and reduced relative humidity (≈54.5% RH), compared to the smaller slot sizes, which exhibited inferior thermal performance. Pronounced thermal stratification and localized hot spots were observed, particularly in the 2.5 mm and 3.5 mm configurations. Statistical analysis using one-way ANOVA revealed significant differences in air velocity and relative humidity among the tested configurations ($p < 0.05$). Post hoc comparisons confirmed that the 6 mm slot significantly outperformed the other designs in terms of airflow stability and environmental control. These findings highlight that air discharge slot geometry plays a critical role in enhancing air curtain effectiveness and minimizing ambient air infiltration. The 6 mm slot configuration is identified as the optimal design, offering improved temperature uniformity and humidity control within open refrigerated display cabinets.

Keywords: Air curtain, Open refrigerated display cabinet, Air discharge configuration, Temperature distribution, Relative humidity

1. Statement of the Problem

Open refrigerated display cabinets are essential equipment in modern retail businesses such as convenience stores and supermarkets, as they facilitate easy product access and enhance consumers' purchasing decisions. However, their open design allows continuous air exchange between the interior and exterior, leading to significant cooling loss and increased workload on the refrigeration system. As a result, these cabinets account for a substantial proportion of total electricity consumption. Evaluating energy use and improving the performance of electrical equipment in convenience stores can effectively reduce overall energy consumption (Hidayat et al., 2025**).** Furthermore, structural improvements and the adoption of CO_2 refrigerants have been shown to significantly enhance system performance and reduce energy usage (Thanasoulas & Molinari, 2025**).** Refrigerated display cabinets play a crucial role in maintaining food and beverage temperatures at safe levels, particularly during the COVID-19 pandemic, when consumers became

more concerned about hygiene and extended food preservation. This has led retailers to invest in cabinets with precise temperature control and reduced shared surface contact (Boots et al., 2021**).** Consequently, energy consumption in convenience stores requires thorough investigation to develop more efficient energy-saving strategies (Krataikaew, 2019**).** Comparative studies of open display cabinets in retail environments have found that shelf arrangement and air curtain design directly affect air exchange and energy consumption (Liu et al., 2025**).** In addition, improving air-conditioning system performance and controlling freezer door operation can significantly reduce overall energy consumption in convenience stores (Thitiporn Thomyapitak et al., 2024**).** Open display cabinets also play an important role in stimulating impulse buying by providing clear product visibility and easy access. However, they suffer from high cooling energy losses. To address this issue, "air curtain" technology has been developed to control air exchange between the cabinet interior and the external environment, reducing energy consumption by approximately 10–25% **(**Akerma et al., 2020**).** The air curtain functions by discharging a vertical stream of air from top to bottom, acting as a barrier between cold and ambient air. Nevertheless, the performance of an air curtain depends on several factors, particularly the "air supply outlet configuration," which directly influences airflow structure, stability of the air curtain, and the infiltration of external air. In practice, insufficient air curtain performance can lead to uneven temperature distribution within the cabinet and moisture accumulation, resulting in condensation, frost formation, and deterioration of product quality—especially for fresh food products that are highly sensitive to temperature and humidity. Moreover, it increases the load on the refrigeration system, leading to higher energy consumption. Therefore, studying the effects of air supply outlet configurations on temperature and humidity distribution is essential, particularly for plug-in open display cabinets widely used in the retail sector. This research aims to analyze the influence of air outlet design in a 90-cm open refrigerated display cabinet to identify design guidelines that enhance performance and improve product quality preservation.

2. Objectives

To investigate the effects of air outlet configurations on the performance of temperature and humidity distribution, and to provide design guidelines for optimizing air outlet structures in open refrigerated display cabinets for enhanced performance.

3. Conceptual Framework and Hypothesis

The conceptual framework of this study focuses on investigating the effects of air discharge configurations on the performance of the air curtain in an open refrigerated display cabinet. This is examined through airflow behavior and the resulting thermal and humidity conditions within the system. The relationships among the variables can be described as follows:

Independent Variable:

- Air discharge configuration (honeycomb outlet size in three different designs)

Dependent Variables:

- Internal cabinet temperature (°C)
- Relative humidity inside the cabinet (%RH)
- Air velocity of the air curtain (m/s)

Research Hypotheses:

1. Different air discharge configurations affect the temperature distribution inside the open refrigerated display cabinet.
2. Different air discharge configurations affect the humidity distribution inside the open refrigerated display cabinet.

3. At least one air discharge configuration provides significantly better performance in controlling temperature and humidity compared to others at a 0.05 level of statistical significance.

4. Research Methodology

4.1 Experimental Research This study adopts an experimental research approach aimed at investigating the effects of air discharge configurations on the performance of temperature and humidity distribution in an open refrigerated display cabinet. The air discharge configuration is defined as the independent variable, while the impacts on dependent variables—temperature, relative humidity, air velocity. The experiments are conducted under controlled environmental conditions to ensure clear comparison among configurations and statistical reliability.

4.1.1 Population and Sample This research does not involve human subjects but focuses on an experimental refrigeration system. The sample consists of one plug-in open refrigerated display cabinet (90 cm in width). Three air discharge configurations are tested: 6 mm, 3.5 mm, and 2.5 mm honeycomb outlet sizes. Each configuration is tested with at least three repetitions to improve data reliability.

4.1.2 Research Instruments The instruments used in this study include Vane Anemometer (for air velocity measurement), Thermal Camera (for temperature measurement), Temperature and Humidity, Data Logger Power Meter (for energy consumption measurement), Smoke Generator (for airflow visualization)

4.2 Research procedure

Step 1: Study of Concepts and Theories. Study the working principles of open refrigerated display cabinets and air curtain systems. Review literature related to air discharge design in air curtains. Analyze factors affecting energy consumption, including airflow rate and cooling loss. Study energy efficiency standards in the refrigeration industry.

Step 2: Research Design. Clearly define the research objectives. Identify experimental variables as follows. Independent variable: characteristics of air discharge configuration in the air curtain. Dependent variables: energy consumption, internal cabinet temperature, and air curtain performance. Controlled variables: ambient temperature 25 ^{o} C, product load inside the cabinet (Artificial meat, M-Pack 500g, and a water bottle) , relative humidity 60%, etc. Design the experimental setup to compare the effects of different air discharge configurations

Step 3: Equipment and Instrument Preparation. Select a 90-cm plug-in open refrigerated display cabinet for the experiment. Prepare an air curtain system with adjustable air discharge configurations. Prepare measurement instruments, including a power meter, temperature and humidity data logger, anemometer, and pressure sensor. Calibrate all instruments to ensure accuracy

Step 4: Experimental Procedure. Install measurement instruments at designated positions. Set the cabinet to the required operating conditions test various air discharge configurations, such as standard outlets, angled outlets, enlarged outlets, and outlets with airflow distribution enhancers. Collect data on energy consumption, internal temperature, and airflow characteristics for each configuration. Repeat experiments to improve accuracy and reduce errors

Step 5: Data Analysis. Verify and validate collected data. Analyze data trends using statistical methods such as mean and standard deviation. Compare energy consumption among different configurations. Perform statistical tests such as ANOVA and t-test. Conclude which air discharge configuration provides the highest performance in energy efficiency.

5. Results

The smoke test technique, as shown in Figure 1, was conducted to investigate the airflow behavior at the front opening of the open refrigerated display cabinet. The movement of smoke serves as a qualitative indicator of the direction and characteristics of the air curtain. The

observations revealed that the airflow was not consistently laminar throughout the entire flow path. Instead, deviations and dispersion were observed in certain regions, particularly near the lower edge and side boundaries of the cabinet opening. These behaviors indicate the presence of turbulent flow and the entrainment of ambient air into the cabinet. Such phenomena result in discontinuity of the air curtain and reduce its effectiveness in maintaining the cold air within the cabinet, thereby negatively impacting overall thermal performance.

Figure 1 Smoke Test Experiment (Nutthakit 2026)

Table 1 Air velocity measurement results for three air discharge configurations

Condition Type		L	Vane Anemometer m/s							R	AVG.
		1	2	3	4	5	6	7	8	9	
6mm.	Honeycomb	0.56	0.56	0.59	0.58	0.58	0.57	0.55	0.54	0.53	0.56
	Return	0.89	1.07	1.45	1.85	2.01	1.85	1.46	1.07	0.78	1.38
3.5mm.	Honeycomb	0.48	0.48	0.49	0.49	0.53	0.51	0.47	0.48	0.47	0.49
	Return	0.91	0.96	1.19	1.70	2.00	1.82	1.27	1.16	1.07	1.34
2.5mm.	Honeycomb	0.48	0.48	0.50	0.49	0.49	0.49	0.46	0.45	0.45	0.47
	Return	0.96	1.20	1.66	1.85	1.88	1.47	1.27	1.14	0.93	1.37

The preliminary analysis of air velocity measurements using a vane anemometer along the cabinet opening (positions 1–9) indicates that the airflow structure can be divided into two main regions: the supply side (Honeycomb) and the return side. On the Honeycomb side, the air velocity is relatively uniform in all cases (0.47–0.56 m/s), reflecting a stable airflow distribution, which is a critical condition for the formation of a vertical air curtain. In contrast, the return side exhibits significantly higher air velocity values (1.34–1.38 m/s) with noticeable non-uniformity. The highest velocities are observed in the central region (positions 4–6), corresponding to the location of the return fan. This indicates jet concentration and airflow acceleration before entering the return inlet. Considering the effect of honeycomb size, the 6 mm configuration provides the highest average air velocity (0.56 m/s), resulting in a high-momentum air curtain with strong structural stability. However, it also shows greater velocity variation on the return side, suggesting increased turbulent flow and air entrainment. On the other hand, the 2.5 mm configuration yields the lowest air velocity (0.47 m/s) but demonstrates better airflow uniformity, leading to a smoother flow structure.

In summary, although the small opening size (2.5 mm) causes a higher pressure drop, it can generate a more uniform airflow with higher jet momentum. As a result, the air curtain becomes more stable and experiences less velocity decay than larger openings. In addition, it helps reduce the mixing of warm ambient air with the cold air inside the cabinet, thereby improving the temperature retention performance of the refrigerated display cabinet.

Table 2 Comparing the difference in wind speed values using an anemometer in m/s

Honeycomb	**Average wind speed (m/s)**	**standard deviation (SD)**
6mm.	0.562	0.019
3.5mm.	0.489	0.020
2.5mm.	0.476	0.018

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
6mm.	9	5.06	0.562222	0.000394
3.5mm.	9	4.4	0.488889	0.000386
2.5mm.	9	4.29	0.476667	0.00035

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.038541	2	0.01927	51.13514	2.22E-09	3.402826
Within Groups	0.009044	24	0.000377			
Total	0.047585	26				

t-Test: Two-Sample Assuming Unequal Variances

	6mm.	*3.5mm.*
Mean	0.562222222	0.488888889
Variance	0.000394444	0.000386111
Observations	9	9
Hypothesized Mean Difference	0	
df	16	
t Stat	7.874459819	
P(T<=t) one-tail	3.40221E-07	
t Critical one-tail	2.318278416	
P(T<=t) two-tail	6.80442E-07	
t Critical two-tail	2.663339125	

	3.5mm.	*2.5mm.*
Mean	0.488888889	0.476666667
Variance	0.000386111	0.00035
Observations	9	9
Hypothesized Mean Difference	0	
df	16	
t Stat	1.351449257	
P(T<=t) one-tail	0.097675689	
t Critical one-tail	2.318278416	
P(T<=t) two-tail	0.195351379	
t Critical two-tail	2.663339125	

	6mm.	*2.5mm.*
Mean	0.562222222	0.476666667
Variance	0.000394444	0.00035
Observations	9	9
Hypothesized Mean Difference	0	
df	16	
t Stat	9.407047215	
P(T<=t) one-tail	3.19276E-08	
t Critical one-tail	2.318278416	
P(T<=t) two-tail	6.38552E-08	
t Critical two-tail	2.663339125	

Summary of Statistical Results
At a significance level of $\alpha = 0.05$,
the obtained F-value was much higher than the F-critical value.
Because the p-value < 0.05, H_0 is rejected.
In conclusion, the mean wind speeds of the three groups differed significantly at the 0.05 significance level.
Pair-up comparisons: From the t-test (Table 2), it was found that: The 6 mm hole had significantly higher wind speeds than the 3.5 mm and 2.5 mm holes ($p < 0.001$).
There was no significant difference between 3.5 mm and 2.5 mm holes ($p = 0.195$).

Thermal performance was further evaluated using thermal imaging, as shown in Figure 2. Infrared thermography is effective for assessing refrigeration system performance because it enables rapid, non-contact surface temperature measurement without disturbing the internal airflow, which is crucial for air curtain studies. It also allows immediate detection of temperature non-uniformity.When comparing the three air discharge configurations: Figure 1 (6 mm) shows a central temperature of approximately 2.3°C, with a maximum of 26.4°C and a minimum of 0.9°C. Figure 2 (3.5 mm) shows a central temperature of approximately 4.9°C, with a maximum of

27.5°C and a minimum of 3.5°C. Figure 3 (2.5 mm) shows a central temperature of approximately 5.8°C, with a maximum of 30.4°C and a minimum of 3.7°C.

It is evident that the 3.5 mm and 2.5 mm configurations exhibit higher temperatures across all measurement points (center, maximum, and minimum) compared to the 6 mm configuration. This reflects a significant increase in thermal load inside the cabinet.Moreover, the temperature distribution in the 6 mm case is more uniform, as indicated by the predominance of dark blue tones across most areas within the cabinet, suggesting better cooling performance and more effective air curtain operation.

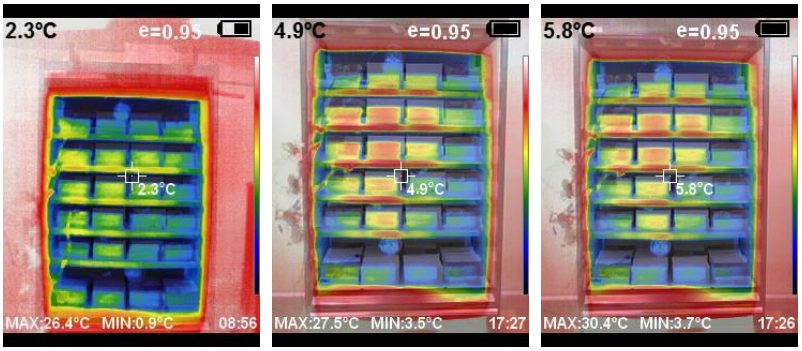

Figure 2 Thermal Images of Air Discharge Configurations 1–3 (Nutthakit 2026)

Table 3 Product temperature at each shelf for the 6 mm air discharge configuration

Diameter 6 mm. °C						
Shelf 6	Tag 0011	Tag 0012	Tag 0013	Tag 0014	Tag 0015	AVG.
	3.8	8.4	3.1	3.9	6.0	5.04
Shelf 5	Tag 0016	Tag 0017	Tag 0018	Tag 0019	Tag 0020	AVG.
	2.8	8.5	3.9	2.7	7.0	4.98
Shelf 4	Tag 0021	Tag 0022	Tag 0023	Tag 0024	Tag 0025	AVG.
	2.2	7.6	2.2	2.1	6.4	4.1
Shelf 3	Tag 0026	Tag 0027	Tag 0028	Tag 0029	Tag 0030	AVG.
	1.1	5.9	2.0	1.4	5.3	3.14
Shelf 2	Tag 0031	Tag 0032	Tag 0033	Tag 0034	Tag 0035	AVG.
	1.3	4.8	1.8	1.2	4.9	2.8
Shelf 1	Tag 0036	Tag 0037	Tag 0038	Tag 0039	Tag 0040	AVG.
	2.8	6.7	3.2	2.8	3.2	3.74
Total						4.012

The results of temperature measurements for the 6 mm air discharge configuration show that the overall average system temperature is 4.012 °C, indicating that the cabinet can maintain temperatures within an appropriate range for product preservation. However, when considering spatial temperature distribution, noticeable non-uniformity is observed. Vertically, the highest temperatures occur at the top shelves (shelves 6 and 5), with values of 5.04 °C and 4.98 °C, respectively. The temperature then gradually decreases through the middle shelves (shelves 4 to 2: 4.10, 3.14, and 2.80 °C) before slightly increasing again at the bottom shelf (3.74 °C). This pattern reflects the presence of thermal stratification within the cabinet. At specific measurement points, relatively high variability is also observed. In particular, the upper region shows maximum temperatures as high as 8.5 °C and 8.4 °C, indicating the presence of hot spots caused by external air infiltration or discontinuities in the air curtain. In contrast, the middle-to-lower regions exhibit lower temperatures, with a minimum value of 1.1 °C, suggesting effective cold air accumulation. Nevertheless, some non-uniformity still exists in certain areas, likely due to airflow recirculation, turbulence, and disturbances from external air. The slightly higher temperature observed at the bottom shelf may also result from airflow patterns within the system or external air intrusion.

Table 4 Product temperature at each shelf for the 3.5 mm air discharge configuration

Diameter 3.5 mm. °C						
Shelf 6	Tag 0011	Tag 0012	Tag 0013	Tag 0014	Tag 0015	AVG.
	5.2	8.6	4.8	5.0	7.4	6.2
Shelf 5	Tag 0016	Tag 0017	Tag 0018	Tag 0019	Tag 0020	AVG.
	4.7	11.7	6.3	3.9	8.5	7.02
Shelf 4	Tag 0021	Tag 0022	Tag 0023	Tag 0024	Tag 0025	AVG.
	4.1	4.0	3.2	3.0	7.1	4.28
Shelf 3	Tag 0026	Tag 0027	Tag 0028	Tag 0029	Tag 0030	AVG.
	2.4	7.4	2.8	2.4	5.9	4.18
Shelf 2	Tag 0031	Tag 0032	Tag 0033	Tag 0034	Tag 0035	AVG.
	1.9	5.9	3.0	2.3	5.6	3.74
Shelf 1	Tag 0036	Tag 0037	Tag 0038	Tag 0039	Tag 0040	AVG.
	3.2	7.4	3.5	4.2	3.8	4.42
	Total					5.084

The results of temperature measurements for the 3.5 mm air discharge configuration show that the overall average system temperature is 5.084 °C, which is significantly higher than that of the 6 mm configuration. This indicates that reducing the air discharge size negatively affects the thermal performance of the open refrigerated display cabinet, leading to an increase in the average internal temperature. Considering the spatial temperature distribution, particularly in the upper shelves, clear non-uniformity is observed. This reflects instability in cold air distribution and indicates that the air curtain is not fully effective in preventing external air infiltration. In terms of vertical distribution, shelf 6 has an average temperature of 6.20 °C, while shelf 5 reaches the

highest average at 7.02 °C. These upper regions, located near the cabinet opening, are most susceptible to external heat gain. The temperature decreases at shelf 4 (4.28 °C) and continues to decrease at shelves 3 and 2 (4.18 °C and 3.74 °C, respectively), indicating improved cooling performance in the lower sections compared to the top. However, point measurements reveal considerable variability. Some locations exhibit abnormally high temperatures, such as Tag 0017 = 11.7 °C, Tag 0022 = 4.0 °C, and Tag 0032 = 5.9 °C, indicating localized hot spots. These may result from air curtain leakage, external air entrainment, or internal airflow recirculation. At shelf 1, the average temperature increases slightly to 4.42 °C. Although still lower than the top shelves, it is higher than shelves 2 and 3, suggesting uneven cold air distribution throughout the cabinet. This may be caused by heat accumulation or airflow disturbances near the bottom section, reducing temperature control performance in this area. Overall, the minimum recorded temperature is 1.9 °C (shelf 2, Tag 0031), while the maximum reaches 11.7 °C (shelf 5, Tag 0017), resulting in a relatively wide temperature range. This indicates significant non-uniformity in temperature distribution within the cabinet, particularly between the upper and lower regions.

Table 5 Product temperature at each shelf for the 2.5 mm air discharge configuration

Diameter 2.5 mm. °C						
Shelf 6	Tag 0011	Tag 0012	Tag 0013	Tag 0014	Tag 0015	AVG.
	5.1	8.9	5.0	5.1	7.5	6.32
Shelf 5	Tag 0016	Tag 0017	Tag 0018	Tag 0019	Tag 0020	AVG.
	4.6	11.8	6.2	3.8	8.4	6.96
Shelf 4	Tag 0021	Tag 0022	Tag 0023	Tag 0024	Tag 0025	AVG.
	3.7	3.6	3.8	2.9	6.9	4.18
Shelf 3	Tag 0026	Tag 0027	Tag 0028	Tag 0029	Tag 0030	AVG.
	2.2	7.3	2.7	2.4	5.8	4.08
Shelf 2	Tag 0031	Tag 0032	Tag 0033	Tag 0034	Tag 0035	AVG.
	1.8	5.7	2.8	2.2	5.5	3.6
Shelf 1	Tag 0036	Tag 0037	Tag 0038	Tag 0039	Tag 0040	AVG.
	3.1	7.2	3.4	3.9	3.6	4.24
Total						5.028

The temperature measurement results for the 2.5 mm air discharge configuration show that the overall average system temperature is 5.028 °C. This value is close to that of the 3.5 mm configuration (5.084 °C) but remains significantly higher than the 6 mm configuration (4.012 °C). This indicates that reducing the air discharge size tends to decrease the system's temperature control performance, particularly in terms of temperature uniformity and the ability to limit external air infiltration. Considering the vertical temperature distribution, shelves 6 and 5 exhibit the highest average temperatures, at 6.32 °C and 6.96 °C, respectively. These values are clearly higher than those of the 6 mm configuration, reflecting that the upper region of the cabinet is most affected by external air intrusion. The smaller air discharge size is insufficient to generate a stable air curtain. For shelves 4 to 2, the average temperatures are 4.18 °C, 4.08 °C, and 3.60 °C,

respectively. Although the temperature decreases with height, these values remain higher than those observed in the larger outlet configuration. Additionally, significant temperature variation and hot spots are observed, with values reaching 8.9 °C and 11.8 °C, which are notably higher than in the 6 mm case. At shelf 1, the average temperature is 4.24 °C, showing a slight increase, likely due to airflow disturbances near the bottom of the cabinet. The overall temperature range is relatively wide (approximately 1.8–11.8 °C), indicating considerable non-uniformity in temperature distribution throughout the system.

Table 6 Relative humidity of the three air discharge configurations

Relative Humidity (%)		
Diameter 6mm.	**Diameter 3.5mm.**	**Diameter 2.5mm.**
54	66	67
55	68	68
54.5	67	67.5

Groups	*Count*	*Sum*	*Average*	*Variance*
6mm.	3	163.5	54.5	0.25
3.5mm.	3	201	67	1
2.5mm.	3	202.5	67.5	0.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	325.5	2	162.75	325.5	7.62E-07	5.143253
Within Groups	3	6	0.5			
Total	328.5	8				

Summary of Statistical Results:

At a significance level of $\alpha = 0.05$,

the obtained F-value is much higher than the F-critical value.

Therefore, H_0 is rejected (Null Hypothesis).
The %RH values of all three sizes are "statistically significant".

The analysis of relative humidity inside the refrigerated cabinet, controlled at 60% RH, reveals that variations in humidity due to different air discharge sizes have a direct impact on product quality and shelf life. In particular, the 3.5 mm and 2.5 mm configurations exhibit relatively high average humidity levels of approximately 67–67.5% RH, compared to only 54.5% RH for the 6 mm configuration. This indicates that increased humidity within the system can significantly contribute to negative effects on stored products. From a physical perspective, higher relative humidity increases the amount of water vapor in the air, which may lead to condensation on product surfaces and internal cabinet walls—especially in areas where the temperature falls below the dew point. The formation of water droplets not only affects product appearance but also

promotes the growth of microorganisms such as bacteria and fungi. This accelerates the spoilage process of fresh and processed foods and may further contribute to temperature fluctuations within the cabinet. These effects can significantly reduce product quality, particularly for temperature-sensitive items such as fresh vegetables, meat, and dairy products. For fruits and vegetables, excessively high relative humidity can lead to spoilage, reducing shelf life and overall product value.

6. Conclusion and Discussion

The research findings indicate that airflow within an open refrigerated display cabinet can form an air curtain; however, turbulence and external air entrainment still occur, affecting overall performance. The 6 mm air discharge configuration provides the highest air velocity and the most stable air curtain, resulting in a lower average temperature (≈4.01 °C) and more uniform cooling distribution. In contrast, the 3.5 mm and 2.5 mm configurations exhibit higher temperatures, clear thermal stratification, and noticeable hot spots. They also show higher relative humidity levels (≈67% RH), which increase the risk of condensation and product deterioration. These results demonstrate that both the size and configuration of the air discharge outlet directly influence air curtain performance in open refrigerated display cabinets. The 6 mm configuration generates a more stable airflow, enabling better temperature control with lower and more uniform temperature distribution. It also reduces thermal stratification and minimizes the occurrence of hot spots compared to the 3.5 mm and 2.5 mm configurations. Additionally, it provides better control of relative humidity, thereby reducing the risk of condensation and product quality degradation. In conclusion, the 6 mm air discharge configuration delivers the best overall performance, as it effectively reduces external air infiltration and significantly enhances refrigeration system efficiency. Supporting studies further confirm that modifying air discharge angles or incorporating aerofoil structures can reduce average inlet air temperature by approximately 0.6 °C and improve heat transfer efficiency, leading to better food preservation (Tukmakov, 2022; Vengalis & Mokšin, 2022). Moreover, installing separate air curtains for each shelf can reduce temperature and heat load (Liu et al., 2024), while adjusting shelf perforation ratios to 25% can decrease internal temperature differences to around 4.3 °C (Xia et al., 2022).

7. Suggestions

The recommendations from this study suggest that the design of air discharge configurations in open refrigerated display cabinets should consider an appropriate outlet size, particularly around 6 mm, as it enhances air curtain stability and effectively reduces external air infiltration. In addition, the outlet design, position, and angle should be optimized in conjunction with proper air velocity control to achieve uniform airflow distribution. This will improve temperature and humidity control within the cabinet. The findings of this study can be applied to the design and improvement of refrigerated display cabinets in the retail sector, contributing to enhanced product preservation quality and overall system performance.

8. Acknowledgements

The authors would like to express their sincere gratitude to IARP Asia Co., Ltd., located at 231 Moo 6, Khao Yai Subdistrict, Cha-am District, Phetchaburi 76120, Thailand, for kindly providing the testing facilities and measurement instruments used in this study.

9. References

Kratai Kaew, S. (2019). Energy consumption for freezers in convenience stores. *Chulalongkorn University Theses and Dissertations (Chula ETD). 6964.* https://doi.org/https://doi.org/10.58837/chula.is.2019.98

Akerma, M., Hoang, H.-M., Leducq, D., & Delahaye, A. (2020). Experimental characterization of demand response in a refrigerated cold room. *International Journal of Refrigeration*, 113, 256-265. https://doi.org/https://doi.org/10.1016/j.ijrefrig.2020.02.006

Boots, J. N. M., Humblet-Hua, N. P. K., Tonneijck, L., Fokkink, R., van der Gucht, J., & Kodger, T. E. (2021). Characterization of the local mechanical texture of animal meat and meat replacements using multi-point indentation. *Journal of Food Engineering*, 300, 110505. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2021.110505

Hidayat, K., Permana, I., Chiang, W., Wang, F.-J., & Liou, C. (2022). Energy Consumption Analysis for Coupling Air Conditioners and Cold Storage Showcase Equipment in a Convenience Store. *Energies*, 15, 4857. https://doi.org/10.3390/en15134857

Liu, S., Wang, P., Zhang, Y., Meng, D., Zhang, Z., & Li, X. (2025). Performance differences of open refrigerated display cabinet under different package layouts. *Applied Thermal Engineering*, 281, 128573. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2025.128573

Liu, S., Zhang, S., Li, X., Hu, X., & Wang, Q. (2024). Technical feasibility study of open refrigerated display cabinet with independent air curtain [Article]. *Thermal Science and Engineering Progress*, 53, Article 102723. https://doi.org/10.1016/j.tsep.2024.102723

Thanasoulas, S., & Molinari, M. (2025). Advancing energy efficiency and sustainability in supermarkets: A comprehensive analysis of integrated technologies and their impact on energy consumption. *Energy Reports*, 13, 2855-2875. https://doi.org/https://doi.org/10.1016/j.egyr.2025.02.021

Thomyapitak, T., Saengsikhiao, P., Vessakosol, P., & Taweekun, J. (2024). A Study on the Energy Efficiency of an Energy Management System for Convenience Stores. *Energies*, 17, 4941. https://doi.org/10.3390/en17194941

Tukmakov, A. L. (2022). CFD simulation of heat transfer and airflows in an open refrigerated display cabinet. https://doi.org/https://doi.org/10.1088/1757-899x/1239/1/012005

Vengalis, T., & Mokšin, V. (2022). 2D CFD Simulation of Dynamic Heat Transfer in an Open-Type Refrigerated Display Cabinet [Article]. *Applied Sciences (Switzerland),* 12(14), Article 6916. https://doi.org/10.3390/app12146916

Xia, J., Guo, J., Wei, X., Zeng, Z., & Lü, E. (2022). Effect of Shelf Aperture Ratio on the Temperature Distribution of an Open Refrigerated Display Cabinet [Article]. *Applied Sciences (Switzerland)*, 12(20), Article 10296. https://doi.org/10.3390/app122010296

ENERGY EFFICIENCY IMPROVEMENT OF OPEN REFRIGERATED DISPLAY CABINETS VIA AIR DUCT DESIGN: A CASE STUDY OF PLUG-IN UNITS

Nutthakit Hanboonyanon*, Songwut Egwutvongsa, and Thanate Piromgarn

66036076@kmitl.ac.th, momojojo108@gmail.com, and thanate.pi@kmitl.ac.th

Department of Architectural and Design Education,
School of Industrial Education and Technology
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 66036076@kmitl.ac.th

ABSTRACT

This study investigates the influence of airflow discharge configurations on temperature distribution, relative humidity, and energy consumption in an open refrigerated display cabinet (plug-in type). Three honeycomb air discharge sizes (6 mm, 3.5 mm, and 2.5 mm) were evaluated as independent variables, while temperature, relative humidity, air velocity, and energy consumption were measured under controlled conditions. Statistical analyses were performed using descriptive statistics, one-way ANOVA, and independent t-tests at a significance level of 0.05. The results reveal that the 6 mm configuration achieved the highest average air velocity (0.562 m/s), leading to a more stable air curtain. This configuration provided the lowest average temperature (4.012 °C) and relative humidity (54.5%RH), significantly outperforming the 3.5 mm and 2.5 mm configurations ($p < 0.05$). Additionally, the 6 mm configuration exhibited the lowest energy consumption (24.15 kWh/day), indicating improved thermal performance and reduced cooling load. These findings highlight the critical role of airflow design in enhancing air curtain stability and energy efficiency. The 6 mm configuration is identified as the optimal design for improving thermal performance and reducing energy consumption in open refrigerated display cabinets.

Keywords: Air curtain, Open refrigerated display cabinet, Air discharge configuration, Temperature distribution, Relative humidity

1. Statement of the Problem

Refrigeration systems represent the largest share of electricity consumption in convenience stores, making energy efficiency improvement a critical issue (Hidayat et al., 2022). Structural modifications of display cabinets and the adoption of CO_2 refrigerants have been shown to significantly reduce energy consumption (Thanasoulas & Molinari, 2025).

Open refrigerated display cabinets are widely used due to their ability to enhance product visibility and stimulate impulse buying. However, these systems experience substantial cooling losses due to continuous air exchange with the surrounding environment. To mitigate this issue, air curtain technology has been introduced, which can reduce energy consumption by approximately 10–25% (Akerma et al., 2020). Nevertheless, the effectiveness of an air curtain depends strongly on the characteristics of the air discharge outlet, such as size, shape, and flow structure, which directly influence airflow stability and the ability to prevent air infiltration (Liu et al., 2025). For small plug-in display cabinets (approximately 90 cm), space limitations often lead to suboptimal

designs, resulting in unstable air curtains and increased cooling losses. Although studies have explored honeycomb structures to improve performance (Pongsupat et al., 2022), the role of air discharge characteristics remains insufficiently investigated. Therefore, this study aims to examine the effects of air discharge configurations on air curtain performance based on fluid dynamics principles. The objective is to identify optimal design guidelines that can reduce energy consumption and enhance the thermal performance of open refrigerated display cabinets. In particular, this study focuses on a 90-cm plug-in type cabinet as a case study to develop practical design approaches applicable for commercial use.

2. Objectives

To investigate the effects of air discharge characteristics on air curtain performance and energy consumption in open refrigerated display cabinets, and to determine the most optimal design approach.

3. Conceptual Framework and Hypothesis

In this study, the air discharge characteristics are defined as the independent variable, which influence airflow behavior and air curtain stability, thereby affecting the performance of the open refrigerated display cabinet as follows:

Independent Variable:

- Air discharge configuration (honeycomb outlet size in three different designs)

Dependent Variables:

- Internal cabinet temperature (°C)
- Relative humidity inside the cabinet (%RH)
- Air velocity of the air curtain (m/s)

Research Hypotheses:

At least one air discharge configuration provides significantly better energy consumption performance (kWh/day) than the others at a 0.05 level of statistical significance.

4. Research Methodology

4.1 Research methodology, this study employs a quantitative experimental approach to investigate the effects of air discharge characteristics on the performance of the air curtain in a plug-in type open refrigerated display cabinet. The air discharge sizes (6 mm, 3.5 mm, and 2.5 mm) are defined as the independent variables under controlled conditions. Data collection is carried out by measuring temperature, relative humidity, air velocity, and energy consumption as dependent variables. All measurements are obtained using calibrated instruments installed at appropriate locations. Each experimental condition is repeated to enhance data reliability. The collected data are analyzed using both descriptive and inferential statistics. Descriptive statistics include mean and standard deviation, while inferential analysis involves One-way ANOVA and t-test at a significance level of 0.05 to compare differences among the test conditions. The research instruments include a vane anemometer, infrared thermometer/thermal camera, temperature and humidity data logger, power meter, and smoke generator, among others.

4.2 Research procedure

Step 1: Study relevant concepts and theories, including the working principles of open refrigerated display cabinets, air curtain systems, air discharge design, factors affecting energy consumption, and energy efficiency standards.

Step 2: Design the research by defining objectives, identifying variables—independent variable (air discharge characteristics), dependent variables (energy consumption, temperature, air curtain performance), and Controlled variables: ambient temperature 25 o C, product load inside the cabinet (Artificial meat, M-Pack 500g, and a water bottle) , relative humidity 60%, etc. Design

the experimental setup to compare the effects of different air discharge configurations and planning comparative experiments.

Step 3: Prepare equipment, including a 90 cm display cabinet, air curtain system, and measurement (Power Meter, ultrasonic anemometer, IR camera, RH sensor)
(Pressure Sensor) and calibrate all instruments.

Step 4: Conduct experiments by installing instruments, testing different air discharge configurations, collecting data on energy consumption, temperature, and airflow, and repeating trials to reduce errors.

Step 5: Analyze data using descriptive and inferential statistics, such as ANOVA and t-test, to compare results and determine the most efficient air discharge configuration.

4.3 Data Collection was conducted at IARP Asia Co., Ltd., located at 231 Moo 6, Khao Yai Subdistrict, Cha-am District, Phetchaburi 76120, Thailand. The entire research plan spans 12 months, including 3 months of testing and 30 days of data collection on energy usage patterns for different air vent designs (10 days per design).

4.4 Data Analysis using both descriptive and inferential statistics. Descriptive analysis included the calculation of mean and standard deviation to assess the distribution of temperature and relative humidity at different locations.

For inferential statistics, One-way ANOVA was used to compare the mean values of dependent variables among the three air discharge configurations. Additionally, independent samples t-tests were performed to examine pairwise differences between each configuration

Figure 1 Test Room (Nutthakit 2026)

Figure 2 Connecting sensors and recording energy consumption data (Nutthakit 2026)

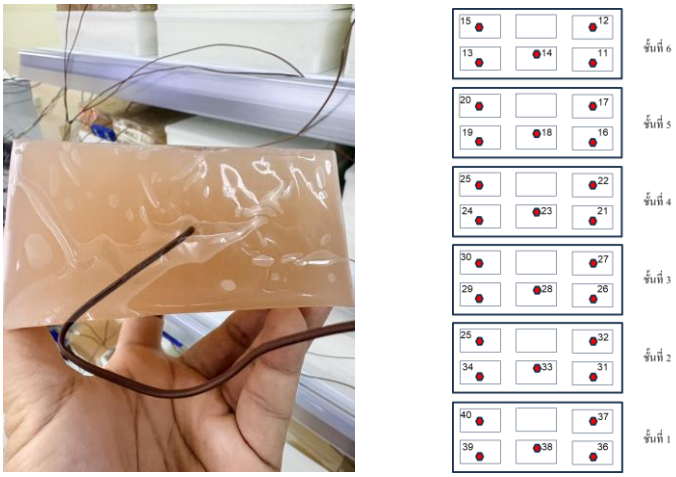

Figure 3 Artificial meat(M-Pack) used in product packaging and the location of temperature measurements in each layer. (Nutthakit 2026)

5. Results

5.1 Preliminary Data Analysis

Table 1 Air discharge configurations and energy consumption (kw/day)

Condition Type R-404		Temperature °C	Humidity (%RH)	Energy Consumption (kW/day)
6mm.	Top	4	54	24.15
	Bottom	3	55	
	Room Test	27.5	58	
3.5mm.	Top	5	66	25.00
	Bottom	3	68	
	Room Test	27	66	
2.5mm.	Top	4	67	25.08
	Bottom	2	68	
	Room Test	26.5	62	

The experimental results showed that the air outlet slot size significantly affected the performance and energy consumption of the refrigerated cabinet. The 6 mm air outlet slot provided the best performance, with the lowest average energy consumption of 24.15 kW/day, while the 3.5 mm and 2.5 mm slots consumed higher energy at 25.00 and 25.08 kW/day, respectively. This indicates that a larger air outlet slot can effectively reduce the cooling load of the refrigeration system. From a thermal perspective, the larger slot created a more stable air curtain, reducing outside air infiltration into the cabinet and lowering both sensible and latent heat loads. As a result, the compressor and refrigeration system required less operation and consumed less energy. In contrast, the medium and small slots allowed greater air leakage and mixing, increasing the cooling load and energy consumption. In addition, the 6 mm slot maintained lower temperature and relative humidity levels more effectively than the other cases, confirming the relationship between air curtain performance and refrigeration energy efficiency. Therefore, the 6 mm air outlet slot was the most suitable configuration for improving cooling performance and reducing energy consumption under the experimental conditions.

Figure 4 Refrigerators in convenience stores (Nutthakit 2026)

Calculate electricity costs:
size 6 mm. Average energy consumption = 24.15 kW/day
Electricity cost = 24.15 × 4.0 = 96.60 THB/day = 2,898 THB/month
size 3.5 mm. Average energy consumption = 24.99 kW/day
Electricity cost = 24.99 × 4.0 = 99.96 THB/day = 2,998 THB/month
size 2.5 mm. Average energy consumption = 25.09 kW/day
Electricity cost = 25.09 × 4.0 = 100.36 THB/day = 3,011 THB/month
Considering the practical application in a convenience store, a typical store would have 1,880 x 6 = 900 x 12 refrigerators. The calculation can be done as follows:

Table 2 Compare electricity bills

Size	Energy Consumption (kW/day)	Electricity Cost (THB/day)	Electricity Cost (THB/month)	Estimated Additional Cost for 12 Cabinets (THB/year/store)	Performance Summary
6 mm	24.15	96.6	2,898	–	Best performance, lowest energy consumption, stable air curtain
3.5 mm	24.99	99.96	2,998	14,544	Higher air leakage and cooling load than 6 mm
2.5 mm	25.09	100.36	3,011	16,272	Highest energy consumption and greatest cooling loss

The analysis shows that the 6 mm air outlet slot provided the best performance, with the lowest energy consumption of 24.15 kW/day and an electricity cost of approximately 2,898 THB/month. In contrast, the 3.5 mm and 2.5 mm slots consumed more energy and resulted in higher electricity costs due to greater cooling loss and outside air infiltration. For a convenience store operating 12 refrigerated cabinets, the additional electricity cost would increase by approximately 14,544 THB/year for the 3.5 mm slot and 16,272 THB/year for the 2.5 mm slot compared to the 6 mm slot. Therefore, the 6 mm air outlet slot is the most suitable design for improving cooling performance and reducing energy costs in commercial applications.

5.2 Data Analysis for Hypothesis Testing

This research on the effects of air discharge characteristics in an air curtain system on energy savings of an open refrigerated display cabinet (case study: 90 cm plug-in type) establishes three hypotheses. The statistical significance level is set at 0.05. In hypothesis testing, if the result leads to rejection of the null hypothesis (H_0) and acceptance of the alternative hypothesis (H_1), it indicates that the proposed hypothesis is supported. Conversely, if H_0 is accepted and H_1 is rejected, the hypothesis is not supported. One-way ANOVA is used to determine whether the mean energy consumption among the three groups differs significantly.

Hypothesis 1: The mean energy consumption of the three air discharge sizes (6 mm, 3.5 mm, and 2.5 mm) is not different.

Statistical hypotheses can be formulated as follows:

H_0: The mean energy consumption of the three air discharge sizes (6 mm, 3.5 mm, and 2.5 mm) is not significantly different.

H_1: At least one pair of mean energy consumption values among the three air discharge sizes (6 mm, 3.5 mm, and 2.5 mm) is significantly different.

Table 3 Comparison of air discharge diameter / energy consumption (kW/day)

SUMMARY

Groups	Count	Sum	Average	Variance
Diameter 6mm.	3	72.44	24.14667	0.005033
Diameter 3.5mm.	3	74.97	24.99	0.0019
Diameter 2.5mm.	3	75.26	25.08667	0.005733

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.604155556	2	0.802078	189.9658	3.76E-06	5.143253
Within Groups	0.025333333	6	0.004222			
Total	1.629488889	8				

	Diameter 6mm.	Diameter 3.5mm.
Mean	24.14666667	24.99
Variance	0.005033333	0.0019
Observations	3	3
Hypothesized Mean Difference	0	
df	3	
t Stat	-17.54239371	
P(T<=t) one-tail	0.000201891	
t Critical one-tail	3.711765094	
P(T<=t) two-tail	0.000403782	
t Critical two-tail	4.821498923	

	Diameter 3.5mm.	Diameter 2.5mm.
Mean	24.99	25.08666667
Variance	0.0019	0.005733333
Observations	3	3
Hypothesized Mean Difference	0	
df	3	
t Stat	-1.916373941	
P(T<=t) one-tail	0.075587677	
t Critical one-tail	3.711765094	
P(T<=t) two-tail	0.151175355	
t Critical two-tail	4.821498923	

Table 3 (continued)

	Diameter 6mm.	Diameter 2.5mm.
Mean	24.14666667	25.08666667
Variance	0.005033333	0.005733333
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-15.69089973	
P(T<=t) one-tail	4.81793E-05	
t Critical one-tail	3.165627618	
P(T<=t) two-tail	9.63587E-05	
t Critical two-tail	3.937182246	

Pairwise comparison from the t-test results (Table 2) showed that:

The 6 mm air discharge differs significantly from the 3.5 mm ($p < 0.001$).

The 6 mm air discharge differs significantly from the 2.5 mm ($p < 0.001$).

The 3.5 mm and 2.5 mm air discharges do not differ significantly ($p = 0.151$).

Statistical summary:

At a significance level of $\alpha = 0.05$:

The F-value is much greater than the F-critical value.

$P = 0.00000376$, and since $p < 0.05$, H_0 is rejected.

Conclusion: The mean energy consumption of the three air discharge groups differs significantly at the 0.05 significance level.

6. Conclusion and Discussion

The study found that the characteristics of the air outlet significantly influence the performance of the air curtain and the overall efficiency of an open display refrigerator, affecting airflow velocity, temperature, relative humidity, and energy consumption. Quantitative experiments showed that the 6 mm air outlet provided the highest and most uniform airflow, resulting in better control of temperature (mean = 4.012 °C) and relative humidity (54.5% RH) compared to the 3.5 mm and 2.5 mm outlets, with statistically significant differences ($p < 0.05$). Moreover, the 6 mm outlet consumed the least energy (24.15 kWh/day), indicating higher air curtain efficiency in reducing infiltration of external air. In conclusion, the 6 mm air outlet is the most suitable design, as it stabilizes the air curtain, reduces cooling losses, and improves energy efficiency. Previous studies have demonstrated that properly designed air curtains and air outlets can significantly enhance display case performance. For instance, installing separate air curtains for each shelf reduces temperature and heat gain (Liu et al., 2024), while adjusting the shelf aperture ratio to 25% decreases temperature variation within the cabinet to 4.3 °C (Xia et al., 2022). Energy use studies in Thai convenience stores indicate that refrigeration systems account for 72% of total energy consumption (Thitiporn Thomyapitak et al., 2024). Advanced technologies such as AI models have been used to predict product temperature and energy demand in upright closed refrigerators (Priyadarshi et al., 2025). Air Curtain Grid Systems (ACGS) are applied in large buildings to control heat exchange and reduce convective load by over 50% (Song et al., 2023). Curved Refrigeration Cooling Panels (CRCP) enhance cooling efficiency and heat transfer for large spaces (Ye et al., 2023). Vengalis & Mokšin (2023) reported that optimized air outlet and air curtain design can reduce energy consumption by 10–20%.

7. Suggestions

Future studies should investigate additional factors, including the shape, angle, flow rate, and installation position of the air outlets. Integrating computational fluid dynamics (CFD) simulations with experimental measurements is recommended to enhance accuracy. Furthermore, extending the research to multiple refrigerator types and real-world operating conditions will improve the reliability of the findings and facilitate their application on an industrial scale.

8. Acknowledgements

The authors would like to express their sincere gratitude to IARP Asia Co., Ltd., located at 231 Moo 6, Khao Yai Subdistrict, Cha-am District, Phetchaburi 76120, Thailand, for kindly providing the testing facilities and measurement instruments used in this study.

9. References

Akerma, M., Hoang, H.-M., Leducq, D., & Delahaye, A. (2020). Experimental characterization of demand response in a refrigerated cold room. *International Journal of Refrigeration*, 113, 256-265. https://doi.org/https://doi.org/10.1016/j.ijrefrig.2020.02.006

Hidayat, K., Permana, I., Chiang, W., Wang, F.-J., & Liou, C. (2022). Energy Consumption Analysis for Coupling Air Conditioners and Cold Storage Showcase Equipment in a Convenience Store. *Energies*, 15, 4857. https://doi.org/10.3390/en15134857

Liu, S., Wang, P., Zhang, Y., Meng, D., Zhang, Z., & Li, X. (2025). Performance differences of open refrigerated display cabinet under different package layouts. *Applied Thermal Engineering*, 281, 128573. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2025.128573

Liu, S., Zhang, S., Li, X., Hu, X., & Wang, Q. (2024). Technical feasibility study of open refrigerated display cabinet with independent air curtain [Article]. *Thermal Science and Engineering Progress*, 53, Article 102723. https://doi.org/10.1016/j.tsep.2024.102723

Priyadarshi, G., Hoang, H.-M., Hunlede, R., Paviet-Salomon, Y., Delahaye, A., & Naik, B. K. (2025). Application of artificial intelligence models for assessing the performance of closed vertical refrigerated display cabinet-A comparative study of different operating scenarios. *Engineering Applications of Artificial Intelligence,* 147, 110332.

Pongsupat, P., Taweekun, J., & Saengsikhiao, P. (2022a). Investigation and Analysis of Air Curtains for the Improvement of Refrigeration Energy Efficiency [Article]. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,* 92(1), 212-225. https://doi.org/10.37934/arfmts.92.1.212225

Song, L., Li, K., Zhang, X., Hua, J., & Zhang, C. (2023). Differentiated Control of Large Spatial Environments: Air Curtain Grid System [Article]. *Sustainability (Switzerland),* 15(6), Article 5489. https://doi.org/10.3390/su15065489

Thanasoulas, S., & Molinari, M. (2025). Advancing energy efficiency and sustainability in supermarkets: A comprehensive analysis of integrated technologies and their impact on energy consumption. *Energy Reports*, 13, 2855-2875. https://doi.org/https://doi.org/10.1016/j.egyr.2025.02.021

Thomyapitak, T., Saengsikhiao, P., Vessakosol, P., & Taweekun, J. (2024). A Study on the Energy Efficiency of an Energy Management System for Convenience Stores. *Energies*, 17, 4941. https://doi.org/10.3390/en17194941

Xia, J., Guo, J., Wei, X., Zeng, Z., & Lü, E. (2022). Effect of Shelf Aperture Ratio on the Temperature Distribution of an Open Refrigerated Display Cabinet [Article]. *Applied Sciences (Switzerland)*, 12(20), Article 10296. https://doi.org/10.3390/app122010296

Ye, M., Serageldin, A. A., & Nagano, K. (2023). Numerical and Parametric Study on Open-Type Ceiling Radiant Cooling Panel with Curved and Segmented Structure [Article]. *Energies*, 16(6), Article 2705. https://doi.org/10.3390/en16062705

PHYSICAL AND SPATIAL FACTORS INFLUENCING THE ADAPTIVE REUSE OF SHOPHOUSES AS CREATIVE PRODUCTION STUDIOS IN BANGKOK, THAILAND

Ladapan Chokchaiyakul and Piyarat Nanta*

65026045@kmitl.ac.th and piyarat.na@kmitl.ac.th

Department of Interior Architecture, School of Architecture, Art, and Design,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: piyarat.na@kmitl.ac.th

ABSTRACT

Greater Bangkok has a significant number of vacant shophouses that are frequently overlooked as potential sites for film and advertising production studios. This study addresses three primary questions: which physical characteristics render a shophouse suitable as a cost-effective studio; to what extent do these spaces meet professional production requirements; and how do studio operators accommodate technical needs within buildings not originally designed for such purposes. The research utilizes an inductive qualitative methodology, employing a multi-case study approach to provide an in-depth analysis. Five studios Camelian, Camelots, Eatery 3, Studio Bangna, and Wayra Studio were purposively selected because they are renovated old shophouses and commercial buildings that have become popular filming locations within the past 5 years. These case studies are located across Greater Bangkok and its surrounding suburban areas, specifically featuring shophouse and row house typologies, excluding detached houses, to focus on the unique constraints of urban commercial structures. Data collection involved systematic site visits, detailed photographic documentation, and semi-structured interviews with a sample group consisting of building owners and professional studio managers (Informants S1, S2, and S3) to understand design strategies and production requirements. The findings indicate that multi-story configurations are particularly advantageous, as they allow shooting, storage, wardrobe, and set construction to occur within a single building, thereby reducing time lost to inter-site transfers. The flexible layouts facilitate reconfiguration between productions without necessitating major structural alterations. Although parking is limited at most sites, central locations and nearby off-site arrangements generally mitigate this challenge. The buildings typically possess sufficient structural integrity for professional equipment, though some require targeted reinforcement prior to use. Renovation costs were substantially lower than those for new construction, with owners reporting savings of up to 50%. Additionally, features such as worn walls, historic shopfront details, and the authentic atmosphere of established neighborhoods impart productions with a texture and authenticity that purpose-built studios cannot replicate. The adaptive reuse of shophouses thus emerges as a practical and cost-effective strategy for expanding studio capacity while productively utilizing otherwise vacant buildings.

Keywords: Adaptive reuse, Shophouses, Creative production studios, Sense of place, Urban regeneration

1. Statement of the Problem

Vacant buildings are a common problem in cities around the world. In Italy, some local governments sell abandoned properties for €1 to help bring people back to declining towns. In Japan, foreigners can buy akiya, or empty houses, to help revive shrinking rural areas (Peterson, 2024). Even though the policies differ, the main issue is the same: unused buildings have negative effects on their neighborhoods. Bangkok faces these challenges as well (McLaughlin, 2024).

Studies show that reusing old buildings can help prevent neighborhood decline and keep parts of local history alive (Bullen & Love, 2011; Mısırlısoy & Günçe, 2016). In film production, there is a strong preference for real locations over built sets, both because they can be cheaper and because existing buildings have unique looks that are hard to replicate in a studio (Unzurrunzaga & Branchi, 2013). As a result, more producers and studio operators in Bangkok are interested in using vacant shophouses.

One reason for vacant buildings in Bangkok is that younger people now prefer to live in condos near transit and city centers. This shift has led to many shophouses and older family homes being left empty for long periods (Ramasoot, 2022). These empty buildings make streets less lively, lower property values, and create a feeling of neglect that is hard to fix with rules alone (Bullen, 2007; Conejos et al., 2011; Escolà-Gascón et al., 2024). To solve this, new ideas are needed to reuse these buildings.

People working in Thailand's creative industries have started turning empty shophouses into permanent production spaces, instead of renting places like restaurants or hotel lobbies for short periods. This has clear benefits: these adapted shophouses can be modified to meet the technical needs of professional shoots, such as stronger floors, better equipment movement, and sufficient power for lighting requirements that temporary venues often lack (Ampansuk, 2018). While it is not yet clear how widely this practice will spread, early examples show great promise.

Despite the growing body of literature on adaptive reuse, most existing studies primarily focus on architectural conservation, sustainability, and economic feasibility (Bullen & Love, 2011; Conejos et al., 2011; Vafaie et al., 2023). While these frameworks provide valuable criteria for evaluating physical building performance, they remain largely detached from the operational realities of creative production environments, particularly in film and advertising industries.

At the same time, research on creative industries tends to emphasize cultural economy, urban branding, and location aesthetics (Scott, 2010; Pratt, 2012; Richards, 2011), but rarely examines how spatial configuration, building systems, and vertical logistics directly affect production workflows. This creates a critical disconnect between architectural evaluation models and industry-specific spatial performance.

Moreover, there is a lack of empirical research focusing on Southeast Asian contexts especially Bangkok where shophouse typologies present unique spatial constraints, such as narrow floor plates, vertical stacking, and limited access. Existing studies seldom address how these buildings can be transformed into integrated, one-stop production environments that support both technical and creative requirements.

Therefore, this study addresses three key gaps: (1) the absence of an integrated framework linking adaptive reuse with creative production workflows, (2) the limited understanding of how spatial and technical factors influence film production in reused buildings, and (3) the lack of context-specific research on shophouse transformation in rapidly changing urban environments.

This study has three main goals: to see if vacant shophouses can be used as affordable professional studios, to check how well their design and layout match Boonprasong's evaluative framework (Boonprasong, 2022), and to find out how studio operators have added technical

production needs to buildings that were not built for this purpose. The research also examines specific building features, such as floor-to-floor height, structural load capacity, and vertical circulation, that affect building selection.

By addressing these gaps, this research contributes to the development of a performance-oriented adaptive reuse model that integrates architectural, technical, and experiential dimensions within creative production contexts. More generally, it aims to show that careful adaptive reuse can bring economic and social benefits to both studios and their neighborhoods (Chaiyarattanon, 2025).

2. Objectives

These objectives guide the study and shape the methods and analysis described next. Together, they demonstrate how the research addresses the issues discussed earlier.

2.1 To identify key architectural factors and industry-specific criteria such as vertical logistics—that influence the selection of filming locations and parking management, based on Boonprasong's conceptual framework (Boonprasong, 2022).

2.2 To promote sustainable metropolitan management by creating incentives for the preservation of valuable existing buildings through adaptive reuse and to create guidelines for determining the layout of usable space in a building, generating both economic and social returns on investment (SROI) (Chaiyarattanon, 2025).

3. Conceptual Framework and Hypothesis

The framework illustrates how adaptive reuse transforms vacant shophouses into integrated spatial systems by combining tangible and intangible components, resulting in production-oriented spatial performance and generating economic, creative, and urban values.

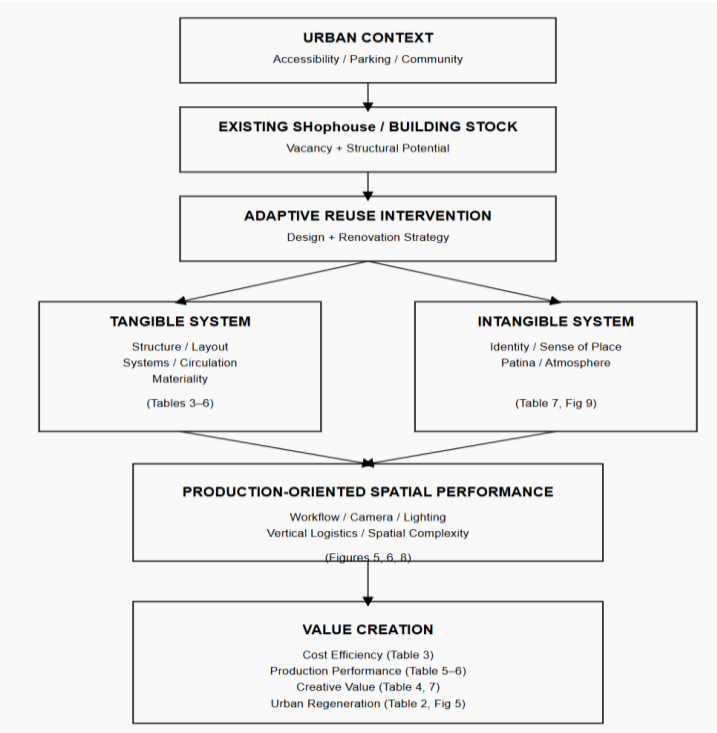

Figure 1 Conceptual Framework Linking Adaptive Reuse to Production-Oriented Spatial Performance

This study uses an approach that considers both the building's physical features and how well it functions as a studio. These factors are seen as connected, not separate. The layout, structure, and materials of a building together shape what can and cannot be done during daily production. Each case is studied in its city setting, with a focus on how space works in practice.

The primary analytical tool is Boonprasong's evaluative framework, which extends beyond physical description to assess the functional and experiential value a building can realistically support. The criteria are divided into two groups (Boonprasong, 2022):

3.1 Tangible Components: This group evaluates the building's physical suitability for professional film production across several dimensions. Site context (the physical setting, including geographic location, access routes, and parking availability) shapes logistical feasibility before a crew even enters the building. Floor structural capacity means the building's ability to bear loads, such as heavy lighting rigs, camera platforms, and set materials. Visible finishes, including the final surface of floors and walls, influence the range of looks a studio can offer without extensive dressing. Building systems, especially three-phase electrical supply (an advanced form of electrical wiring that provides greater power capacity) determine if the infrastructure can sustain the power demands of professional equipment. Service lifts (elevators designed to transport equipment and materials), internal layout (the arrangement of rooms), and circulation flows (how people and items move through space) govern process efficiency during production. Furniture arrangements, whether movable or built-in, affect how easily the space can be rearranged, while ceiling height (the distance from floor to ceiling) and façade design (the building's exterior appearance) shape both practical and visual aspects of the studio.

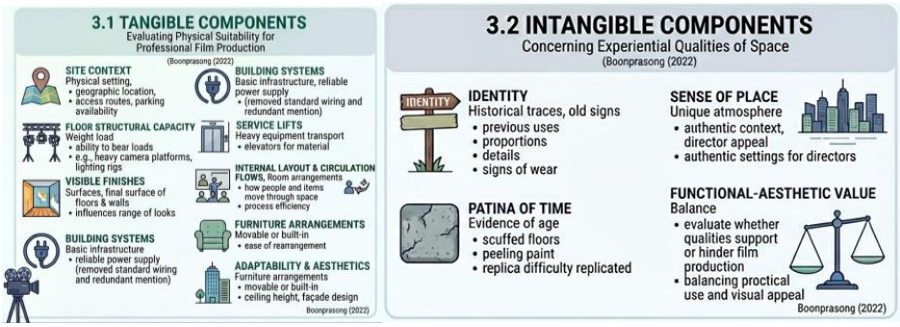

Figure 2 Tangible Components and Intangible Components

3.2 Intangible Components: While tangible criteria address a building's physical capacity, intangible criteria concern the experiential qualities of space. Identity refers to the historical traces left by a building's previous uses, such as proportions, details, and signs of wear. Sense of place denotes the unique atmosphere that situates a building within its specific context, which is immediately apparent to directors seeking authentic settings. Patina of time encompasses visible evidence of age, including scuffed floors, peeling paint, and weathered concrete features that develop over years and cannot be easily replicated in new buildings. Functional-aesthetic value evaluates whether these qualities support or hinder film production by balancing practical use and visual appeal (Boonprasong, 2022).

4. Research Methodology

4.1 Research Design and Approach

This study adopts a qualitative, inductive multi-case study design with embedded comparative and quasi-experimental analytical logic to investigate the adaptive reuse of shophouses as creative production studios in Bangkok. The research is exploratory, addressing an underexamined intersection between architectural reuse and film production environments.

While the study does not test predefined hypotheses, it develops analytical generalizations through systematic cross-case comparison. To strengthen methodological rigor, quasi-experimental logic is incorporated by evaluating multiple cases under a shared analytical framework (Boonprasong, 2022). Each case functions as a comparable unit of analysis, enabling controlled examination of how spatial, structural, and contextual variables influence production performance.

The research follows a replication logic, where patterns identified across cases increase reliability and support theory-building beyond individual observations. This approach aligns with established qualitative research methodologies in architecture and urban studies.

Five case studies Camelian Theme Studio, Camelots Studio, Eatery 3, Studio Bangna, and Wayra Studio were selected through purposive sampling, based on the following criteria:

- adaptive reuse of shophouses or commercial buildings,
- active use as film or photography studios within the past five years, and
- variation in scale, location, and operational characteristics.

The study focuses on Greater Bangkok, particularly dense urban and peri-urban areas, to examine the constraints and potential of commercial building typologies. Detached houses were excluded to maintain typological consistency.

4.2 Research Procedure

The study follows a structured multi-phase research procedure to ensure methodological transparency and replicability:

- Case identification and selection using purpose and snowball sampling
- Field investigation through multiple site visits under different operational conditions (inactive vs active production)
- Systematic spatial and technical documentation
- Semi-structured interviews with key stakeholders
- Cross-case comparative analysis
- Synthesis and framework development

This stepwise process ensures a clear linkage between data collection, analysis, and theoretical interpretation.

4.3 Data Collection Methods

Data collection employed methodological triangulation, integrating three primary sources:

- On-site Observation and Spatial Documentation
- Systematic field observations documented spatial configuration, circulation patterns, material conditions, and technical systems (lighting, electrical capacity, HVAC, and vertical logistics). Photographic and diagrammatic records were used to support spatial analysis.
- Semi-Structured Interviews

Interviews were conducted with key informants (S1–S3), including building owners and studio managers. The interview protocol was structured based on Boonprasong's evaluative framework, ensuring consistent coverage of both tangible and intangible dimensions across all cases.

- Secondary Data and Supporting Materials

Supplementary sources, including studio media, online documentation, and prior research, were used to contextualize findings and support interpretation.

Sampling combined purposive selection (to ensure relevance) and snowball sampling (to identify key stakeholders), enabling both depth and contextual richness.

4.4 Analytical Framework and Comparative Logic

The analysis is guided by Boonprasong's evaluative framework (2022), which categorizes findings into:

- Tangible components (e.g., structure, layout, building systems)
- Intangible components (e.g., identity, sense of place, patina, functional–aesthetic value)

To enhance analytical rigor, the study applies a quasi-experimental comparative structure, in which:

- All cases are evaluated using identical criteria (controlled variables)
- Variations in spatial and contextual conditions are treated as independent variables
- Observed differences in production performance (e.g., workflow efficiency, spatial usability) are interpreted as outcomes

This approach enables a form of controlled qualitative comparison, allowing the study to move beyond descriptive analysis toward causal interpretation in a non-statistical framework.

4.5 Validity, Reliability, and Research Rigor

To ensure methodological robustness, the study applies multiple validation strategies:

- Triangulation: Cross-verification of observational, interview, and visual data
- Member Checking: Informants reviewed interview transcripts and preliminary findings
- Cross-Case Replication Logic: Repeated patterns across cases strengthen reliability
- Thick Description: Detailed spatial and operational documentation enhances transferability
- Analytical Transparency: Explicit linkage between data, framework, and conclusions

These measures enhance the study's credibility, dependability, and confirmability, aligning with international qualitative research standards.

4.6 Scope and Limitations

Despite its strengths, the study has several limitations:

- The sample size (five cases) limits statistical generalization
- Findings are context-specific to Bangkok's urban environment
- The qualitative approach prioritizes depth over quantitative measurement

However, through comparative multi-case analysis and quasi-experimental logic, the study achieves analytical generalization, making the findings applicable to similar adaptive reuse contexts in other metropolitan settings.

5. Results

The results are based on site observations, field data, and semi-structured interviews with key informants. These sources, along with supplementary research, informed the comparative study of the five case study buildings, clarifying their technical and physical attributes in accordance with Boonprasong's conceptual framework.

Table 1 Summary of in-depth interviews and comparative analytical findings

Informant & Role/Experience	Shared Findings (Convergence)	Distinct Emphases (Divergence)
S1: Mr. P (Camelian & Camelots) Building owner & photographer (12+ years)	All cases emphasize spatial flexibility, functional zoning, and material authenticity to support filming. Existing structures are adapted rather than demolished, enabling efficient workflows. Intangible qualities identity, atmosphere, and uniqueness enhance visual and market value.	Focus on preservation of original materials (brick, concrete) and structural reinforcement; strong emotional attachment to family-owned building; emphasis on "timeless aesthetic" and urban character.
S2: Ms. L (Eatery 3 & Studio Bangna) Building owner (4+ years commercial operations)		Prioritizes accessibility and logistics, including main-road location and parking (15–18 spaces); highlights flexibility via loose furniture and zoning; views uniqueness as a competitive advantage.
S3: Ms. N (Wayra Studio) Studio manager (2 years)		Emphasizes adaptation within residential constraints; limits crew size (≤30); focuses on community sensitivity and creating a "home-like" atmosphere.

Successful adaptive reuse of shophouses as production studios relies on integrating spatial, technical, and intangible factors. Flexible layouts, efficient circulation, and authentic materiality support filming operations, while identity and atmosphere enhance creative value. Key differences lie in priorities: preservation and aesthetics (S1), accessibility and commercial optimization (S2), and constraint-based adaptation within residential contexts (S3).

Table 2 Comparative analysis of architectural and environmental conditions

Case Study & Typology/Scale	Spatial & Physical Characteristics	Urban Context & Accessibility
Camelian (Single unit, 4 floors, 256 sqm)	Mixed-use (café + studio); attic and basement; dedicated staff circulation; preserved material palette	Traditional alley (Wat Tha Phra); restricted access; no on-site parking
Camelots (3-unit, 5 floors, 1,400 sqm)	Interconnected volumes; double-height void; skylight; loading slope; segregated circulation; reinforced structure	Inner urban corridor (Ekachai–Bang Bon); moderate-to-high accessibility; external parking
Eatery 3 (2-unit corner, 400 sqm)	Mezzanine insertion; lightweight partitions; vaulted ceiling; flexible spatial zoning	Corner site (Bangna–Trad Soi 16); high visibility; good vehicular access
Studio Bangna (3-unit, 3 floors, 580 sqm)	Multi-scenario zoning; service lift; blackout systems; large floor plates	Arterial road (Bangna–Trad Km.2); high accessibility; outsourced parking
Wayra Studio (Townhome, 3.5–4.5 floors, 300 sqm)	Double-height living space; balcony lighting; adaptable rooms; mobile setup	Gated residential enclave (Romklao); limited access and parking

(a) (b) (c) (d) (e)

Figure 3 Case study production studios adapted from shophouses in Greater Bangkok: (a) Camelian; (b) Camelots; (c) Eatery 3; (d) Studio Bangna; and (e) Wayra Studio

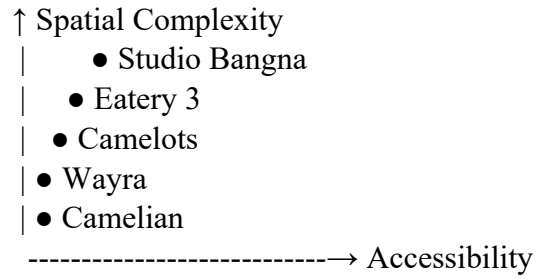

Figure 4 Spatial Complexity vs Accessibility of Case Study Shophouses

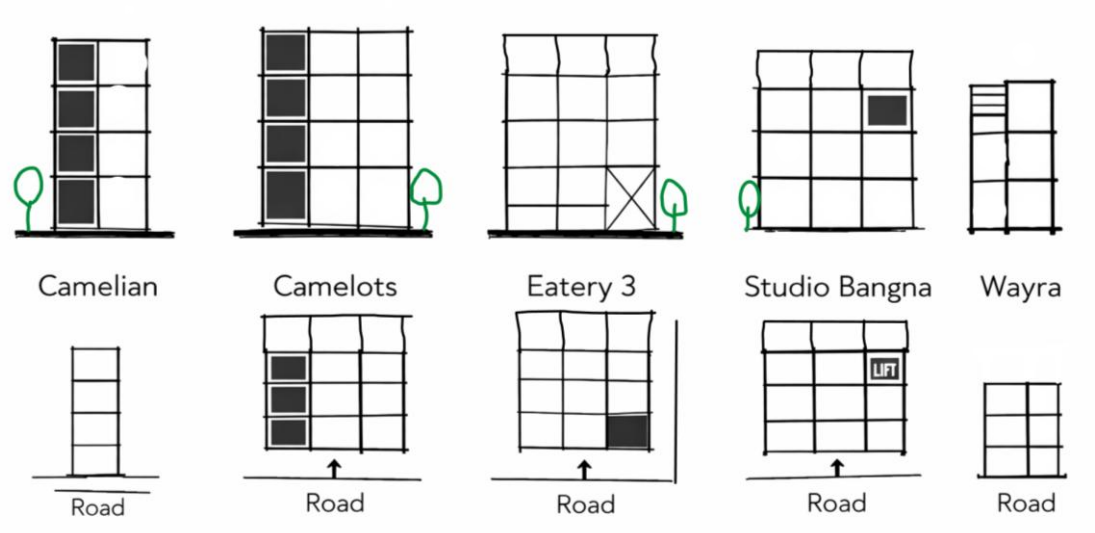

Figure 5 Comparative Sections and Plans of Adaptive Reused Shophouse Case Studies in Greater Bangkok

Across all cases, adaptive reuse is shaped by accessibility, parking, and community context. Limited on-site parking is a consistent constraint, often resolved through external solutions. Main-road locations support higher production intensity and integrated workflows, while alley and

residential settings impose limits on access, noise, and crew size. Smaller units enable niche, small-scale production, whereas multi-unit buildings support greater integration and logistical complexity. Overall, success depends on aligning spatial capacity with accessibility and contextual constraints.

Table 3 Cross-case synthesis of structural and architectural characteristics

Synthesis Categories	Common Conditions (Cross-Case)	Case Mapping with Spatial Evidence
Original Typology & Scale	Shophouse-derived typologies with vertical stacking (single, multi-unit, corner, townhouse)	Case 1 Camelian *(256 sqm)*: compact single-unit Case 2 Camelots *(1,400 sqm)*: multi-unit aggregation Case 3Eatery 3 *(400 sqm)*: corner typology Case 4 Studio Bangna *(580 sqm)*: commercial multi-unit Case 5 Wayra *(300 sqm)*: townhouse adaptation
Structural Condition & Intervention	Generally, structurally viable; selective reinforcement; adaptive reuse preferred over demolition	Case 1: minor reinforcement (café + studio reuse) Case 2: steel reinforcement (dungeon/basement) Case 3: minimal intervention Case 4: repaired + reinforced Case 5: low intervention (existing residential structure)
Spatial Organization & Innovation	Vertical zoning, split circulation, and flexible layouts support production workflows	Case 1: café + deep-plan studio (split circulation) Case 2: mezzanine + "dungeon" basement for scenographic depth Case 3: mezzanine + flexible zoning Case 4: vertical multi-theme studio (stacked production floors) Case 5: double-height space enabling lighting + camera angles
Materiality & Architectural Character	Retention of original materials enhances authenticity and visual quality	Case 1: brick, travertine, exposed finishes Case 3: preserved curved ceiling Others: partial retention + adaptation
Technical Systems & Infrastructure	Upgraded systems support production requirements	Case 2 & 4: three-phase electricity, service systems Case 1 & 3: moderate upgrades Case 5: standard residential systems
Low-Intervention Adaptation	Minimal modification strategies for small-scale production	Case 5 (primary), Case 3 (secondary)

(a) (b) (c) (d) (e)

Figure 6 Case mapping of structural and spatial adaptation: (a) Camelian café + deep-plan studio; (b) Camelots mezzanine + dungeon basement; (c) Eatery 3 mezzanine + flexible zoning; (d) Studio Bangna vertical multi-theme studio; (e) Wayra Studio double-height

Structural capacity and building scale directly influence the degree of intervention and spatial transformation. Larger multi-unit configurations (Cases 2 and 4) enable complex, high-intensity production through vertical integration and technical upgrades, while smaller units (Cases 1 and 5) rely on spatial efficiency and selective adaptation. Case 3 represents a hybrid condition, emphasizing flexibility and rapid reconfiguration. Spatial elements such as basements, mezzanines, and double-height volumes function as critical architectural devices that expand production capability within constrained footprints.

Table 4 Cross-case synthesis of surface finishes and material strategies

Synthesis Categories	Common Conditions (Cross-Case)	Case Mapping
Materiality & Surface Expression	Predominant use of natural materials (stone, brick, concrete) to enhance visual realism under production lighting	Case 1, 2, 3, 4
Surface Variation by Zone	Finishes vary across floors and spaces, reflecting different thematic and production requirements within the same building	Case 1, 2, 3, 4
Patina & Imperfection as Asset	Aging surfaces and material imperfections are leveraged to enhance narrative depth and authenticity	Case 1, 2
Flexible & Thematic Surfaces	Use of adaptable finishes (lightweight walls, decorative layers) to support rapid scene transformation	Case 3, 4
Technical Surface Control	Integration of lighting control elements (e.g., blackout systems) to regulate visual environments	Case 4
Standardized Finishes (Low Diversity)	More uniform and conventional finishes with limited variation	Case 5
Support Spaces & User Functionality	Emphasis on dressing rooms, restrooms, and crew support areas to enhance operational efficiency	Case 3, 4

Surface finish strategies balance realism, flexibility, and operational performance. Natural materials dominate due to their visual reliability under lighting conditions, while variation across zones enables multiple scenic application uses within a single structure. Key differences emerge between cases emphasizing authenticity and patina (Cases 1–2), expressive and highly adaptable environments (Cases 3–4), and standardized, low-intervention finishes (Case 5). Overall, surface design functions as both a visual and operational system supporting production efficiency

Table 5 Cross-case synthesis of building equipment systems

Synthesis Categories	Common Conditions (Cross-Case)	Case Mapping
Electrical Capacity & Lighting	Enhanced electrical systems are essential for production; three-phase power supports high-intensity lighting and equipment	Case 1, 2, 4
Water & Sanitary Systems	Standard systems are generally sufficient, with selective upgrades to support crew usage and production needs	Case 1, 2, 3, 4, 5
Environmental Control (HVAC & Acoustics)	Air conditioning and noise control are critical for filming performance and comfort	Case 2, 3, 4, 5
Digital Connectivity	Reliable high-speed internet supports digital production workflows	Case 1, 2, 3, 4, 5
Vertical Circulation & Logistics	Movement systems (e.g., service lifts, staff circulation) are key to managing equipment and workflows in multi-story buildings	Case 1, 2, 3, 4
Low-Intensity Systems	Basic residential systems with minimal upgrades; reliance on portable or temporary equipment	Case 5

Building systems function as a critical enabler of production performance, particularly in terms of electrical capacity, environmental control, and logistical efficiency. Across cases, infrastructure evolves from basic residential setups to more integrated, production-oriented systems. Higher-capacity buildings (Cases 2 and 4) incorporate advanced electrical and circulation systems to support intensive workflows, while smaller-scale cases (1 and 3) adopt selective upgrades within spatial constraints. Case 5 represents a low-intensity model, relying on minimal infrastructure and portable solutions. Overall, system integration reflects the alignment between building capacity and production demands.

Table 6 Cross-case synthesis of interior space, furniture, and production functionality

Synthesis Categories	Common Conditions (Cross-Case)	Case Mapping with Spatial Evidence
Spatial Configuration & Camera Logic	Interiors are organized to optimize sightlines, camera paths, and focal length requirements; vertical stacking enables multi-scene production	Case 1: Deep-plan (3 units), long focal length (200mm), tall window volumes *(Insert image: deep perspective shot)* Case 2: Lens-oriented layout (35/50mm), attic and dungeon spaces with controlled camera paths *(Insert image: camera path / dungeon)* Case 3: floor-based programming *(Insert image: sectional zoning)* Case 4: vertical multi-theme zoning *(Insert image: stacked scenes)* Case 5: double-height domestic space *(Insert image: lighting volume)*
Furniture & Furnishing Strategy	Predominantly movable, adaptable, and scene-oriented furniture to support rapid reconfiguration	Case 1: curated vintage + patina Case2: luxury-realistic, lens-prioritized materials Case 3: lightweight + stenographic surfaces Case 4: thematic sets + seasonal props Case 5: minimal, fully movable furniture
Production Functionality & Workflow	Efficient circulation, zoning, and flexible setups enable multi-scene and multi-use production within constrained footprints	Case 1: controlled circulation (staff vs camera) Case 2: high-capacity workflow + lighting control Case 3: mixed-use adaptability Case 4: one-stop production system Case 5: small crew, domestic control
Spatial Identity & Scene Creation	Spatial constraints are transformed into distinctive scenographic environments, enhancing uniqueness and production value	Case 1–2: cinematic realism through depth + patina Case 3–4: high thematic Case 5: domestic realism

(a) (b) (c) (d) (e)

Figure 7 Comparative spatial and scenographic strategies in adaptive reuse studios
(a) Camelian deep perspective (200mm); (b) Camelots dungeon and camera path; (c) Eatery 3 mezzanine and flexible layout; (d) Studio Bangna multi-theme vertical studio; (e) Wayra Studio double-height with natural light

Interior design operates as a performance-driven system integrating spatial configuration, furniture adaptability, and production workflow. Across cases, unobstructed sightlines, movable furnishings, and vertical zoning enable efficient multi-scene production. Differences emerge in scale and intensity: larger, multi-unit studios (Cases 2 and 4) support complex, high-capacity production environments, while smaller cases (1 and 5) rely on controlled layouts and spatial efficiency. Case 3 represents a hybrid model emphasizing flexibility and rapid transformation. Overall, interior strategies align spatial design with production performance, maximizing both functional efficiency and scenographic value.

Table 7 Cross-case synthesis of intangible elements

Synthesis Categories	Common Conditions	Case Mapping with Spatial/Visual Evidence
Tracing of Identity	Adaptive reuse reinterprets existing building narratives into new production identities, enhancing storytelling value and market positioning	Case 1: industrial office → cinematic infrastructure *(Insert image: exposed structure)* Case 2: Mezzanine-constrained layout → niche thematic sets (attic/sewer) *(Insert image)* Case 3: corner commercial → branded studio *(Insert image: façade/interior branding)* Case 4: fragmented building → "scar as identity" *(Insert image: structural traces)* Case 5: show house → idealized domestic setting *(Insert image: staged interior)*
Sense of Place	Atmosphere is deliberately constructed to support specific cinematic moods and audience perception	Case 1: luxury European/NYC ambiance *(Insert image: high angle shot)* Case 2 niche thematic sets (attic, sewer) *(Insert image)* Case 3: vintage café realism *(Insert image)* Case 4: multi-theme vertical environments *image:* Case 5: minimal domestic atmosphere
Patina of Time	Material aging and imperfections are leveraged as visual assets to enhance realism and reduce production costs	Case 1–2: strong patina expression *(Insert image: texture close-up)* Case 3: selective preservation *(Insert image: curved ceiling)* Case 4: imperfections as scenographic assets Case 5: minimal patina, controlled perfection
Functional–Aesthetic Integration	Spatial identity and aesthetic qualities are closely linked to production performance and workflow efficiency	Case 1: lens-driven narrative space Case 2: long focal length + circulation efficiency Case 3: one-stop flexible system Case 4: high-performance vertical production *(Insert image: workflow)* Case 5: small-scale flexible domestic setup

(a) (b) (c) (d) (e)

Figure 8 Cross-Case Synthesis of Intangible Elements (a) Camelian: Industrial traces → cinematic studio, (b) Camelots: Spatial constraints → niche sets, (c) Eatery 3: Corner unit → branded studio, (d) Studio Bangna: Structural scars → identity; minimal reuse, maximum reconfiguration(e) Wayra Studio: Show house → domestic realism

Intangible elements play a critical role in shaping the success of adaptive reuse as production environments. Across cases, identity transformation enhances narrative depth and market differentiation, while a strong sense of place enables studios to operate within distinct visual niches. Patina is widely recognized as both a visual and economic asset, contributing to realism and reducing the need for artificial set construction. Differences emerge in the degree of control and expression: Cases 1 and 2 emphasize authenticity and material memory, Cases 3 and 4 prioritize thematic diversity and adaptability, and Case 5 reflects controlled minimalism. Overall, the integration of identity, atmosphere, and spatial performance generates both cultural and commercial value.

6. Conclusion and Discussion

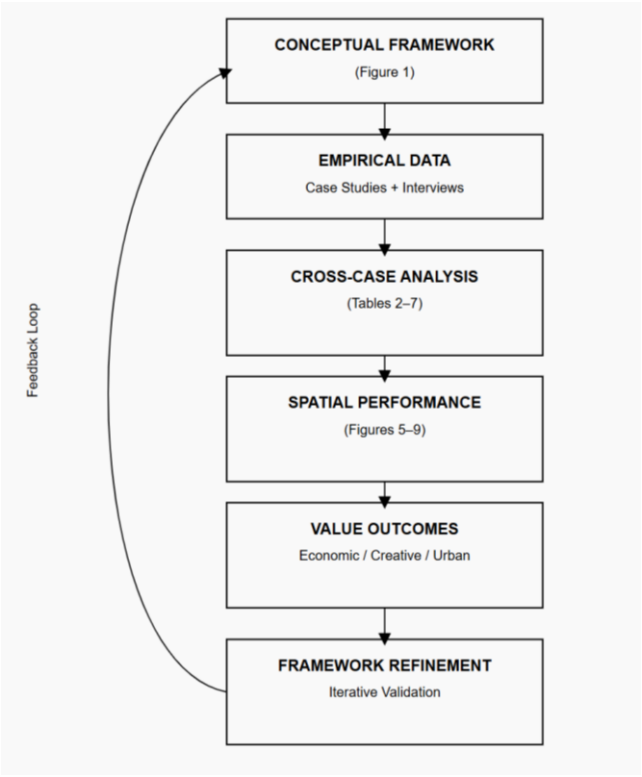

Figure 9 Validation Loop of the Proposed Framework

The diagram illustrates the iterative validation process in which the conceptual framework (Figure 1) is tested against empirical findings (Tables 2–7 and Figures 5–8). The results inform value outcomes and subsequently refine the framework, demonstrating a feedback loop between theory and practice.

This study demonstrates that vacant shophouses and commercial buildings in Greater Bangkok possess strong potential for adaptive reuse as film and advertising studios. The findings indicate that reusing existing structures can significantly reduce construction costs by up to 50 percent while simultaneously minimizing material consumption and environmental impact, aligning with established adaptive reuse literature (Bullen, 2007; Bullen & Love, 2011; Douglas, 2006). Empirical evidence from the five case studies further confirms that vertical spatial configurations enable efficient "one-stop" production systems, integrating multiple functions within a single structure. This is clearly supported by Table 3 and Figure 6, where competitive advantages. As shown in Table 1 and Table 2, operators prioritize flexibility, identity, and accessibility as critical factors influencing both operational efficiency and market positioning. These findings are consistent with urban theory on creative industries, which highlights the importance of space, identity, and cultural production in shaping economic value (Evans, 2009; Pratt, 2008). Furthermore, in film-related contexts, the use of real locations enhances both production quality and cultural engagement, reinforcing the value of adaptive reuse in media production (Beeton, 2016).

Despite these contributions, the study also identifies several limitations. Parking constraints, accessibility challenges, community vertical zoning, structural adaptation, and spatial stacking directly contribute to production efficiency and operational integration. At the urban scale, these findings reinforce the role of adaptive reuse as a sustainable development strategy that preserves built heritage while generating new economic value (Conejos et al., 2011).

The study also validates the applicability of Boonprasong's evaluative framework in assessing the physical suitability of buildings for adaptive reuse, particularly in relation to structure, layout, and building systems. However, the findings suggest that creative production environments require an expanded evaluative scope beyond conventional architectural criteria. While Boonprasong's framework effectively addresses measurable physical components (Boonprasong, 2022), this research demonstrates that adaptive reuse must also incorporate experiential, cultural, and performance-based dimensions. This aligns with international studies emphasizing that adaptive reuse involves both tangible and intangible values, including cultural significance and user experience (Plevoets & Van Cleempoel, 2011; Yung & Chan, 2012). Evidence from Table 7 and Figure 7 highlights how identity, sense of place, and patina of time function as critical drivers of both aesthetic and economic value in production spaces.

A key finding of this study is that spatial configuration must be understood as a performance-driven system rather than static architectural condition. The organization of space directly influences filming logic, including camera movement, sightlines, and production workflow. This is particularly evident in Table 6 and Figure 6, where spatial arrangements such as deep-plan layouts, mezzanines, and double-height volumes enable diverse filming scenarios within constrained footprints. These findings are consistent with film production theory, which emphasizes the importance of spatial control and workflow efficiency in audiovisual environments (Rosenthal & Eckhardt, 2015). Moreover, from a spatial theory perspective, the results support the notion that spatial configuration fundamentally shapes movement patterns and operational performance (Hillier, 1996). In this context, vertical circulation systems, zoning strategies, and internal layouts become critical determinants of studio functionality.

Materiality also emerges as a significant factor in adaptive reuse for creative production. The study finds that natural materials such as exposed brick, concrete, and aged finishes enhance visual realism under studio lighting conditions, reducing the need for artificial set construction. This is strongly supported by Table 4, which demonstrates consistent use of authentic materials across

multiple cases. Additionally, the concept of "patina of time" is identified as both a visual and economic asset, contributing to narrative depth and production value. These findings align with broader research highlighting the role of material authenticity and aging in enhancing the success of adaptive reuse projects (Vafaie et al., 2023; Plevoets & Van Cleempoel, 2011).

Beyond architectural performance, this study situates adaptive reuse within the broader context of the creative economy. The transformation of vacant shophouses into production studios contributes to the development of creative industry ecosystems, where spatial uniqueness and authenticity become key regulations, particularly in residential areas, remaining significant barriers to large-scale production. These issues are evident in Figure 4, where lower accessibility correlates with reduced spatial complexity and production capacity. Such constraints are consistent with findings from international adaptive reuse studies in dense urban environments (Maghsoodi Tilaki et al., 2026; Escolà-Gascón et al., 2024). Additionally, the study is limited by its qualitative methodology and relatively small sample size of five case studies, which may affect the generalizability of the findings.

Future research should address these limitations by incorporating quantitative evaluation methods, such as Social Return on Investment (SROI), to measure economic, social, and environmental impacts more systematically. Longitudinal studies could also track the performance of adaptive reuse projects over time, including metrics such as revenue generation, occupancy rates, user satisfaction, and changes in property value. Furthermore, emerging technologies—such as virtual production and integrated digital systems—offer new opportunities to expand the capabilities of adaptive reuse studios, suggesting a promising direction for future investigation (Vafaie et al., 2023).

This study makes a clear theoretical contribution by extending adaptive reuse discourse from a static, object-based evaluation toward a performance-oriented spatial framework. Specifically, it integrates three domains: (1) architectural evaluation frameworks focused on physical and functional criteria (Boonprasong, 2022; Plevoets & Van Cleempoel, 2011), (2) spatial configuration theory emphasizing movement, efficiency, and spatial logic (Hillier, 1996), and (3) creative industry theory highlighting the role of space in cultural and economic production (Evans, 2009; Pratt, 2008). By synthesizing these perspectives, the study proposes a hybrid model of adaptive reuse that positions space as an active agent in production performance, rather than a passive container. This conceptual shift contributes new knowledge to the fields of architecture and design by demonstrating how spatial, material, and experiential factors can be strategically integrated to enhance both functional efficiency and creative value.

In practical terms, the findings offer a comprehensive framework for architects, developers, and creative professionals to evaluate and implement adaptive reuse projects. By combining structural, spatial, technical, and intangible factors, this approach enables the transformation of underutilized buildings into competitive, flexible, and sustainable production environments. Ultimately, the study highlights that adaptive reuse is not merely a technical solution to urban vacancy, but a design-driven process that generates cultural, economic, and spatial innovation.

7. References

Álex Escolà-Gascón, A., Dagnall, N., Drinkwater, K., & Denovan, A. (2024). Abandoned vs. regenerated places: Evidence of five social impacts that improve urban planning. Cities, 146, 104739. https://doi.org/10.1016/j.cities.2023.104739

Ampansuk, P. (2018). Adaptive reuse of historic buildings for creative learning spaces: Case studies of buildings in Bangkok conservation areas (master's thesis, Chulalongkorn University). https://digital.car.chula.ac.th/chulaetd/3531

ARCH 311w. (2015). Adaptive reuse is better than new construction. https://sites.psu.edu/arch311w/2015/12/13/adaptive-reuse-is-better-than-new-construction/

Boonprasong, P. (2022). Brief for changing the use of old buildings. Salapimkan.
Bullen, P. A. (2007). Adaptive reuse and sustainability of commercial buildings. Facilities, 25(1–2), 20–31.
Bullen, P. A., & Love, P. E. D. (2011). Adaptive reuse of heritage buildings. Structural Survey, 29(5), 411–437.
Brown, B., & Sorensen, J. (2009). Cinematic cities: Film and urban space. Columbia University Press.
Chaiyarattanon, P. (2025). Final report: Co-living housing model—Sustainable urban housing management processes for disadvantaged groups (Grant No. A13F670202). School of Architecture, Art and Design, King Mongkut's Institute of Technology Ladkrabang.
Colomb, C. (2012). Pushing the urban frontier: Temporary uses of space, city marketing, and the creative city discourse. Journal of Urban Affairs, 34(2), 131–152.
Conejos, S., Langston, C., Smith, J., & Chan, E. (2011). AdaptSTAR model: A climate-friendly strategy to promote built environment sustainability. Habitat International, 35(4), 619–626.
Lash, S., & Urry, J. (1994). Economies of signs and space. Sage Publications.
Maghsoodi Tilaki, M. J., Wan Ibrahim, W. M. M., & Abdullah, A. (2026). Exploring challenges of adaptive reusing of vacant shophouses in Penang's heritage zone. Cities, 170, 106663. https://doi.org/10.1016/j.cities.2025.106663
McLaughlin, K. (2024). Unpacking akiya: The millions of empty houses in Japan. Architectural Digest. https://www.architecturaldigest.com/story/unpacking-akiya-the-millions-of-empty-houses-in-japan
Mısırlısoy, D., & Günçe, K. (2016). Adaptive reuse strategies for heritage buildings: A holistic approach. Sustainable Cities and Society, 26, 91–98.
Peterson, M. (2024). Americans bought abandoned $1 Italian homes—Was it worth it? CNBC. https://www.cnbc.com/2024/02/22/americans-bought-abandoned-1-italian-homes-was-it-worth-it.html
Pratt, A. C. (2012). The cultural and creative industries: Organisational and spatial challenges to their governance. Die Erde, 143(4), 317–334.
Ramasoot, N. (2022). Urban adaptation and sustainability: The case of Bangkok's suburban residences. Asian Urban Studies, 5(2), 123–140.
Richards, G. (2011). Creativity and tourism: The state of the art. Annals of Tourism Research, 38(4), 1225–1253.
Room Books. (2022, June 10). Studio Bangna: Transforming a shophouse into a photography studio, whatever the theme or style, a complete and cost-effective one-stop service [Facebook post]. Facebook. https://www.facebook.com/roomfan/posts/10160480182316419/
Scott, A. J. (2010). Cultural economy and the creative field of the city. Geografiska Annaler: Series B, Human Geography, 92(2), 115–130.
Thompson, K., & Bordwell, D. (2010). Film history: An introduction (3rd ed.). McGraw-Hill.
Unzurrunzaga, A., & Branchi, P. (2013). Repurposing spaces: Adaptive reuse in urban contexts. Architectural Heritage Press.
Vafaie, F., Remøy, H., & Gruis, V. (2023). Adaptive reuse of heritage buildings: A systematic literature review of success factors. Journal of Environmental Management. https://doi.org/10.1016/j.jenvman.2023.116907

HOW VR SHAPES VISIT INTENTION IN AN INTANGIBLE CULTURAL HERITAGE MUSEUM: A KOLB LEARNING CYCLE PERSPECTIVE

Ran Shao and Atit Tippichai*

67026002@kmitl.ac.th, and atit.ti@kmitl.ac.th

Department of Multidisciplinary Design Research, School of Architecture, Art, and Design, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: atit.ti@kmitl.ac.th

ABSTRACT

Virtual reality (VR) has become an important medium for presenting intangible cultural heritage, yet the mechanism through which VR experience is transformed into offline visit intention remains insufficiently understood. Grounded in Kolb's experiential learning theory, this study proposes a staged learning model to examine how immersion, interactivity, and perceived authenticity influence visit intention in a VR embroidery museum. Specifically, it aims to clarify whether VR-based heritage experience affects visit intention directly or through a structured experiential learning process. A laboratory-based VR experiment was conducted in China, in which participants completed a structured VR learning experience based on four sequential stages: demonstration viewing, guided reflection, concept integration, and a virtual stitching task. These stages were designed to correspond to concrete experience, reflective observation, abstract conceptualization, and active experimentation. Data were collected through a post-experience questionnaire survey. A total of 310 participants took part in the experiment, and 238 valid responses were retained after data screening. Covariance-based structural equation modeling was used to test the proposed relationships. The results show that immersion and interactivity mainly influenced concrete experience and reflective observation, while perceived authenticity significantly affected concrete experience and abstract conceptualization. The sequential learning chain from concrete experience to reflective observation, abstract conceptualization, and active experimentation was supported. Active experimentation also fed back into concrete experience and directly predicted visit intention. These findings extend Kolb's experiential learning theory to VR-based intangible cultural heritage museums and provide practical guidance for designing learning-oriented VR museum systems that support cultural learning and future offline visitation.

Keywords: Virtual reality, Intangible cultural heritage, Digital museum, Experiential learning, Visit intention

1. Statement of the Problem

Virtual reality has become an important tool for presenting intangible cultural heritage because it can create immersive cultural environments, support interaction, and strengthen users' sense of presence. These affordances make VR increasingly relevant to heritage preservation, communication, and education (Bekele & Champion, 2019; Huang et al., 2025; Zhang & Chen, 2025).

Yet the effectiveness of VR heritage systems should not be judged only by technical sophistication or visual appeal. A more important issue is how immersive experience is transformed into meaningful learning and, ultimately, into intention to visit the related physical museum or heritage site. Existing studies have reported positive links between immersion,

presence, enjoyment, and behavioral intention, but the staged learning mechanism underlying this process remains underexplored (Atzeni et al., 2021; Hwang et al., 2023; Lee et al., 2020; Sun & Othman, 2025).

Embroidery is a suitable case for examining this problem because it is both artifact-based and process-based, involving techniques, symbols, and tacit knowledge. A VR embroidery museum can therefore support experiential learning rather than simple visual display. This makes Kolb's experiential learning theory particularly relevant, as it explains learning through four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984).

Based on this perspective, the present study examines how immersion, interactivity, and authenticity influence different stages of the Kolb learning cycle and how these stages shape visit intention. By doing so, it clarifies whether visit intention is formed directly after VR exposure or through later-stage learning transformation. The findings are expected to contribute to both theory and practice by showing how VR heritage systems can be designed as structured learning environments rather than as technology-centered displays (Bekele & Champion, 2019; Kolb, 1984; Morris, 2019).

2. Objectives

This study has three objectives:

2.1 To examine the effects of immersion, interactivity, and perceived authenticity on the four stages of Kolb's experiential learning cycle in a VR embroidery digital museum.

2.2 To design and test a concrete four-stage VR learning experience sequence, including demonstration viewing, guided reflection, concept integration, and a virtual stitching task, and to examine whether this sequence explains users' visit intention through Kolb's experiential learning chain.

2.3 To derive design implications for developing learning-oriented VR museum systems for intangible cultural heritage.

3. Conceptual Framework and Hypotheses

The conceptual framework of this study proposes that immersion, interactivity, and perceived authenticity influence visit intention through staged experiential learning in a VR embroidery digital museum. Drawing on Kolb's experiential learning theory, the model conceptualizes learning as a dynamic process involving concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). These stages explain how VR-based cultural experiences are transformed into behavioral intention toward the related offline museum (Bekele & Champion, 2019; Kolb, 1984; Hu et al., 2021; Lee et al., 2020; Morris, 2019).

In the proposed model, immersion and interactivity are expected to influence the earlier stages of learning, especially CE and RO, because they shape users' entry into the virtual environment and their engagement with the learning task (Bekele & Champion, 2019; Lee et al., 2020). Perceived authenticity is expected to contribute to experiential entry and deeper cognitive processing by strengthening the cultural credibility and meaningfulness of the VR content (Champion, 2021; Jin et al., 2020; Zhang & Chen, 2025). The learning process is modeled as a path from CE to RO, from RO to AC, and from AC to AE, while AE is further assumed to feed back into CE, reflecting the recursive logic of experiential learning. At the outcome level, visit intention is assumed to be directly influenced by AE, as action-oriented experience can strengthen users' behavioral intention toward future museum visitation (Atzeni et al., 2021; Chekembayeva & Garaus, 2024; Loureiro & Rato, 2024).

Accordingly, the following hypotheses are proposed:

H1a: Immersion positively affects concrete experience (CE).
H1b: Immersion positively affects reflective observation (RO).
H2a: Interactivity positively affects concrete experience (CE).
H2b: Interactivity positively affects reflective observation (RO).
H3a: Perceived authenticity positively affects concrete experience (CE).
H3b: Perceived authenticity positively affects abstract conceptualization (AC).
H4: Concrete experience (CE) positively affects reflective observation (RO).
H5: Reflective observation (RO) positively affects abstract conceptualization (AC).
H6: Abstract conceptualization (AC) positively affects active experimentation (AE).
H7: Active experimentation (AE) positively affects visit intention (VI).
H8: Active experimentation (AE) positively affects concrete experience (CE).

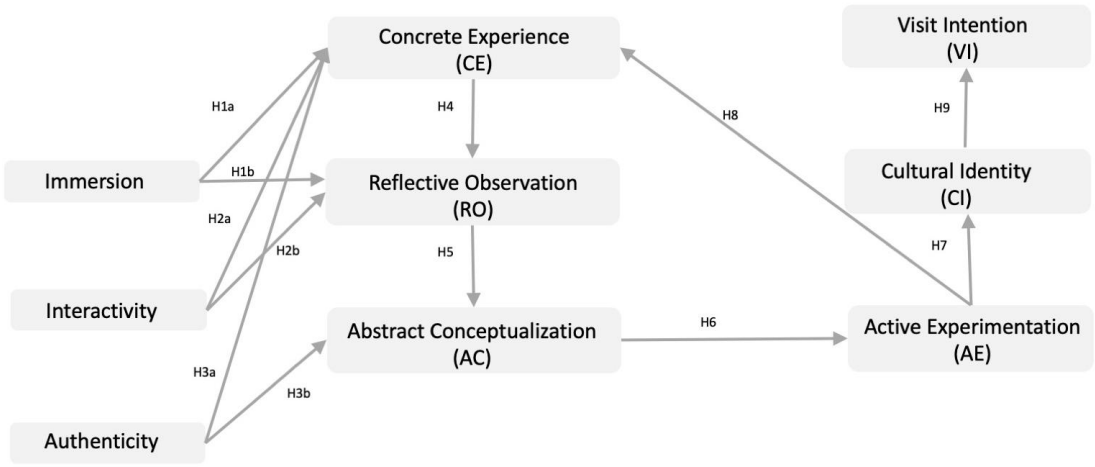

Figure 1 Research Hypothetical Model

4. Research Methodology

4.1 Research Design

This study employed a laboratory-based VR experiment combined with a structured questionnaire survey and covariance-based structural equation modeling (CB-SEM). The research design was intended to examine how key VR attributes influence the stages of experiential learning and, in turn, shape visit intention in a VR embroidery digital museum context (Kolb, 1984; Lee et al., 2020).

4.2 Research Procedure

Participants completed a standardized VR experience designed in accordance with Kolb's experiential learning cycle. The VR embroidery museum was designed as an interactive learning environment rather than a purely visual exhibition. Participants entered the virtual museum through a first-person perspective and interacted with embroidery-related content, including digital embroidery objects, pattern details, stitch-process demonstrations, cultural interpretation panels, and a virtual stitching task. The interaction design allowed participants to observe embroidery details, follow guided explanations, compare cultural symbols, and complete a simple practice-based task in the VR environment (Bekele & Champion, 2019; Hu et al., 2021).

The procedure included four sequential stages: demonstration viewing, guided reflection, concept integration, and a virtual stitching task, corresponding respectively to concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). These functions were designed to support the transition from sensory experience to

reflection, conceptual understanding, and active experimentation (Kolb, 1984; Morris, 2019). After the VR session, participants completed a structured questionnaire.

4.3 Data Collection

A total of 310 university students in China were recruited to participate in the VR embroidery museum experiment. They were selected because young adult learners are frequent users of digital technologies and represent an important potential audience for VR-based museum education and intangible cultural heritage communication. Before completing the questionnaire, all participants experienced the same standardized VR embroidery museum procedure described above. Participation was voluntary, and the participants were informed of the research purpose before the experiment.

After the VR experience, data were collected through a structured questionnaire. The initial dataset included 310 responses. During data screening, incomplete questionnaires, responses with obvious repetitive answer patterns, and questionnaires that did not meet the basic quality requirements were removed. Finally, 238 valid questionnaires were retained for the final analysis. The valid sample included both male and female participants from different grade levels, and most participants reported prior VR experience and prior knowledge of intangible cultural heritage. The main characteristics of the valid sample are presented in Table 1.

4.4 Measures and Data Analysis

All constructs were measured using a five-point Likert scale. SPSS 26.0 was used for descriptive statistics, reliability analysis, and preliminary data screening, while AMOS was used to conduct confirmatory factor analysis (CFA) and structural equation modeling (SEM) (Anderson & Gerbing, 1988; Kline, 2023).

Table 1 Profile of the valid sample (N = 238)

Profile	Category	Percentage
Gender	Male	49.07
	Female	50.93
Grade	Freshman	13.89
	Sophomore	20.83
	Junior	28.24
	Senior and above	37.04
Prior VR experience	Yes	67.13
Prior ICH knowledge	Yes	72.22

As shown in Table 1, the valid sample was relatively balanced in gender, with 49.07% male and 50.93% female participants. The sample also covered different grade levels, with junior and senior students accounting for the largest proportion. In addition, 67.13% of the participants had prior VR experience, and 72.22% had prior knowledge of intangible cultural heritage. This

sample profile suggests that the participants had sufficient familiarity with digital technologies and heritage-related topics to evaluate the VR embroidery museum experience (Bekele & Champion, 2019; Hu et al., 2021; Lee et al., 2020).

5. Results

5.1 Preliminary Tests and Measurement Model

5.1.1 Reliability Analysis

Reliability analysis showed that all constructs had acceptable internal consistency. As presented in Table 2, the Cronbach's alpha coefficients of all latent variables exceeded 0.70, and the corrected item-total correlation (CITC) values of all items were above 0.40. In addition, the Cronbach's alpha coefficients after deleting any item did not exceed the overall alpha values of the original constructs. These results indicate that the scale had satisfactory internal consistency and was suitable for subsequent validity testing and structural model analysis.

Table 2 Reliability analysis

Measurements	Item	CITC	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
CE Concrete Experience	CE1	0.787	0.825	0.882
	CE2	0.737	0.864	
	CE3	0.800	0.809	
RO Reflective Observation	RO1	0.801	0.804	0.881
	RO2	0.742	0.856	
	RO3	0.769	0.834	
Interactivity	Interactivity1	0.725	0.838	0.869
	Interactivity2	0.780	0.786	
	Interactivity3	0.746	0.819	
Immersion	Immersion1	0.775	0.815	0.877
	Immersion2	0.744	0.846	
	Immersion3	0.773	0.817	
Authenticity	Authenticity1	0.664	0.717	0.804
	Authenticity2	0.647	0.735	
	Authenticity3	0.639	0.743	
AC Abstract Conceptualization	AC1	0.667	0.727	0.808
	AC2	0.679	0.715	
	AC3	0.625	0.770	
AE Active Experimentation	AE1	0.672	0.716	0.806
	AE2	0.702	0.682	
	AE3	0.589	0.800	
VI Visit Intention	VI1	0.687	0.724	0.815
	VI2	0.688	0.725	
	VI3	0.626	0.787	

Table 2 indicates that all constructs achieved acceptable internal consistency. The Cronbach's alpha values ranged from 0.804 to 0.882, exceeding the commonly recommended threshold of 0.70. The CITC values were also above 0.40, suggesting that each item contributed adequately to its corresponding construct. Therefore, all measurement items were retained for subsequent validity analysis and structural model testing (Sijtsma, 2009; Trizano-Hermosilla & Alvarado, 2016).

5.1.2 Validity Analysis

To further examine the structural validity of the scale, exploratory factor analysis was conducted. As shown in Table 3, the KMO value was 0.849, which exceeded the recommended

threshold of 0.70, and Bartlett's test of sphericity was significant ($\chi^2 = 2995.643$, df = 276, $p < 0.001$). These findings indicate that the data were suitable for factor analysis and provide support for subsequent confirmatory factor analysis (Anderson & Gerbing, 1988; Kline, 2023).

Table 3 KMO and Bartlett's test

KMO Measure of Sampling Adequacy		0.849
Bartlett's Test of Sphericity	Approximate Chi-Square	2995.643
	Degrees of Freedom (df)	276.0
	Significance (p-value)	0.000

Further analysis showed that eight factors were extracted from the questionnaire, with a cumulative variance explained of 77.288%, exceeding the recommended threshold of 70%. This suggests that the factor structure retained substantial information from the original dataset. Moreover, the first unrotated factor accounted for 31.056% of the variance, which was below the 40% benchmark, suggesting that no severe common method bias was present (Podsakoff et al., 2024; Tehseen et al., 2017). Overall, the extracted factors were consistent with the predefined dimensions, providing further support for the structural validity of the scale (Table 4).

Table 4 Total variance explained

Factor	**Initial Eigenvalue**	**Variance (%)**	**Cumulative (%)**
1	7.454	31.056	31.056
2	2.069	8.621	39.677
3	1.868	7.782	47.459
4	1.753	7.304	54.763
5	1.653	6.886	61.649
6	1.423	5.929	67.579
7	1.305	5.437	73.016
8	1.025	4.272	77.288

Overall, the exploratory factor analysis results supported the structural validity of the questionnaire. As shown in Table 5, all items loaded strongly on their intended factors, and the observed factor pattern was consistent with the predefined eight-dimensional structure. These findings suggest that the measurement model was appropriate for subsequent confirmatory factor analysis and structural equation modeling.

Table 5 Rotated component matrix

	Factor							
	CE	**RO**	**Interactivity**	**Immersion**	**Authenticity**	**AC**	**AE**	**VI**
CE1	0.847							
CE2	0.814							
CE3	0.785							
RO1		0.853						
RO2		0.826						
RO3		0.833						
Interactivity1			0.847					
Interactivity2			0.839					
Interactivity3			0.812					
Immersion1				0.864				
Immersion2				0.835				
Immersion3				0.846				

Table 5 (continued)

	Factor							
	CE	**RO**	**Interactivity**	**Immersion**	**Authenticity**	**AC**	**AE**	**VI**
Authenticity1					0.813			
Authenticity2					0.835			
Authenticity3					0.770			
AC1						0.837		
AC2						0.836		
AC3						0.786		
AE1							0.777	
AE2							0.838	
AE3							0.775	
VI1								0.842
VI2								0.840
VI3								0.755

Table 5 further supports the expected eight-factor structure of the questionnaire. All items loaded clearly on their intended constructs, including CE, RO, interactivity, immersion, authenticity, AC, AE, and VI. The factor loading pattern was consistent with the conceptual framework, indicating that the observed items were well aligned with their theoretical dimensions. This result provided an empirical basis for the subsequent confirmatory factor analysis and structural equation modeling (Anderson & Gerbing, 1988; Kline, 2023).

5.1.3 Descriptive Statistics of Variables

Descriptive statistics were calculated for all latent variables, including minimum, maximum, mean, standard deviation, skewness, and kurtosis. As shown in Table 6, the mean values ranged from 3.91 to 4.25, indicating relatively positive perceptions across all dimensions. In addition, the absolute values of skewness were below 3 and those of kurtosis were below 10, suggesting that the data did not seriously violate the assumption of normality and were suitable for subsequent structural equation modeling (Kline, 2023).

Table 6 Descriptive statistics of the study variables

Variable	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
CE	1.0	5.0	4.15	0.664	-1.816	6.525
RO	1.0	5.0	4.25	0.683	-1.871	6.882
Interactivity	1.0	5.0	3.91	0.752	-1.225	2.964
Immersion	1.0	5.0	4.18	0.749	-2.227	6.867
Authenticity	1.0	5.0	4.06	0.673	-2.015	7.134
AC	1.0	5.0	4.21	0.654	-2.328	8.927
AE	1.0	5.0	4.14	0.669	-1.760	5.490
VI	1.0	5.0	4.20	0.627	-2.145	8.306

5.1.4 Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships among the latent variables. As shown in Table 7, all variables were significantly and positively correlated at the 0.01 level, consistent with the theoretical expectations of the study. The correlation coefficients ranged from 0.220 to 0.448, indicating weak to moderate associations among the constructs. Overall, these findings provided a statistical basis for subsequent structural equation modeling.

Table 7 Correlation matrix

	CE	RO	Interactivity	Immersion	Authenticity	AC	AE	VI
CE	1.000							
RO	0.417**	1.000						
Interactivity	0.448**	0.403**	1.000					
Immersion	0.401**	0.404**	0.263**	1.000				
Authenticity	0.419**	0.291**	0.279**	0.297**	1.000			
AC	0.250**	0.302**	0.261**	0.254**	0.228**	1.000		
AE	0.423**	0.319**	0.360**	0.297**	0.251**	0.228**	1.000	
VI	0.220**	0.254**	0.303**	0.254**	0.295**	0.313**	0.381**	1.000

5.1.5 Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) was conducted to assess the adequacy of the measurement model prior to structural testing. The results showed that all standardized factor loadings exceeded 0.60, all composite reliability (CR) values were above 0.70, and all average variance extracted (AVE) values were greater than 0.50, indicating satisfactory convergent validity. The model fit indices also demonstrated a good fit to the data (CMIN/DF = 1.102, RMR = 0.022, GFI = 0.924, IFI = 0.992, TLI = 0.990, CFI = 0.992, RMSEA = 0.021), with all values meeting the recommended thresholds. Therefore, the measurement model was considered acceptable for subsequent structural equation modeling (Anderson & Gerbing, 1988; Kline, 2023) (Table 8).

Table 8 Confirmatory factor analysis

Construct	Item	SFL	CR	AVE
CE	CE3	0.905	0.884	0.719
	CE2	0.787		
	CE1	0.848		
RO	RO3	0.843	0.883	0.716
	RO2	0.808		
	RO1	0.885		
Interactivity	Interactivity3	0.83	0.869	0.690
	Interactivity2	0.874		
	Interactivity1	0.785		
Immersion	Immersion3	0.856	0.879	0.708
	Immersion2	0.813		
	Immersion1	0.854		
Authenticity	Authenticity3	0.763	0.803	0.577
	Authenticity2	0.738		
	Authenticity1	0.777		
AC	AC3	0.721	0.810	0.587
	AC2	0.801		
	AC1	0.775		
AE	AE3	0.665	0.811	0.590
	AE2	0.817		
	AE1	0.813		
VI	VI3	0.725	0.818	0.600
	VI2	0.799		
	VI1	0.797		

Discriminant validity was assessed using the Fornell–Larcker criterion. As shown in Table 9, the square root of the AVE for each construct was greater than its correlations with the other

constructs, indicating satisfactory discriminant validity. Therefore, the latent variables were considered empirically distinct and appropriate for subsequent structural model analysis (Fornell & Larcker, 1981; Kline, 2023).

Table 9 Discriminant validity

	CE	RO	Interactivity	Immersion	Authenticity	AC	AE	VI
CE	0.848							
RO	0.471	0.846						
Interactivity	0.512	0.465	0.831					
Immersion	0.455	0.453	0.302	0.841				
Authenticity	0.493	0.346	0.332	0.361	0.760			
AC	0.290	0.356	0.310	0.281	0.285	0.766		
AE	0.495	0.370	0.443	0.351	0.302	0.263	0.768	
VI	0.263	0.300	0.363	0.280	0.365	0.371	0.450	0.775

5.2 Structural Model Results

5.2.1 Model Fit Test

The structural model demonstrated a good fit to the data. As shown in Table 10, all fit indices met the recommended thresholds (CMIN/DF = 1.218, RMR = 0.042, GFI = 0.913, IFI = 0.982, TLI = 0.979, CFI = 0.982, RMSEA = 0.030), indicating that the proposed structural model was acceptable for subsequent structural path analysis.

Table 10 Structural model fit indices

	CMIN/DF	RMR	GFI	IFI	TLI	CFI	RMSEA
Recommended Threshold	≤3.00	≤0.10	≥0.90	≥0.90	≥0.90	≥0.90	≤0.10
Model Fit	1.218	0.042	0.913	0.982	0.979	0.982	0.030

5.2.2 Path Coefficient Significance

After confirming adequate model fit, the hypothesized paths were tested. As shown in Figure 2 and Table 11, immersion had significant positive effects on concrete experience ($\beta = 0.209$, $p = 0.002$) and reflective observation ($\beta = 0.283$, $p < 0.001$). Interactivity also significantly enhanced concrete experience ($\beta = 0.277$, $p < 0.001$) and reflective observation ($\beta = 0.285$, $p < 0.001$). In addition, perceived authenticity exerted significant positive effects on concrete experience ($\beta = 0.263$, $p < 0.001$) and abstract conceptualization ($\beta = 0.193$, $p = 0.019$).

Within the Kolb learning chain, concrete experience positively affected reflective observation ($\beta = 0.194$, $p = 0.013$), reflective observation positively affected abstract conceptualization ($\beta = 0.301$, $p < 0.001$), and abstract conceptualization positively affected active experimentation ($\beta = 0.179$, $p = 0.029$). Active experimentation further exerted a significant positive effect on concrete experience ($\beta = 0.222$, $p = 0.001$), indicating a recursive learning process.

At the outcome level, active experimentation had a significant positive effect on visit intention ($\beta = 0.310$, $p < 0.001$). Overall, all hypothesized paths were supported. These findings indicate that immersion and interactivity mainly influenced the early experiential stages, authenticity contributed to experiential entry and conceptual processing, and visit intention was primarily shaped by the action-oriented stage of learning.

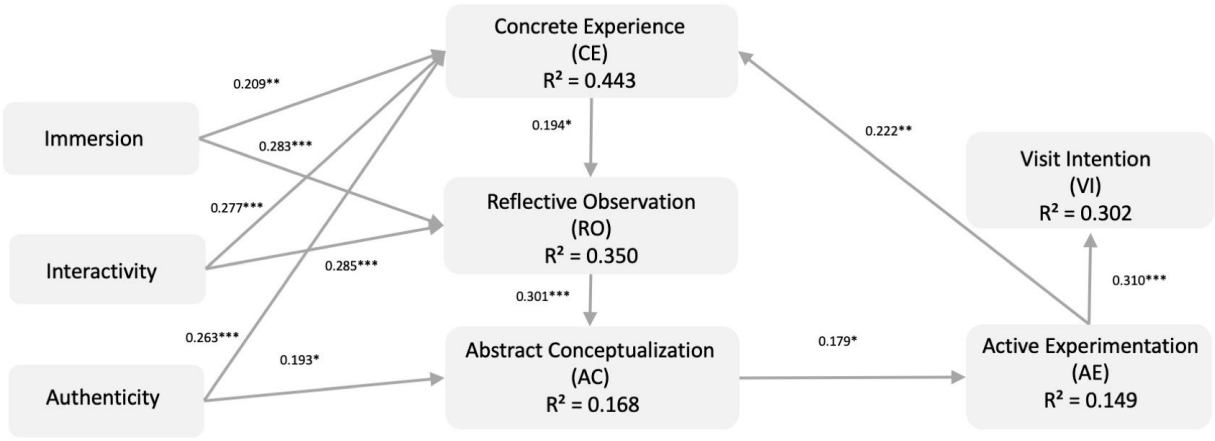

Figure 2 Results of The Hypothesized Structural Equation Model
Note. Standardized path coefficients are reported. R^2 values are shown for endogenous variables.
*p < 0.05, **p < 0.01, ***p < 0.001.

Table 11 Structural path analysis

Path	β	Estimate	S.E.	C.R.	p	Result
Interactivity → CE	0.277	0.271	0.066	4.099	< 0.001	Supported
Immersion → CE	0.209	0.214	0.069	3.109	0.002	Supported
Authenticity → CE	0.263	0.303	0.091	3.334	< 0.001	Supported
Immersion → RO	0.283	0.275	0.070	3.901	< 0.001	Supported
Interactivity → RO	0.285	0.264	0.070	3.783	< 0.001	Supported
Authenticity → AC	0.193	0.175	0.075	2.343	0.019	Supported
CE → RO	0.194	0.184	0.074	2.481	0.013	Supported
RO → AC	0.301	0.250	0.067	3.744	< 0.001	Supported
AC → AE	0.179	0.173	0.080	2.177	0.029	Supported
AE → VI	0.310	0.313	0.085	3.697	< 0.001	Supported
AE → CE	0.222	0.291	0.090	3.248	0.001	Supported

Table 11 shows that all hypothesized paths were statistically supported. Immersion and interactivity mainly affected the early learning stages of CE and RO, while authenticity contributed to CE and AC. The sequential learning chain from CE to RO, from RO to AC, and from AC to AE was also supported, confirming the staged logic of Kolb's experiential learning cycle. In addition, AE directly predicted VI and fed back into CE, suggesting that action-oriented learning plays a key role in transforming VR museum experience into future visit intention (Kolb, 1984; Morris, 2019).

6. Conclusion and Discussion

This study examined how VR experience is transformed into visit intention in an intangible cultural heritage museum through Kolb's experiential learning cycle. The empirical results from Tables 1–10 provide a reliable foundation for testing the proposed model. The sample profile showed that the participants had sufficient familiarity with VR and intangible cultural heritage to evaluate the VR embroidery museum experience. The reliability, exploratory factor analysis, confirmatory factor analysis, and discriminant validity results indicated that the measurement model was acceptable for structural equation modeling.

The structural results in Table 11 show that visit intention was not formed through a simple direct response to VR exposure. Instead, it was developed through a staged learning process. Immersion and interactivity mainly influenced concrete experience and reflective observation,

suggesting that sensory presence and interactive exploration help users enter and reflect on the VR heritage environment. Perceived authenticity affected concrete experience and abstract conceptualization, indicating that cultural credibility and symbolic meaning are important for deeper understanding in VR-based heritage learning (Champion, 2021; Jin et al., 2020; Zhang & Chen, 2025).

The supported CE–RO–AC–AE chain confirms the applicability of Kolb's experiential learning theory in a VR embroidery museum context. More importantly, active experimentation directly predicted visit intention, showing that practice-oriented learning is the key stage through which virtual experience is transformed into behavioral intention. The feedback path from AE to CE further suggests that VR museum learning may operate as a recursive process rather than a one-way sequence (Kolb, 1984; Morris, 2019).

VR heritage systems should not only emphasize visual immersion, but also integrate guided reflection, cultural explanation, and hands-on virtual tasks (Bekele & Champion, 2019; Hu et al., 2021).

However, several limitations should be acknowledged. First, the sample consisted of university students in China, which may limit the generalizability of the findings to broader museum visitor groups, older users, non-student populations, and international audiences. Second, the study relied on self-reported questionnaire data collected after a single VR experience, so it mainly captured perceived learning experience and visit intention rather than long-term behavioral change and may still be subject to common method concerns (Podsakoff et al., 2024; Tehseen et al., 2017). Future studies may use longitudinal designs to examine whether VR-based learning effects persist over time. Behavioral data, such as actual museum visits, task completion records, interaction logs, or time spent in different VR sections, could also be included to provide stronger evidence of how VR heritage experiences are transformed into real-world cultural participation.

7. Suggestions

Based on the findings, VR heritage museums should combine immersive presentation with clearly structured learning tasks, so that users can move from initial sensory experience to reflection, conceptual understanding, and active experimentation. Authenticity cues should be embedded in cultural explanation, symbolic interpretation, and process-based storytelling to strengthen users' understanding of intangible cultural heritage. In addition, practice-oriented tasks, such as virtual stitching, should be included because active experimentation is the key stage linking virtual learning experience with visit intention. Finally, VR exhibitions should relate to offline museum education and visitation programs to support the transformation from virtual experience to real-world cultural participation (Atzeni et al., 2021; Loureiro & Rato, 2024; Zhang & Chen, 2025).

8. References

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin, 103*(3), 411–423. https://doi.org/10.1037/0033-2909.103.3.411

Atzeni, M., Del Chiappa, G., & Pung, J. M. (2021). Enhancing visit intention in heritage tourism: The role of object-based and existential authenticity in non-immersive virtual reality heritage experiences. *International Journal of Tourism Research, 24*(2), 240–255. https://doi.org/10.1002/jtr.2497

Bekele, M. K., & Champion, E. (2019). A comparison of immersive realities and interaction methods: Cultural learning in virtual heritage. *Frontiers in Robotics and AI, 6*, Article 91. https://doi.org/10.3389/frobt.2019.00091

Champion, E. (2021). Preserving authenticity in virtual heritage. In *Virtual heritage: A concise guide*. Ubiquity Press. https://doi.org/10.5334/bck.l

Chekembayeva, G., & Garaus, M. (2024). Authenticity matters: Investigating virtual tours' impact on curiosity and museum visit intentions. *Journal of Services Marketing, 38*(7), 941– 956. https://doi.org/10.1108/JSM-09-2023-0343

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39–50. https://doi.org/10.1177/002224378101800104

Hu, X., Ng, T.-D. J., & Liu, R. (2021). Development and evaluation of a digital museum of a national intangible cultural heritage from China. In *Diversity, divergence, dialogue* (Vol. 12646, pp. 493–501). Springer. https://doi.org/10.1007/978-3-030-71305-8_42

Huang, X., Li, Y., & Tian, F. (2025). Enhancing user experience in interactive virtual museums for cultural heritage learning through extended reality: The case of Sanxingdui Bronzes. *IEEE Access, 13*, 59405–59421. https://doi.org/10.1109/ACCESS.2025.3556938

Hwang, K.-H., tom Dieck, M. C., Jung, T. H., & Kwon, O. (2023). The influence of virtual reality on the experience of religious cultural heritage content. *Internet Research, 34*, 1198– 1218. https://doi.org/10.1108/INTR-08-2022-0669

Jin, L., Xiao, H., & Shen, H. (2020). Experiential authenticity in heritage museums. *Journal of Destination Marketing & Management, 18*, Article 100493. https://doi.org/10.1016/j.jdmm.2020.100493

Kline, R. B. (2023). *Principles and practice of structural equation modeling* (5th ed.). Guilford Press.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Lee, H., Jung, T. H., tom Dieck, M. C., & Chung, N. (2020). Experiencing immersive virtual reality in museums. *Information & Management, 57*(5), Article 103229. https://doi.org/10.1016/j.im.2019.103229

Loureiro, S. M. C., & Rato, D. (2024). Stimulating the visit of a physical museum through a virtual one. *Anatolia, 35*(2), 269–281. https://doi.org/10.1080/13032917.2023.2172596

Morris, T. H. (2019). Experiential learning—A systematic review and revision of Kolb's model. *Interactive Learning Environments, 28*(8), 1064–1077. https://doi.org/10.1080/10494820.2019.1570279

Podsakoff, P. M., Podsakoff, N. P., Williams, L. J., Huang, C., & Yang, J. (2024). Common method bias: It's bad, it's complex, it's widespread, and it's not easy to fix. *Annual Review of Organizational Psychology and Organizational Behavior, 11*, 17–61. https://doi.org/10.1146/annurev-orgpsych-110721-040030

Sijtsma, K. (2009). On the use, the misuse, and the very limited usefulness of Cronbach's alpha. *Psychometrika, 74*(1), 107–120. https://doi.org/10.1007/s11336-008-9101-0

Sun, M., & Othman, A. N. B. (2025). The impact of virtual reality technology on emotional resonance and behavioral intentions in cultural heritage museums: A case study of the Shaanxi Shadow Puppet Culture Museum. *International Journal of Academic Research in Business and Social Sciences, 15*(5), 1047–1063. https://doi.org/10.6007/IJARBSS/v15- i5/25482

Tehseen, S., Ramayah, T., & Sajilan, S. (2017). Testing and controlling for common method variance: A review of available methods. *Journal of Management Sciences, 4*(2), 146–175. https://doi.org/10.20547/jms.2014.1704202

Trizano-Hermosilla, I., & Alvarado, J. M. (2016). Best alternatives to Cronbach's alpha reliability in realistic conditions: Congeneric and asymmetrical measurements. *Frontiers in Psychology, 7*, Article 769. https://doi.org/10.3389/fpsyg.2016.00769

Zhang, W., & Chen, Z. (2025). How does virtual reality facilitate museum interpretation? The experience of perceived authenticity. *Tourism Recreation Research, 50*(6), 1436–1448. https://doi.org/10.1080/02508281.2024.2424621

ENHANCING USER SATISFACTION IN HAINING SHADOW PLAY LAMPSHADE DESIGN THROUGH QUESTIONNAIRE AND INTERVIEW-BASED RESEARCH

Hua Tong and Pastraporn Thipayasothorn
68036070@kmitl.ac.th and pastraporn.th@kmitl.ac.th

Department of Architectural and Design Education,
School of Industrial Education and Technology,
King Mongkut's Institute of Technology, Bangkok 10520 Thailand

*Corresponding Author E-mail: 68036070@kmitl.ac.th

ABSTRACT

This study explores user satisfaction in Haining shadow play lampshade design by integrating both quantitative and qualitative research methods. The research addresses three main objectives: to investigate users' perceptions and expectations of lampshade design, to analyze expert opinions through interviews, and to evaluate user satisfaction using structured questionnaires. mixed-method approach was adopted. Quantitative data were collected from 427 valid responses using a questionnaire based on the Yamane sampling method to ensure appropriate representation. Qualitative data were obtained through semi-structured interviews with design experts. The data were analyzed using descriptive statistics and thematic analysis The findings indicate that users place significant importance on aesthetic design, functionality, and design uniqueness. More than 67% of respondents confirmed that uniqueness strongly influences purchasing decisions. In addition, users show strong interest in integrating cultural elements such as shadow play into modern product design. Expert insights further highlight that combining user-centered design with cultural innovation can enhance product competitiveness. his study contributes to design research by providing a structured approach to integrating traditional cultural elements into modern products while improving user satisfaction.

Keywords: Lampshade design, Shadow play, User satisfaction, Cultural design

1. Statement of the Problem

In many contemporary product design practices, there is a growing emphasis on improving user satisfaction and experience. However, many products still fail to effectively integrate cultural elements with modern functionality and aesthetics. Traditional art forms, such as Haining shadow play, are often underutilized in modern design, resulting in a loss of cultural identity and reduced product differentiation.

At the same time, design decisions are frequently based on subjective judgment rather than systematic user research. This can lead to a mismatch between user expectations and final design outcomes. Previous studies have highlighted the importance of user-centered design and cultural integration in enhancing product value (Norman, 2004; Bonsiepe, 1991). In addition, cultural design has been widely recognized as an effective strategy to enhance product differentiation and user engagement (Lin, 2007; Wang, 2018).

Therefore, this study aims to address the gap between traditional culture and modern product design by applying a mixed-method approach. By combining questionnaire data and expert interviews, the research seeks to develop more effective design strategies that enhance both user satisfaction and cultural value.

2. Objectives

The objectives of this study guide the research design and analysis. They demonstrate how the study responds to the issues identified above.

2.1 To investigate users' perceptions and expectations of lampshade design through a questionnaire survey.

2.2 To explore expert opinions on improving shadow play lampshade design using interview methods.

2.3 To evaluate user satisfaction with lampshade design through a satisfaction questionnaire.

3. Conceptual Framework and Hypothesis

This study is based on user-centered design theory, which emphasizes designing products according to users' needs and behaviors (Norman, 2004; ISO 9241-210, 2010). It also incorporates the concept of cultural design integration, highlighting the importance of embedding traditional cultural elements into modern products (Lin, 2007; Li, 2019).

The conceptual framework considers three interrelated components: user perception, expert evaluation, and user satisfaction. User perception provides initial insights into preferences, expert interviews guide design improvement, and satisfaction evaluation reflects the effectiveness of the final design.

The relationship among these components can be summarized as follows:

User Perception → Expert Evaluation → Design Improvement → User Satisfaction

Hypothesis: The integration of cultural elements and user-centered design principles significantly improves user satisfaction in lampshade design.

Figure 1 Examples of Haining Shadow Play Art from Field Observation

4. Research Methodology

4.1 Research Methodology

This study adopts a mixed-method approach, combining quantitative and qualitative methods to provide comprehensive insights. The study was conducted in Haining, China, a region well known for its shadow play culture. The target population includes local residents and potential consumers of cultural creative products. The sample size was determined using the Yamane formula to ensure representativeness.

4.2 Research Procedure

The research process involved designing questionnaires and interview questions, collecting data from users and experts, analyzing quantitative and qualitative data, and interpreting the results to draw conclusions.

4.3 Data Collection

Data were collected through three main methods: a general questionnaire to understand user preferences, semi-structured interviews with design experts, and a satisfaction questionnaire to evaluate design outcomes. A total of 427 valid responses were collected.

4.4 Data Analysis

Quantitative data were analyzed using descriptive statistics, including percentages and distribution analysis. Qualitative data were analyzed using thematic analysis to identify patterns and key insights.

5. Results

The results are based on questionnaire data and expert interviews. The findings are presented through tables and analytical descriptions to provide a clear understanding of user preferences and design implications.

5.1 User Preferences

To examine user preferences, the key factors are summarized in Table 1.

Table 1 User preferences for lampshade design (n = 427)

Design Factor	Percentage (%)
Aesthetic Design	78%
Functionality	72%
Ease of Use	69%

The data indicate that aesthetic design is the most important factor, followed by functionality and ease of use. This suggests that users not only value practical usability but also emphasize visual experience. This finding is consistent with previous studies indicating that users prioritize both functional and aesthetic aspects in product design (Heskett, 2002).

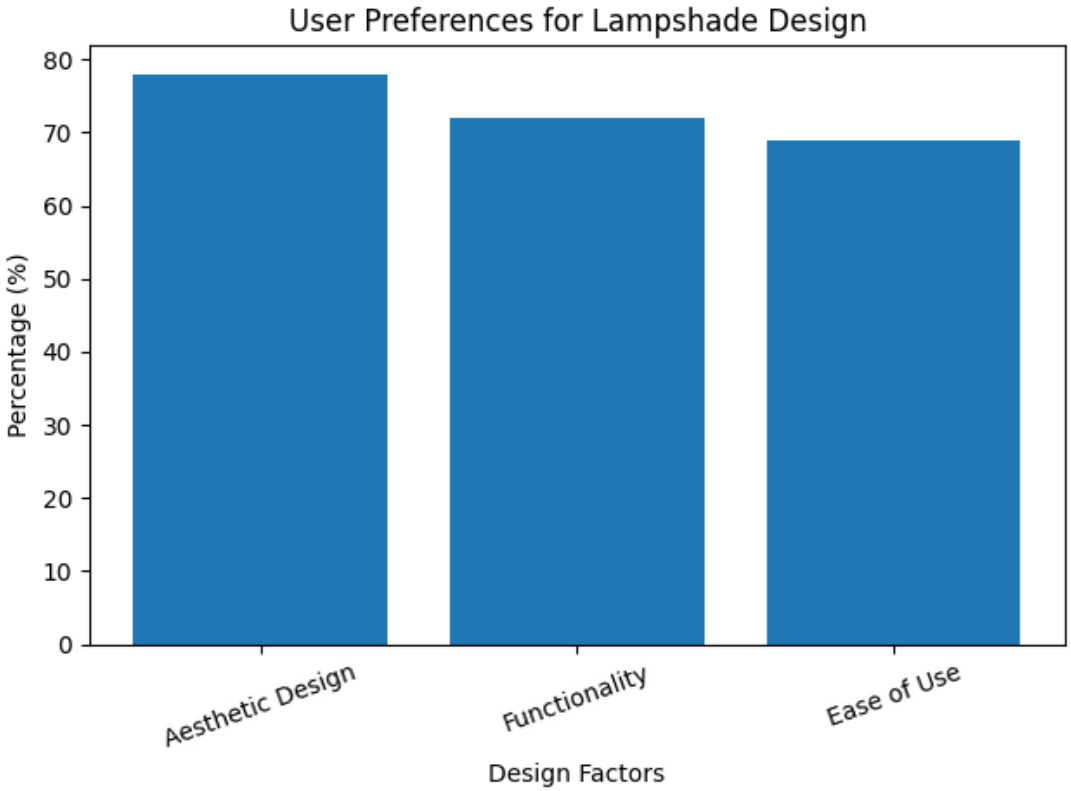

Figure 2 User Preferences for Lampshade Design

Compared with traditional lampshade products that mainly focus on functionality, modern users show a stronger preference for designs that combine aesthetics and emotional engagement. This reflects the increasing importance of user experience in product design.

5.2 Cultural Element Integration

A large proportion of respondents expressed positive attitudes toward incorporating shadow play elements into lampshade design. This suggests that cultural integration enhances both product uniqueness and emotional value.

Compared with conventional products lacking cultural identity, designs incorporating traditional elements are perceived as more meaningful and distinctive. This enhances their attractiveness and competitiveness in the market. This result aligns with previous research showing that integrating cultural elements can enhance product identity and emotional value (Lin, 2007; Wang, 2018).

5.3 Design Uniqueness and Purchase Intention

The influence of design uniqueness is summarized in Table 2.

Table 2 Influence of design uniqueness on purchase intention

Response Category	Percentage (%)
Strongly Agree	34.7%
Agree	32.3%
Neutral	21.5%
Disagree	11.5%

The results show that more than 67% of respondents believe that uniqueness significantly influences purchasing decisions. This indicates that innovative design is a key factor in attracting users This finding supports earlier studies suggesting that product uniqueness plays a critical role in influencing consumer behavior (Heskett, 2002).

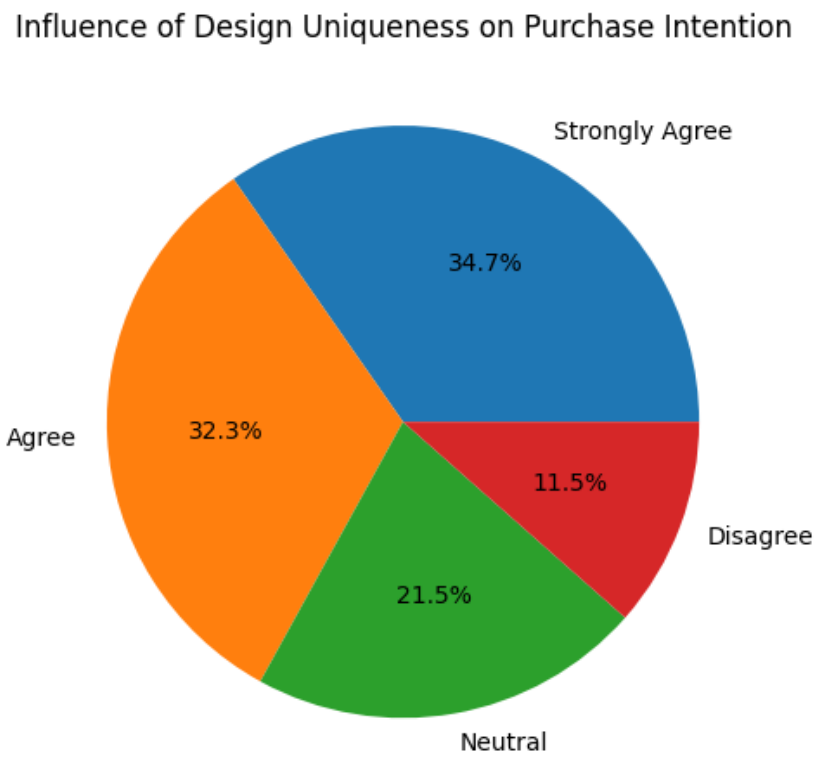

Figure 3 Influence of Design Uniqueness on Purchase Intention.

Compared with standardized products, unique designs are more effective in enhancing user interest and market competitiveness.

5.4 Light and Shadow Effects

Users show a strong preference for lampshades that create dynamic light and shadow effects, which align with the characteristics of shadow play art.

Compared with existing lampshade products in the local market, traditional designs mainly provide basic lighting functions without interactive or cultural elements. In contrast, shadow play integration introduces visual storytelling and enhances user engagement.

This suggests that combining traditional art with modern design can improve both aesthetic value and user experience. The use of visual and interactive elements is consistent with emotional design principles, which emphasize user engagement and experiential value (Norman, 2004).

5.5 Expert Interview Findings

Expert interviews indicate that user-centered design, cultural storytelling, and iterative design processes are essential for successful product development. Experts also emphasize that integrating traditional art with modern technology can enhance innovation and product value.

5.6 Overall Findings

The findings demonstrate that users prefer designs that combine functionality, aesthetics, and cultural value. While functionality remains fundamental, users increasingly prioritize aesthetic and emotional experience.

Cultural integration enhances product attractiveness, while innovative features such as light and shadow interaction influence purchase intention and satisfaction. Overall, successful design requires balancing practicality with cultural creativity.

6. Conclusion and Discussion

This study confirms that integrating user feedback and expert insights is an effective strategy for improving lampshade design. The findings are consistent with emotional design theory, which highlights the importance of user emotion in product interaction (Norman, 2004; Csikszentmihalyi, 1990).

The integration of cultural elements enhances user experience and strengthens product identity (Bonsiepe, 1991). However, the study has limitations, including sample diversity and reliance on self-reported data.

Future research could expand the sample size and explore advanced design technologies. Overall, this study provides valuable insights for both academic research and practical design applications.

7. Suggestions

7.1 Practical Suggestions

Designers should integrate cultural elements into modern product design to enhance aesthetic value and cultural identity. Applying user-centered design principles can improve usability and user satisfaction. Continuous user feedback should also be incorporated to optimize product performance (Norman, 2004).

7.2 Future Research Suggestions

Future research should explore broader cultural applications and integrate advanced technologies such as interactive lighting. Expanding studies to diverse user groups would improve the generalizability of findings. These approaches align with user-centered design principles that emphasize usability and user satisfaction (ISO 9241-210, 2010).

8. Acknowledgements

The author would like to thank all participants and experts for their valuable contributions to this research.

9. References

Bonsiepe, G. (1991). *Design, culture and society*. Thames & Hudson.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. Harper & Row.

Heskett, J. (2002). *Toothpicks and logos: Design in everyday life*. Oxford University Press.

ISO 9241-210. (2010). *Ergonomics of human-system interaction—Part 210: Human-centred design for interactive systems*.

Li, H. (2019). The integration of traditional Chinese art into contemporary design. *Modern Design, 6*(1), 56-60.

Lin, R. (2007). Transforming Taiwan aboriginal cultural features into modern product design. *International Journal of Design, 1*(2), 45-53.

Norman, D. (2004). *Emotional design*. Basic Books.

Ulrich, K., & Eppinger, S. (2012). *Product design and development*. McGraw-Hill.

Wang, L. (2018). Application of traditional cultural elements in modern product design. *Design Studies, 12*(4), 78-85.

Zhao, X. (2020). Study on user-centered design methods in product development. *Journal of Design Research, 5*(2), 33-40.

APPLYING NANCHONG'S THREE KINGDOMS CULTURE TO THE OUTER PACKAGING DESIGN OF CHUANBEI LIANGFEN: A DESIGN-ORIENTED STUDY WITH YOUNG CONSUMERS

Lanping Wang* and Pastraporn Thipayasothorn

68036072@kmitl.ac.th and pastraporn.th@kmitl.ac.th

Department of Architectural and Design Education,
School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 68036072@kmitl.ac.th

ABSTRACT

With the growth of cultural tourism and place branding, specialty foods increasingly function as carriers of local identity, and outer packaging has become an important medium for recognition, communication, and cultural expression. Chuanbei Liangfen, a representative snack of Nanchong in Sichuan Province, China, has gradually expanded from on-site consumption to takeaway, delivery, and culture-tourism retail, creating new requirements for clearer visual identity and more effective information presentation. This study aims to explore how Nanchong's Three Kingdoms culture can be applied to the outer packaging design of Chuanbei Liangfen and to identify a design direction that better reflects regional identity and cultural expression. The research adopts literature review, comparative analysis, questionnaire survey, and design practice as its main methods. An online questionnaire survey was conducted with young consumers aged 18–35 in Nanchong and surrounding areas as the target population, and 411 valid responses were obtained for analysis. The results show that respondents generally had a basic to moderate level of knowledge of Nanchong's Three Kingdoms culture and Chuanbei Liangfen. The most frequently identified problem of the existing packaging was insufficient visual attractiveness. For a new packaging design, respondents preferred a combination of traditional and modern styles, red and gold tones, cultural expression, incorporation of Three Kingdoms cultural elements, and simple modern graphics. Based on these findings, the study proposes a packaging direction that integrates Three Kingdoms cultural elements into a more visually distinctive and regionally expressive design.

Keywords: Nanchong, Three Kingdoms culture, Chuanbei Liangfen, Food packaging

1. Statement of the Problem

Nanchong is located in northeastern Sichuan Province along the middle reaches of the Jialing River and possesses strong historical and cultural resources as well as a clear regional identity (Sichuan Provincial Gazetteer Website, 2018, 2019). In recent years, with the advancement of culture–tourism integration and local brand building, distinctive local foods have increasingly become important carriers for communicating city image and local culture. In this context, food packaging is no longer limited to containment and transport, but has become a comprehensive medium that supports identification, communication, and cultural expression (Fu et al., 2018; He, 2015; Gao, 2022). This is especially important for products aimed at tourists and young consumers, because packaging must build a visual system that is easy to recognize, understand, and remember.

Chuanbei Liangfen is one of Nanchong's representative local snacks (Shunqing District Gazetteer Office, 2023; China Food Safety News, n.d.). Traditionally, it has mainly been sold as freshly made, ready-to-eat food. However, as its circulation channels expand from street-side consumption to takeaway, delivery, and culture-tourism retail settings, the outer packaging is required not only to meet basic functions such as hygiene, portability, and labeling, but also to perform image-building and value-communication functions. This shift creates a need for stronger visual identity, clearer information hierarchy, and more stable regional recognition in its outer packaging.

At the same time, Nanchong has notable Three Kingdoms cultural resources. As the hometown of Chen Shou, the author of Records of the Three Kingdoms, the city has clear local connections to historical figures, narratives, and cultural memory associated with the Three Kingdoms period (Sichuan Provincial Gazetteer Website, 2018, 2019). These cultural resources have the potential to be transformed into visual symbols and narrative devices for packaging design, thereby strengthening the regional association between Nanchong and Chuanbei Liangfen. Therefore, the present study explores a practical design pathway for integrating Nanchong's Three Kingdoms culture into the outer packaging design of Chuanbei Liangfen and seeks to provide reference for the visual communication of local specialty foods.

2. Objectives

2.1 To analyze the current situation of Chuanbei Liangfen packaging and identify design problems and needs through literature review, case studies, and market observation.

2.2 To investigate young consumers' knowledge of Nanchong's Three Kingdoms culture, their views on Chuanbei Liangfen and its existing packaging, and their preferences for the direction of a new packaging design.

3. Conceptual Framework and Hypothesis

The conceptual framework of this study is based on the relationship among local cultural resources, packaging visual communication, and young consumers' design preferences. Previous studies have suggested that regional cultural elements can be transformed into packaging visual symbols to strengthen product identity, cultural expression, and consumer perception (He, 2015; Gao, 2022; Jia, 2022). In this study, Nanchong's Three Kingdoms culture is regarded as the main cultural resource, while the existing packaging of Chuanbei Liangfen is regarded as the object of design evaluation and improvement.

The main variables include cultural knowledge, product awareness, evaluation of existing packaging, and preferences for a new packaging design. These variables correspond to the questionnaire structure: basic information, knowledge of local culture, understanding of Chuanbei Liangfen and its existing packaging, and preferences for the direction of a new packaging design. Therefore, the conceptual framework connects cultural resources, consumer perception, packaging evaluation, and design preference in order to guide the development of a new packaging direction for Chuanbei Liangfen.

The hypotheses are used as design-oriented assumptions to guide the questionnaire analysis and packaging design practice. The study is guided by the following hypotheses: (1) young consumers are likely to accept the incorporation of Nanchong's Three Kingdoms cultural elements into Chuanbei Liangfen packaging; and (2) a packaging direction that combines cultural expression, regional recognizability, and modern visual style is likely to be preferred by young consumers.

The conceptual framework of this study is shown in Figure 1

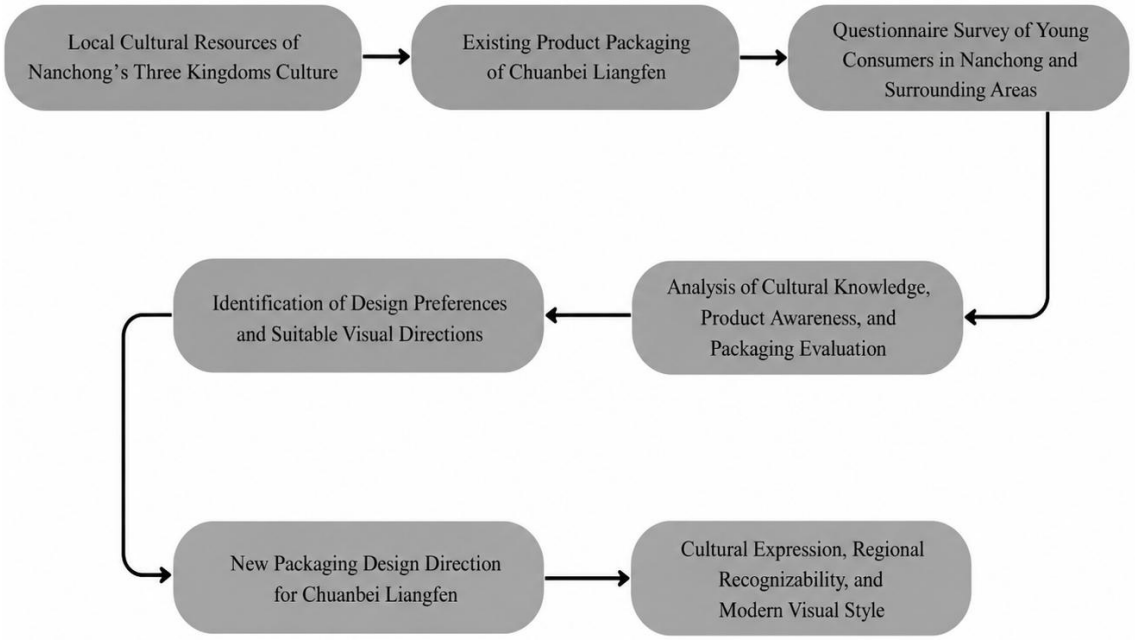

Figure 1 Conceptual Framework of the Study

As shown in Figure 1, the conceptual framework links Nanchong's Three Kingdoms cultural resources, young consumers' cultural and product awareness, their evaluation of existing packaging, and their preferences for a new packaging design direction.

4. Research Methodology

4.1 Research methodology

This study adopts four main methods: literature review, comparative analysis, questionnaire survey, and design practice. Literature review is used to establish the theoretical basis for the study and to identify Three Kingdoms cultural elements suitable for packaging design. Comparative analysis is used to examine existing packaging of Chuanbei Liangfen and similar specialty foods in order to summarize current problems and design needs. Questionnaire survey is used to collect information from young consumers about cultural knowledge, product understanding, views on existing packaging, and preferences for new packaging directions. Design practice is used to translate the identified cultural elements and survey findings into a packaging design proposal.

In the design practice stage, the findings from the literature review, comparative analysis, and questionnaire survey were translated into a preliminary packaging design direction, including cultural element selection, color direction, graphic style, and overall visual positioning.

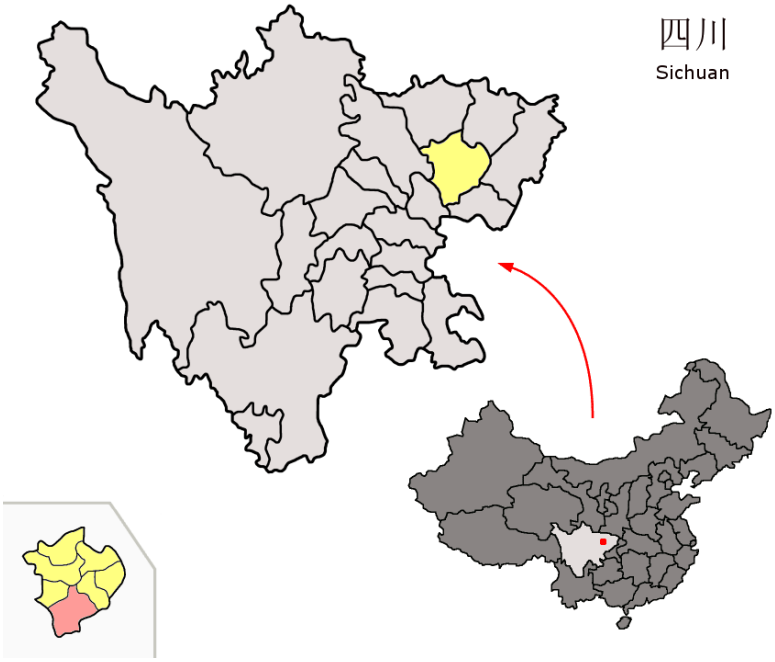

Figure 2 Location Map of Nanchong City (Sichuan Province, China)

As shown in Figure 2, the study was conducted in Nanchong, Sichuan Province, China, which serves as the main research area of this study.

4.2 Research procedure

The research procedure consists of four steps. First, relevant literature on Nanchong regional culture, Three Kingdoms culture, and food packaging design is reviewed. Second, the current packaging of Chuanbei Liangfen and similar specialty foods is compared to identify design problems and opportunities. Third, a questionnaire survey is designed and distributed to young consumers aged 18–35 in Nanchong and surrounding areas. Fourth, based on the cultural resource analysis and survey results, a packaging design proposal integrating Three Kingdoms cultural elements is developed.

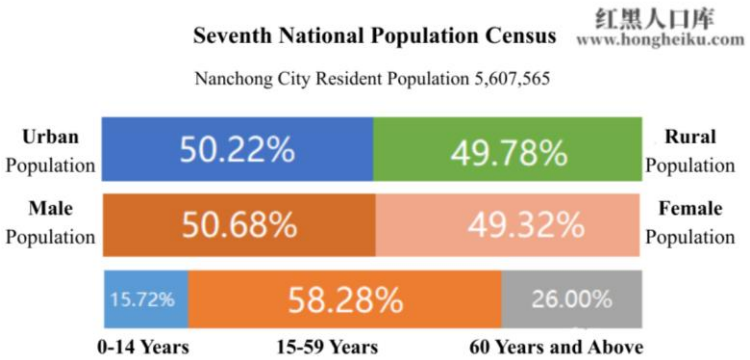

Figure 3 Population ratio of Nanchong, Sichuan

As shown in Figure 3, Nanchong has a balanced urban–rural and gender structure, with a large working-age population, which provides an appropriate demographic basis for this questionnaire survey.

4.3 Data Collection

This study collected data through an online structured questionnaire survey using Google Forms. The target respondents were young people aged 18–35 in Nanchong and surrounding areas. Based on the Yamane (1967) formula with a 5% precision level, the planned sample size was approximately 400 valid questionnaires. The formal questionnaire consisted of 18 closed-ended single-choice items and was divided into four parts: basic information, knowledge of local culture, understanding of Chuanbei Liangfen and its existing packaging, and preferences for the direction of a new packaging design. The questionnaire was developed based on the research objectives, the conceptual framework, the literature review, and the observed problems of existing Chuanbei Liangfen packaging. To ensure the quality of the research instrument, the questionnaire was reviewed by the advisor and experts in related fields in terms of content relevance, clarity of wording, and consistency with the research objectives. After revision, the formal questionnaire was distributed through online platforms such as WeChat and QQ, and 411 valid responses were obtained.

Table 1 Summary of data collection

Item	Description
Data collection tool	Google Forms
Target population	Young consumers aged 18–35 in Nanchong and surrounding areas
Distribution platform	WeChat and QQ
Valid responses	411

The overall data collection information is summarized in Table 1.

4.4 Data Analysis

After the questionnaire was collected, the data were screened to remove invalid responses. The valid data were then organized and analyzed using descriptive statistics, especially frequency and percentage distributions. The analysis focused on respondents' cultural knowledge, their understanding of Chuanbei Liangfen and its existing packaging, and their preferences regarding the color, graphics, cultural elements, and overall direction of a new packaging design. These findings were used as the basis for design development.

5. Results

Before presenting the questionnaire survey results, the findings from the literature review, comparative analysis, and design practice are summarized. The literature review showed that local cultural resources can provide visual symbols and narrative content for packaging design. For Chuanbei Liangfen, Nanchong's Three Kingdoms culture, especially the cultural memory related to Chen Shou and the Records of the Three Kingdoms, can help strengthen regional identity and cultural expression. The comparative analysis showed that the existing packaging mainly emphasizes product information and flavor recognition, but its visual attractiveness, cultural expression, and regional recognizability are still limited. Therefore, the design practice focused on developing a modern cultural packaging direction that combines Three Kingdoms cultural elements with red and gold tones, simple modern graphics, and a balance between traditional and modern styles.

The questionnaire survey was conducted with young consumers in Nanchong and surrounding areas, and 411 valid responses were obtained. The findings are presented in terms of respondent profile, knowledge of local culture and product awareness, views on the existing packaging of Chuanbei Liangfen, preferences for a new packaging design, and overall findings. Tables and figures are used to summarize the key results, followed by analytical descriptions to explain their implications for packaging design.

5.1 Respondent Profile

To provide a general overview of the sample, respondents' basic background information was first analyzed, including gender, age, and area of residence. The results are summarized in Table 2.

Table 2 Respondent profile (n = 411)

Category	Frequency	Percentage（%）
Male	224	54.5
Female	187	45.5
18–22 years old	210	51.1
Shunqing District	192	46.7
Jialing District	35	8.5
Gaoping District	28	6.8
Other districts and counties	156	38.0

As shown in Table 2, the respondents were relatively balanced in gender, with 54.5% male and 45.5% female. In terms of age, the largest group was 18–22 years old, accounting for 51.1% of the sample. In terms of area of residence, the largest proportion of respondents came from Shunqing District, with 192 respondents, accounting for 46.7%, followed by respondents from other districts and counties at 38.0%. Jialing District and Gaoping District accounted for 8.5% and 6.8%, respectively. These results indicate that the sample covered the main urban districts of Nanchong as well as other surrounding districts and counties, which is consistent with the research focus on young consumers in Nanchong and surrounding areas.

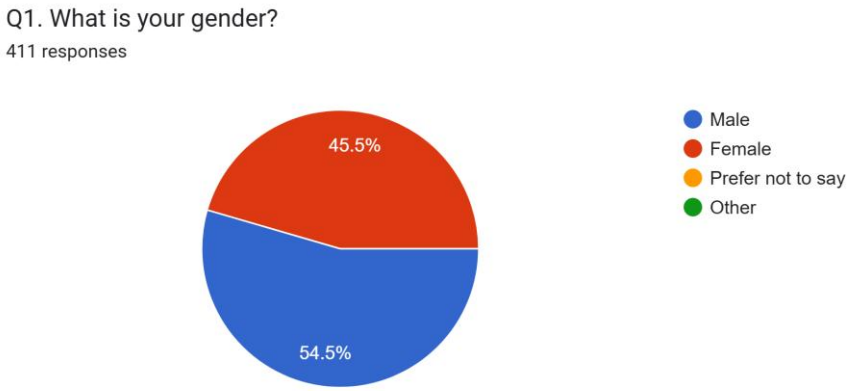

Figure 4 Gender Distribution of the Respondents

As shown in Figure 4, the respondents were relatively balanced in gender, with male respondents slightly outnumbering female respondents.

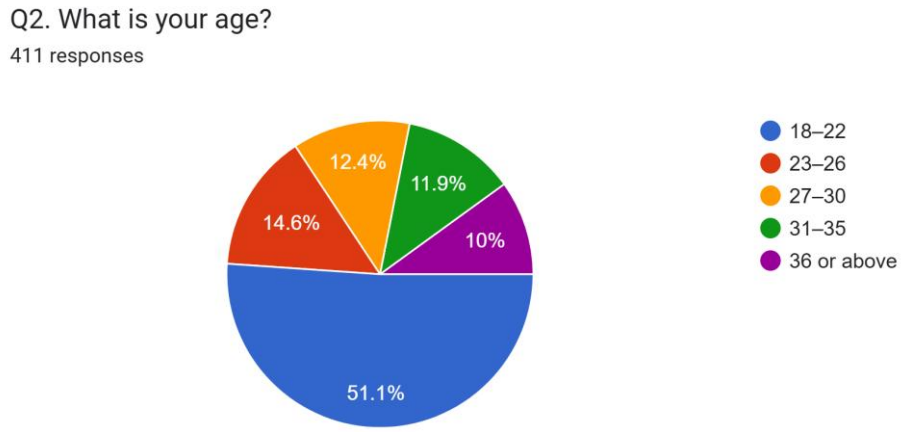

Figure 5 Age Distribution of the Respondents

As shown in Figure 5, the largest age group was 18–22 years old, indicating that younger respondents formed the main part of the sample.

5.2 Knowledge of Culture and Product Awareness

To examine whether respondents had the basic cultural and product awareness necessary for this study, four key indicators were analyzed: familiarity with Nanchong's Three Kingdoms culture, knowledge of Chen Shou, understanding of Chuanbei Liangfen, and purchase frequency of the product. The most common response in each item is presented in Figure 6.

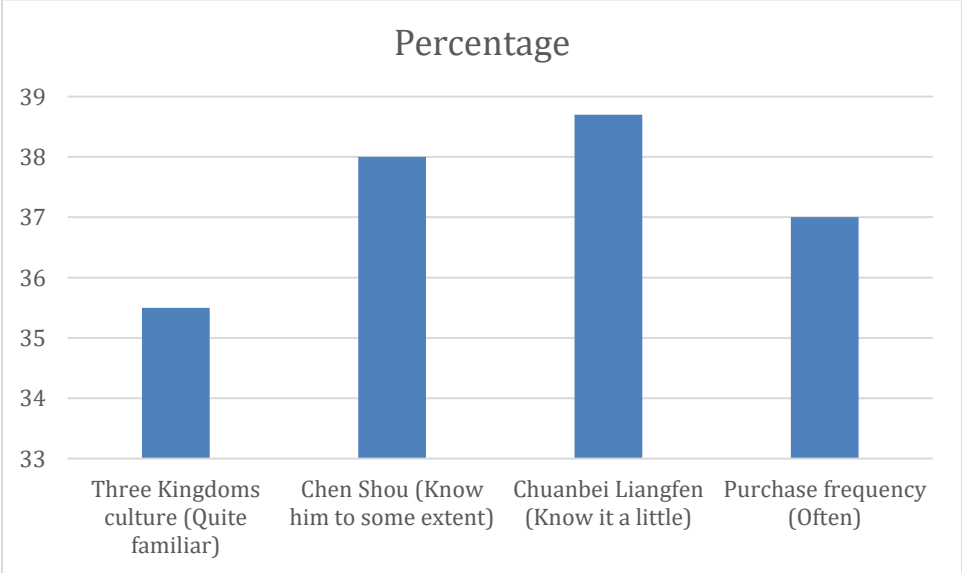

Figure 6 Key Results on Culture and Product Awareness

As shown in Figure 6, the highest response was for respondents who knew Chuanbei Liangfen a little, accounting for 38.7%. This was followed by respondents who knew Chen Shou to some extent at 38.0%, those who often purchased Chuanbei Liangfen at 37.0%, and those who were quite familiar with Nanchong's Three Kingdoms culture at 35.5%.

These results suggest that the respondents generally had a basic to moderate level of knowledge of both the local cultural background and the product itself. Their knowledge of Three Kingdoms culture and Chen Shou indicates that the use of regional cultural elements in packaging

design would be understandable and meaningful to the target group. At the same time, respondents' basic knowledge of Chuanbei Liangfen and their relatively regular purchase frequency suggest that they had practical consumer experience rather than purely abstract opinions. Therefore, the sample can be considered suitable for evaluating the existing packaging and for identifying realistic preferences for a new packaging design.

5.3 Views on the Existing Packaging of Chuanbei Liangfen

The existing packaging image of Chuanbei Liangfen used in the questionnaire is shown in Figure 7. This image was used as a visual reference for respondents when they evaluated purchase intention, packaging problems, and the influence of packaging on purchase choice.

Figure 7 Packaging diagram of Chuanbei Liangfen

To further understand respondents' views on the existing packaging of Chuanbei Liangfen, three aspects were examined: purchase intention after viewing the current packaging image, the main problem of the existing packaging, and the influence of packaging on purchase choice. Among these, the most important issue identified by respondents is presented in Figure 8.

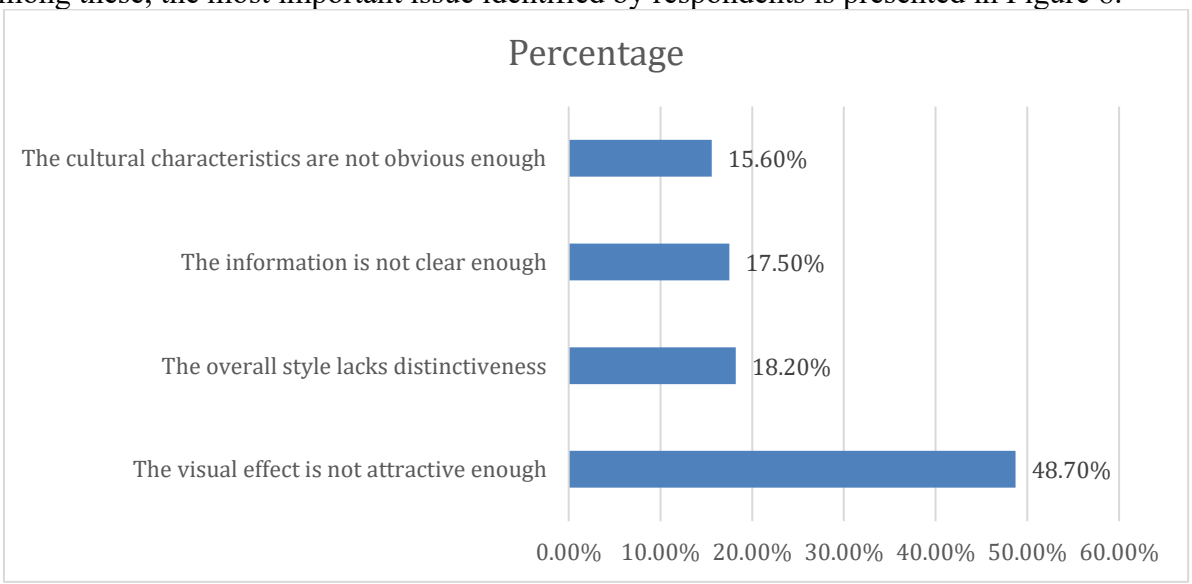

Figure 8 Main Problem with the Existing Packaging of Chuanbei Liangfen

As shown in Figure 8, the most frequently identified problem was that the visual effect was not attractive enough, accounting for 48.7% of responses. This was followed by the overall style

lacking distinctiveness at 18.2%, unclear information at 17.5%, and insufficient cultural characteristics at 15.6%. These results indicate that insufficient visual attractiveness is the most prominent weakness of the current packaging and should be the primary issue addressed in the redesign.

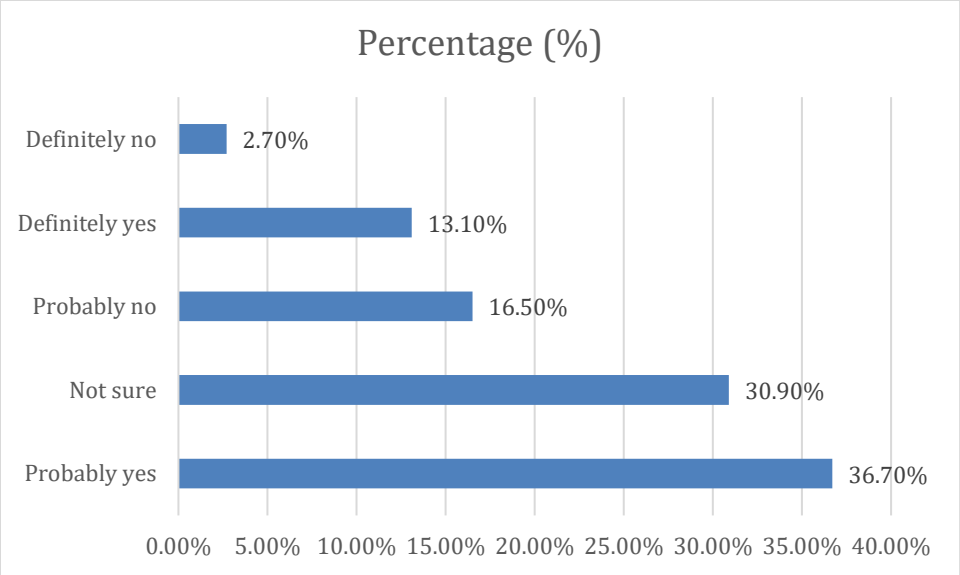

Figure 9 Purchase Intention after Viewing the Existing Packaging

As shown in Figure 9, the highest response for purchase intention after viewing the existing packaging was probably yes, accounting for 36.7%, followed by not sure at 30.9%, probably no at 16.5%, definitely yes at 13.1%, and definitely no at 2.7%. This suggests that the existing packaging can support a certain level of purchase willingness, but it does not strongly encourage purchase intention among most respondents.

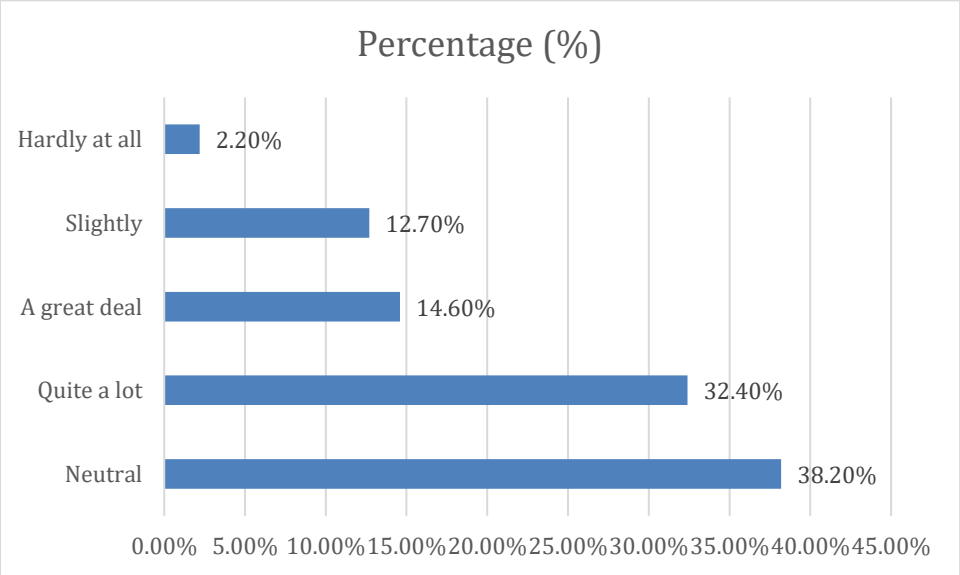

Figure 10 Influence of Packaging on Purchase Choice

As shown in Figure 10, the largest proportion of respondents selected neutral regarding the influence of packaging on purchase choice, accounting for 38.2%. This was followed by quite a

lot at 32.4%, a great deal at 14.6%, slightly at 12.7%, and hardly at all at 2.2%. These results indicate that packaging has a noticeable influence on purchase choice, although it is not the only determining factor.

5.4 Preferences for a New Packaging Design

To identify the most suitable direction for a new packaging design of Chuanbei Liangfen, respondents' preferences for color tone, graphic expression, overall style, and design priority were analyzed. The key results are summarized in Table 3 and Figure 11.

Table 3 Key preferences for a new packaging design

Design Aspect	Main Response	Percentage (%)
Overall style	A combination of traditional and modern styles	51.3
Color tone	Red and gold tones	46.0
Top priority	Cultural expression	42.6
Incorporation of Three Kingdoms culture	Probably yes	40.1
Graphic expression	Simple modern graphics	38.4

As shown in Table 3, the most preferred overall style was a combination of traditional and modern styles, accounting for 51.3%. This was followed by red and gold tones as the preferred color tone at 46.0%, cultural expression as the top design priority at 42.6%, probable acceptance of incorporating Three Kingdoms cultural elements at 40.1%, and simple modern graphics as the preferred graphic expression at 38.4%. These results indicate that respondents preferred a packaging direction that combines cultural meaning with a modern and visually clear design language.

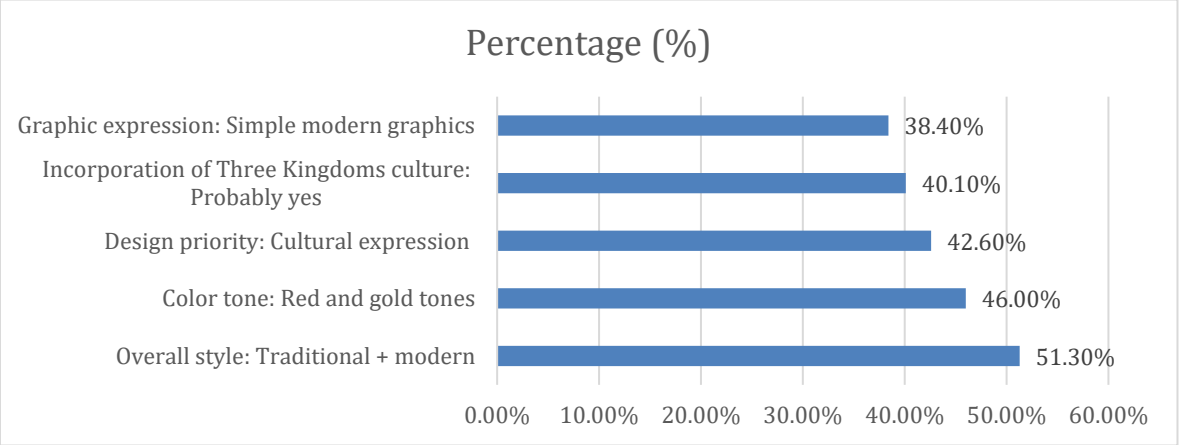

Figure 11 Key Preferences for a New Packaging Design

Figure 11 further presents the five main design preference results in descending order. The results show that respondents did not expect a purely traditional or purely modern packaging style. Instead, they preferred a design direction that combines regional cultural meaning with contemporary visual language. The preference for a combination of traditional and modern styles, red and gold tones, cultural expression, incorporation of Three Kingdoms cultural elements, and simple modern graphics suggests that the new packaging should strengthen cultural identity through refined visual translation rather than direct imitation of historical symbols.

5.5 Overall Findings

Overall, the findings provide several clear directions for improving the outer packaging design of Chuanbei Liangfen. Respondents generally had a basic understanding of both Nanchong's Three Kingdoms culture and Chuanbei Liangfen, which suggests that they were able to give meaningful evaluations and preferences. The existing packaging was not considered entirely ineffective, but its visual attractiveness was still limited, and the most frequently identified problem was that the visual effect was not attractive enough.

The results also show that packaging plays a noticeable role in purchase decisions for local specialty foods. In terms of the new packaging direction, respondents preferred a combination of traditional and modern styles, red and gold tones, cultural expression, incorporation of Three Kingdoms cultural elements, and simple modern graphics. In addition, cultural expression and regional recognizability were regarded as the most important design priorities. These findings suggest that the new packaging design should strengthen visual attractiveness while expressing Nanchong's Three Kingdoms culture in a more modern and refined way.

In summary, the literature review, comparative analysis, questionnaire survey, and design practice together indicate that the redesign of Chuanbei Liangfen packaging should not only improve visual attractiveness, but also strengthen cultural expression and regional recognizability. The proposed design direction should therefore use Nanchong's Three Kingdoms culture as the cultural source, adopt a more modern and simplified visual language, and build a clearer connection among Nanchong, Three Kingdoms culture, and Chuanbei Liangfen.

6. Conclusion and Discussion

6.1 Conclusion related to Objective 1

The first objective of this study was to analyze the current situation of Chuanbei Liangfen packaging and identify its main design problems and needs through literature review, case studies, and market observation. The literature review indicates that local cultural resources can support packaging design by providing symbolic and narrative materials for regional identity construction. The comparative analysis and market observation show that the existing packaging of Chuanbei Liangfen mainly focuses on product information and flavor recognition, but its visual attractiveness, cultural expression, and regional recognizability are still limited. This finding is also supported by the questionnaire results, in which the most frequently identified problem was that the visual effect was not attractive enough. Therefore, the redesign of Chuanbei Liangfen packaging should first improve visual appeal while also strengthening the connection between the product, Nanchong, and Three Kingdoms culture.

6.2 Conclusion related to Objective 2

The second objective of this study was to investigate young consumers' knowledge of Nanchong's Three Kingdoms culture, their views on Chuanbei Liangfen and its existing packaging, and their preferences for the direction of a new packaging design. The findings show that respondents generally had a basic to moderate level of familiarity with both Nanchong's Three Kingdoms culture and Chuanbei Liangfen. In terms of design preferences, respondents preferred a combination of traditional and modern styles, red and gold tones, cultural expression, incorporation of Three Kingdoms cultural elements, and simple modern graphics. These results indicate that the new packaging design should combine regional cultural meaning with a modern and visually clear design language, providing a clear direction for the subsequent design development of Chuanbei Liangfen packaging.

6.3 Discussion

The findings of this study are consistent with previous research on the application of local culture in packaging design. He (2015) pointed out that regional culture should not remain a superficial decorative symbol, but should be integrated into the packaging system to form a complete visual expression. This is similar to the present study, which emphasizes that Three

Kingdoms cultural elements should be translated into a clear and recognizable packaging language. Gao (2022) also argued that traditional cultural elements need to be extracted, reorganized, and redesigned before they can adapt to modern packaging. This is reflected in the current findings, as respondents preferred simple modern graphics and a combination of traditional and modern styles rather than a purely traditional visual form. In addition, Jia (2022) emphasized the importance of audience perception in packaging evaluation. The questionnaire results of this study likewise show that young consumers' preferences are valuable in determining packaging direction, especially in relation to visual attractiveness, cultural expression, and regional recognizability. Therefore, the present study suggests that the redesign of Chuanbei Liangfen packaging should balance cultural identity with contemporary visual communication in order to improve both recognition and appeal.

7. Suggestions

7.1 Practical Suggestions

Based on the research findings, the following practical suggestions are proposed:

- The new packaging design should strengthen visual attractiveness, as weak visual effect was identified as the main problem of the existing packaging.
- Red and gold tones should be considered as the main color direction because they received a high level of preference from respondents and can help create stronger visual recognition.
- Simple modern graphics should be used to present Three Kingdoms cultural elements in a clear and accessible way.
- The design should combine traditional and modern styles rather than relying only on a purely traditional visual form.
- Cultural expression and regional recognizability should be emphasized to build a clearer connection among Nanchong, Three Kingdoms culture, and Chuanbei Liangfen.

7.2 Future Research Suggestions

Future research may further develop this study in the following directions:

- Future studies may compare different packaging design proposals to examine their influence on purchase intention, cultural recognition, and product memory.
- Future research may test different color systems, graphic styles, and levels of Three Kingdoms cultural-element integration.
- The sample may be expanded to include consumers from other regions and different age groups.
- Interviews, experimental testing, or visual preference comparisons may be used together with questionnaire surveys to obtain richer research evidence.

8. Acknowledgements

The author would like to express sincere gratitude to the advisor, experts, and all respondents who contributed to this research. Special thanks are extended to all participants who completed the questionnaire and provided valuable information for the study. Their support and cooperation made this research possible.

9. References

China Food Safety News. (n.d.). Chuanbei Liangfen brand instant liangfen (classic chili oil flavor).

Fu, L., Wang, R., & Zhang, Y. (2018). Research progress of food packaging materials. Packaging and Food Machinery, 36(1), 51–56.

Gao, J. (2022). A study on the application of Yangshao painted pottery patterns in packaging design: A redesign case of "Caitaofang" liquor packaging [Master's thesis, Changchun University of Technology].

He, X. (2015). A study on the application of Xiangshan regional cultural elements in the packaging design of Zhongshan local specialty products [Master's thesis, Hunan Normal University].

Jia, H. (2022). A study on the application of Kansei engineering in tea packaging design [Master's thesis, University of Jinan].

Shunqing District Gazetteer Office. (2023, November 7). Local products and specialties: Chuanbei Liangfen.

Sichuan Provincial Gazetteer Website. (2018, July 5). Administrative evolution of Nanchong: Origin of the name and major characteristics.

Sichuan Provincial Gazetteer Website. (2019, June 13). Scenic spots in Shunqing District.

Yamane, T. (1967). Statistics: An introductory analysis (2nd ed.). Harper & Row.

ATMOSPHERIC PARTICLE MATTER CONTENT MEASURING BY USING SINGLE FREQUENCY GPS SATELLITES DATA

Wanwisa Mantonghlang*, Pattawut Wongsak, Supawit Nambut, Aswin Kingjumpa, and Prasert Kenpankho

66030165@kmitl.ac.th, 67036098@kmitl.ac.th, 66036033@kmitl.ac.th, 67036100@kmitl.ac.th, and prasert.ke@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 66030165@kmitl.ac.th

ABSTRACT

Monitoring PM2.5 is a critical component of air quality assessment, particularly in urban centers such as Bangkok where pollution levels fluctuate significantly. Conventional monitoring relies on ground-based atmospheric sensors, which, while accurate, are limited in spatial coverage and require substantial infrastructure. This study investigates the feasibility of using single-frequency GPS satellite data to estimate PM2.5 concentrations, focusing on observations collected at the KMITL Bangkok station during 1-28 February 2026. The methodology centers on deriving TEC from GPS signals using the iPM, which receives single-frequency GPS data, applies bias compensation, and converts the values into PM2.5 estimates. These estimates were then compared with PM2.5 concentrations measured by an atmospheric sensor. Results are presented both as hourly comparisons by week and daily comparisons across the full month. The weekly hourly analysis demonstrates that iPM values closely follow the temporal fluctuations observed by the atmospheric sensor, with peaks and troughs occurring at corresponding times, although some discrepancies in magnitude were noted, particularly during nighttime hours. The daily comparison across the month further confirms the consistency of the iPM estimates with sensor data, showing aligned trends in pollution variation. Statistical analysis yielded a correlation coefficient of 0.69 and an RMSE of 6.92 μg/m³, indicating a moderate to strong positive relationship with relatively small deviations. These findings highlight the potential of GPS TEC as a supplementary tool for air quality monitoring, offering scalability and cost-effectiveness by leveraging existing GNSS infrastructure. However, limitations include reliance on single-frequency data, short observation period, and sensitivity to ionospheric variability. Future work should extend the analysis to multiple stations, longer timeframes, and multi-frequency GPS signals to improve accuracy and generalizability. Overall, this study demonstrates that GPS satellite techniques can complement conventional sensor networks, enhancing urban air quality monitoring frameworks in regions with limited infrastructure.

Keywords: TEC, PM2.5, GPS satellite, iPM

1. Statement of the Problem

Air quality monitoring is vital in urban areas where particulate matter (PM2.5) poses serious health risks. Conventional sensor networks provide accurate measurements but are limited in coverage and infrastructure. Global Positioning System (GPS) signals, as they pass through the ionosphere, are influenced by variations in electron density, which is quantified as Total Electron Content (TEC). Although TEC primarily reflects ionospheric electron density, it may be indirectly

influenced by lower atmospheric processes through vertical atmospheric coupling mechanisms. This potential linkage suggests that TEC could serve as an indirect indicator of PM2.5 concentrations, offering a cost-effective and wide-coverage complement to traditional monitoring systems. For cities such as Bangkok, where pollution episodes are frequent, TEC-based estimation could enhance air quality assessment and support public health initiatives.

Global Navigation Satellite System (GNSS) based atmospheric monitoring has been extensively applied to ionospheric and tropospheric studies, providing insights into electron density variations, water vapor distribution, and GPS signal delays. In Thailand, significant progress has been made in this field: Keokhumcheng and Kenpankho (2025) demonstrated the use of single-frequency GPS receivers for TEC analysis, Nambut and Kenpankho (2024) investigated water vapor variability over Bangkok and Chumphon, Keokhumcheng and Kenpankho (2024) examined GPS delay times during geomagnetic disturbances, and Nambut et al. (2025) studied tropospheric Precipitable Water Vapor (PWV) retrieval. Earlier foundational studies compared observed TEC values with IRI model predictions at equatorial stations (Kenpankho et al., 2011; 2013), while more recent Thai contributions expanded knowledge on TEC GPS delay relationships and single-frequency GPS-derived TEC (Koetnawi et al., 2024; Phasiw et al., 2024; Photila et al., 2025). Internationally, GNSS applications have been extended to diverse atmospheric contexts, including tropospheric anomalies during sandstorms (Zhou et al., 2022), PWV nowcasting (Guo et al., 2021), and multi-source PWV retrieval (Zhang et al., 2018), building on classic GPS meteorology foundations (Bevis et al., 1992; Bevis et al., 1994). Complementary research has also highlighted broader atmospheric mechanisms influencing particulate matter: Wang et al. (2019) used vertical observations from a 325 m tower and Doppler lidar in Beijing to show that PM2.5 concentrations anticorrelate with boundary layer height, with weakened vertical mixing and temperature inversions exacerbating pollution accumulation, while Yang et al. (2018) applied an online coupled modeling system to quantify the role of urban vegetation in air quality improvement, demonstrating that trees-particularly conifers-enhance dry deposition and reduce PM2.5 concentrations under different greening scenarios. Collectively, these studies confirm that GNSS techniques effectively capture ionospheric and tropospheric dynamics, and when integrated with knowledge of boundary layer processes and vegetation effects, they provide a comprehensive framework for extending TEC analysis toward novel applications such as particulate matter monitoring.

From the review of related studies on GPS satellite signals for atmospheric monitoring, it is recognized that this technology can be effectively applied to estimate particulate matter concentrations. GPS systems provide high-resolution data, wide spatial coverage, and continuous 24-hour operation, making them a reliable technique for analyzing PM2.5. In this study, GPS satellite data are utilized following the approach of Keokhumcheng and Kenpankho (2025), who employed single-frequency GPS receivers to measure TEC over Thailand. TEC values are then used to calculate atmospheric delays, specifically Zenith Total Delay (ZTD), which is separated into Zenith Hydrostatic Delay (ZHD) representing the dry component, and Zenith Wet Delay (ZWD) reflecting the wet component, based on the principles of Bevis et al. (1992). ZWD corresponds to atmospheric water vapor, while ZHD represents the dry atmosphere, and both serve as key variables in estimating total particulate matter concentrations.

The objective of this study is to evaluate the feasibility of using GPS satellite signals as an indirect tool for monitoring PM2.5 concentrations in the lower atmosphere. By integrating GPS TEC and atmospheric delay parameters with ground-based atmospherics sensor air quality measurements, the research seeks to establish statistical relationships that reveal how vertical atmospheric coupling mechanisms may connect ionospheric electron density variations with pollution episodes. The ultimate goal is to expand the application of GPS satellites beyond their

traditional roles in navigation and meteorology, positioning them as a cost-effective and scalable system for air quality assessment. This approach is particularly significant for urban environments such as King Mongkut's Institute of Technology Ladkrabang (KMITL) Bangkok station, where pollution episodes are frequent and monitoring resources are limited, thereby supporting both public health protection and environmental management initiatives.

2. Objectives

2.1 Evaluating the feasibility of using GPS TEC from single-frequency signals, processed through the ionospheric Particulate Matter (iPM) device.

2.2 Comparing PM2.5 from iPM with atmospherics sensor measurements at the KMITL Bangkok station during February 2026.

3. Research Methodology

3.1 Data Collection

This study utilized single-frequency GPS observation data collected from the Bangkok station, comprising NMEA and TEC files recorded by a GPS receiver operating at the L1 frequency (1575.42 MHz). Meteorological parameters such as surface pressure and temperature were also obtained, together with reference PM2.5 data from the official air quality monitoring station. The observation period consisted of continuous hourly measurements, during which GPS satellite signals transmitted from an altitude of approximately 20,200 km propagated through the ionosphere and troposphere before reaching the ground receiver. The delays induced by these atmospheric layers were extracted and analyzed to estimate key atmospheric parameters forming the basis of this research.

3.2 Ionospheric Delay and Total Electron Content

The ionosphere contains free electrons that affect GPS signals, producing delays proportional to TEC. TEC can be measured along both slant and vertical paths:

3.2.1 Slant Total Electron Content (STEC): calculated from dual-frequency GPS carrier phase measurements, as shown (Kenpankho et al. 2011) in Equation (1):

$$STEC = \frac{(2(f_1 f_2)^2)}{k(f_1^2 - f_2^2)}\left(L_1\lambda_1 - L_2\lambda_2\right) \qquad el/m^2 \tag{1}$$

where f_1 = 1575.42 MHz, f_2 = 1227.60 MHz, L_1, L_2 = carrier phases, λ_1, λ_2 = wavelengths, and k = 80.62 m^3/s^2.

3.2.2 Vertical Total Electron Content (VTEC): derived from STEC and the zenith angle χ, as shown (Kenpankho et al. 2011) in Equation (2):

$$VTEC = (STEC - b_s - b_r) \times \cos\chi \tag{2}$$

where χ determined by satellite elevation angle and ionospheric shell height, b_s is satellite bias and b_r is receiver bias.

GPS signals are delayed when passing through the ionosphere due to interactions with free electrons. This delay is proportional to TEC along the signal path and inversely proportional to the square of the signal frequency, as shown (Keokhumcheng & Kenpankho, 2025, p. 4248) in Equation (3). These formulations allow TEC values derived from GPS observations to be used as proxies for ionospheric variability.

$$\Delta t = \frac{A}{cf^2} TEC \tag{3}$$

where:

Δt = ionospheric delay (seconds),

A = $\frac{e^2}{8\pi^2 m\varepsilon_0}$, a constant derived from fundamental physical parameters,

c = speed of light (2.9979x10^8 m/s),

f = GPS signal frequency (Hz),

TEC = Total Electron Content.

This formulation allows TEC values derived from GPS observations to be used as proxies for ionospheric variability.

3.3 Tropospheric Delay Components

The troposphere introduces additional delays due to atmospheric pressure and water vapor. The ZTD represents the combined effect of hydrostatic and wet components, as shown (Zhang et al. 2018, p. 2) in Equation (4):

$$ZTD = ZHD + ZWD \tag{4}$$

3.3.1 Zenith Hydrostatic Delay (ZHD): depends primarily on surface pressure, latitude, and station height, as shown (Bevis et al. 1992, p. 15,790) in Equation (5):

$$ZHD = \frac{2.2768 \times P_s}{1 - \left(0.00266 \times \cos(2\phi)\right) - (0.00028 \times H)} \tag{5}$$

where P_s is the surface pressure in millibar unit, ϕ is the latitude station, and H the station height above mean sea level (m).

3.3.2 Zenith Wet Delay (ZWD): obtained by subtracting ZHD from ZTD, as shown (Numbut & Kenpankho, 2024) in Equation (6):

$$ZWD = ZTD - ZHD \tag{6}$$

Additionally, the total signal delay can be approximated directly by ZTD. Inspired by the studies (Numbut & Kenpankho, 2024; Keokhumcheng & Kenpankho, 2025), as shown in Equation (7):

$$\Delta t \approx ZTD \tag{7}$$

This approximation highlights the dominant role of tropospheric delay in GPS signal propagation.

3.4 Conversion to Precipitable Water Vapor (PWV)

The ZWD is converted into PWV, representing the total atmospheric water vapor content, as shown (Bevis et al. 1994, p. 380) in Equation (8). A conversion factor specific to the KMITL Bangkok station, dependent on mean atmospheric temperature, is applied as shown in Equation (9). This formulation incorporates constants such as water density, the specific gas constant for water vapor, and tropospheric refractivity parameters.

$$PWV = ZWD \times \Pi \tag{8}$$

Where Π is a conversion factor at KMITL Bangkok station which is dependent on mean atmospheric temperature (T_m). Based on Bevis et al. (1994), the formulation has been adapted in this study to local conditions, yielding a modified compensation, as shown in Equation (9):

$$\Pi = \rho_w R_v \left(\frac{k_1}{T_m} + k_2' \right) x\ 10^6 \tag{9}$$

where:

ρ_w = Density of water (999.97 kg/m³),

R_v = Specific gas constant for water vapor (461.525 J/ kg·K),

k_1 = Tropospheric refractivity constant at the maximum temperature (3,739 K²/mbar),

k_2' = Tropospheric refractivity constant at the minimum temperature (22.1 K²/mbar),

T_m = Mean atmospheric temperature, which can be calculated from the surface temperature (T_s).

3.5 Statistical Link to PM2.5

GPS-derived parameters are statistically linked to PM2.5 concentrations. Based on Bevis et al. (1992) and Zhang et al. (2018), this study proposes a modified formulation relating particulate matter to tropospheric delays and water vapor, as shown in Equation (10):

$$PM = ZTD - \frac{PWV}{\Pi} \tag{10}$$

where PM is the particulate matter concentration (PM2.5), ZTD denotes the zenith total delay, PWV represents precipitable water vapor, and Π is the conversion factor.

3.6 Ionospheric Particulate Matter (iPM)

The iPM is a prototype system developed to estimate atmospheric particulate concentrations using single-frequency GPS signals. It operates by analyzing the delay of satellite signals as they pass through the atmosphere, which is subsequently transformed into PM2.5 estimation. The system combines signal reception, data processing, and display functions within a single unit, making it suitable for both laboratory and field applications.

Figure 1 Structure of the iPM system developed

In Figure 1, a GPS antenna receives satellite signals, which are decoded by the GPS receiver into NMEA format containing essential information such as time, position, and satellite availability. These data are then processed by a Raspberry Pi 5 to calculate ionospheric parameters, particularly the TEC. Mathematical models are applied to convert TEC values into estimates of particulate matter concentrations. The results are displayed in real time on a 4-inch Thin-Film Transistor Liquid Crystal Display (TFT LCD) touch screen, while all measurement data are simultaneously recorded through the centralized data system of Space Satellite and Study Lab (SSS Lab) for retrospective analysis. The device is enclosed in a rectangular casing with dust and moisture protection, ventilation for heat dissipation, and a layout that separates the processing and display sections, ensuring durability and reliability during continuous monitoring.

This integrated design highlights the practicality of the iPM system for continuous air quality monitoring. Its ability to combine GPS based ionospheric analysis with particulate estimation provides a novel approach to environmental research. The centralized data recording further ensures reproducibility and facilitates long term comparative studies. Together, these features demonstrate the potential of the iPM system as a supplementary tool for both laboratory experiments and field deployments. In addition, the modular architecture allows future upgrades of processing algorithms and sensor integration. This flexibility ensures that the iPM can evolve alongside advancements in atmospheric monitoring technologies.

4. Results

The dataset analyzed in this section was collected over a one-month period during 1 - 28 February 2026 at the KMITL Bangkok station. The TEC values were obtained using the iPM device, which receives single-frequency GPS signals and processes them to estimate PM2.5 concentrations. The bias compensation was applied to correct systematic errors. The calculated PM2.5 values from iPM were then compared against reference measurements from the Atmospherics Sensor.

4.1 Hourly Comparisons by Week

To evaluate short-term variations, PM2.5 concentrations from the iPM device were compared with atmospherics sensor measurements on an hourly basis during 1-7 February 2026. The analysis shows aligned temporal patterns between the two datasets, with differences in magnitude at certain hours. Examining the highest and lowest values helps assess the reliability of iPM estimates relative to sensor data.

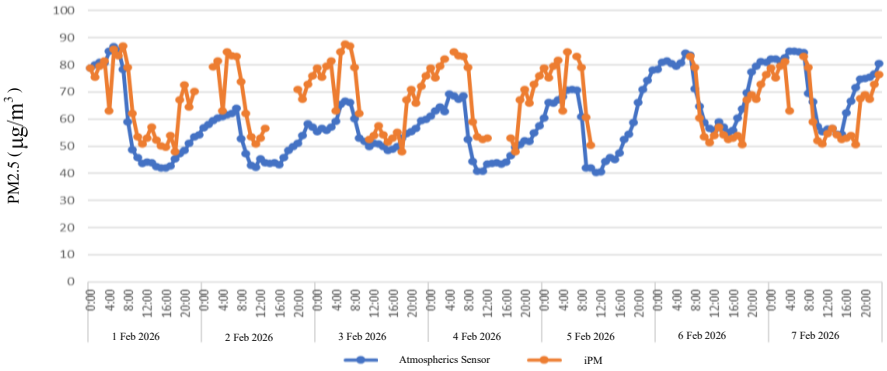

Figure 2 Trends of PM2.5 concentrations from atmospherics sensor and iPM at KMITL Bangkok station during 1-7 February 2026

Figure 2 shows that the atmospherics sensor (blue line) recorded its highest PM2.5 concentration at 86.65 µg/m³ around 05:00 on 1 February, and its lowest at 40.25 µg/m³ around 11:00 on 5 February. The iPM device (orange line) reported a maximum of 87.73 µg/m³ around 06:00 on 3 February, and a minimum of 48.05 µg/m³ around 18:00 on 1 February. Despite differences in magnitude, both datasets display similar hourly fluctuations, suggesting that GPS-derived TEC values processed through the iPM device can capture PM2.5 dynamics, though calibration is needed to reduce bias.

Continuing with the second week's analysis (8-14 February 2026), the hourly comparison shows consistent patterns between atmospherics sensor and iPM measurements. Peaks and troughs align across the week, confirming that GPS TEC can capture short-term PM2.5 dynamics despite occasional differences in magnitude.

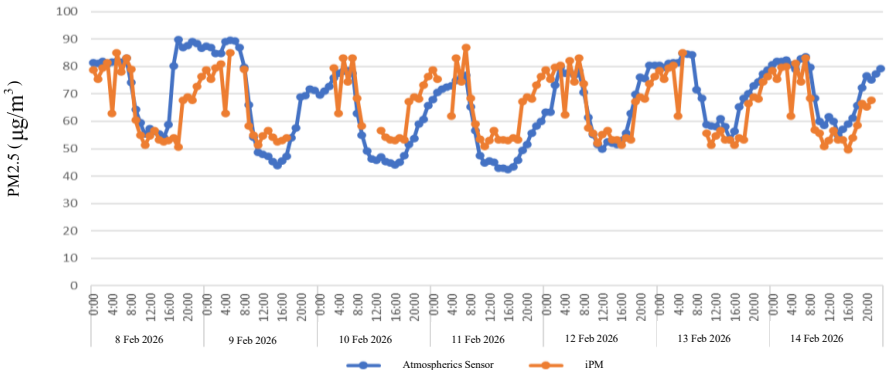

Figure 3 Trends of PM2.5 concentrations from atmospherics sensor and iPM at KMITL Bangkok station during 8-14 February 2026

Figure 3 shows the results which indicate that the atmospherics sensor recorded its highest PM2.5 concentration at 89.75 µg/m³ around 18:00 on 8 February, while the lowest value was observed at 42.55 µg/m³ around 16:00 on 11 February. In comparison, the iPM device reported its maximum value at 86.99 µg/m³ around 07:00 on 11 February, and its minimum value at 49.61 µg/m³ around 16:00 on 14 February. Despite these differences in magnitude, the synchronized timing of peaks and troughs across both datasets highlights the robustness of the method in reflecting daily air quality variations.

During 15-21 February 2026, the hourly comparison between atmospheric sensor and iPM showed consistent temporal dynamics. Both datasets revealed daily cycles with similar peaks and troughs, though iPM occasionally reported different magnitudes. These results confirm the robustness of GPS TEC processed through iPM in reflecting PM2.5 variations across consecutive weeks.

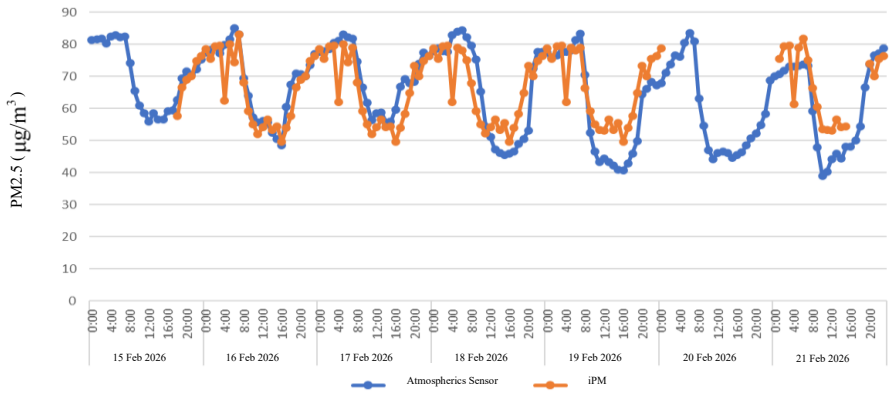

Figure 4 Trends of PM2.5 concentrations from atmospherics sensor and iPM at KMITL Bangkok station during 15-21 February 2026

In Figure 4, the results indicate that the atmospheric sensor recorded its highest PM2.5 concentration at 85.05 µg/m³ around 06:00 on 16 February, while the lowest value was observed at 39.10 µg/m³ around 10:00 on 21 February. In comparison, the iPM device reported its maximum value at 80.3 µg/m³ around 07:00 on 16 February, and its minimum value at 49.61 µg/m³ around 16:00 on 16 February. Despite these differences in magnitude, the synchronized timing of peaks and troughs across both datasets highlights the method's ability to capture short-term PM2.5 dynamics, while also pointing to the need for calibration refinements to improve quantitative accuracy.

During 22-28 February 2026, the hourly comparison between iPM and atmospheric sensor measurements showed consistent temporal variations. Both datasets revealed daily cycles with aligned peaks and troughs, confirming persistent dynamics throughout the month. Although iPM occasionally reported different magnitudes, overall patterns remained synchronized, reinforcing the robustness of GPS TEC in capturing short-term PM2.5 fluctuations.

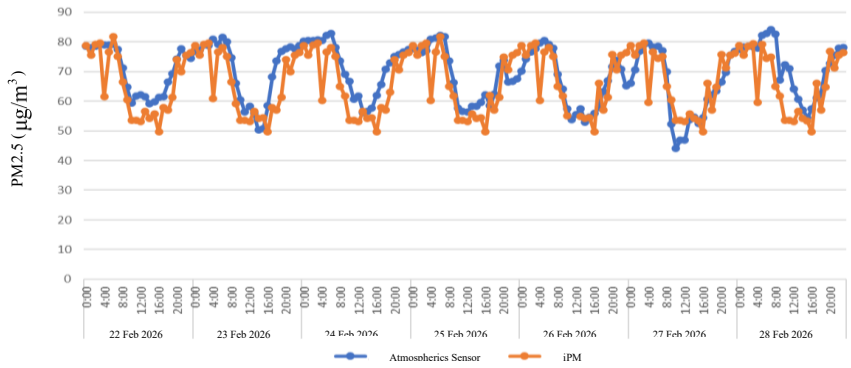

Figure 5 Trends of PM2.5 concentrations from atmospherics sensor and iPM at KMITL Bangkok station during 22-28 February 2026

In Figure 5, the analysis shows that the atmospheric sensor recorded its highest PM2.5 concentration at 84.1 µg/m³ around 07:00 on 28 February, while the lowest value was observed at 44.15 µg/m³ around 10:00 on 27 February. In comparison, the iPM device reported its maximum value at 81.78 µg/m³ around 06:00 on 22 February, and its minimum value at 49.61 µg/m³ around 16:00 on 22 February. Despite differences in magnitude, the synchronized timing of peaks and troughs across both datasets highlights the method's ability to reflect daily air quality variations, while also pointing to the need for calibration refinements to improve quantitative accuracy.

4.2 Daily Comparison for the Entire Month

To complement the weekly hourly comparisons presented in Figures 2-5, the dataset was further analyzed on a daily basis across the entire month of February 2026. This broader perspective allows for the identification of long-term pollution trends and provides a clearer picture of how PM2.5 concentrations varied throughout the observation period. By aggregating the data into daily averages, short-term fluctuations are smoothed, making it possible to highlight consistent patterns and correlations between iPM-derived values and Atmospherics Sensor measurements.

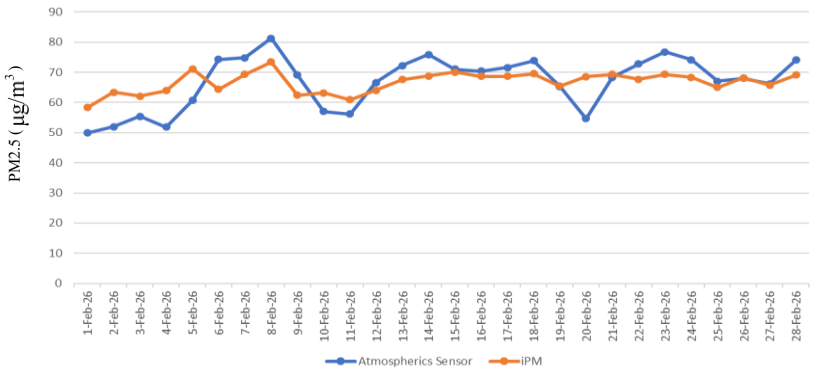

Figure 6 Trends of PM2.5 concentrations from atmospherics sensor and iPM at KMITL Bangkok station during 1-28 February 2026

Figure 6 shows the daily variation of PM2.5 concentrations across February 2026. Both atmospheric sensor data and iPM derived values follow consistent daily cycles, with peaks and troughs aligned throughout the month. Although iPM occasionally overestimated or underestimated magnitudes, the overall temporal patterns remained synchronized. The atmospheric sensor recorded its highest PM2.5 concentration on 8 February at 81.3 µg/m³ and its lowest on 1 February at 49.9 µg/m³. For iPM, the maximum occurred on 8 February with 73.45 µg/m³, while the minimum was observed on 1 February at 58.3 µg/m³. These results further confirm the robustness of GPS TEC processed through iPM in capturing daily PM2.5 fluctuations.

4.3 Correlation coefficient

To quantitatively assess the relationship between iPM values and atmospherics sensor measurements, a correlation analysis was performed using the dataset collected at the KMITL Bangkok station during February 2026. While the graphical comparisons in Figures 2-6 illustrate consistent temporal trends across both hourly and daily timescales, the statistical correlation provides a more precise measure of agreement between the two methods.

Table 1 Correlation between atmospherics sensor and iPM measurements at KMITL Bangkok station (February 2026)

Comparison	Correlation coefficient
Atmospherics sensor and iPM	0.69

In Table 1, the correlation coefficient between iPM values and atmospherics sensor measurements was 0.69, indicating a moderate-to-strong positive relationship. These findings confirm that GPS TEC values processed through the iPM device can serve as reliable indirect indicators of PM2.5 concentrations. The hourly comparisons in Figures 2-5 demonstrate the robustness of the method across short time intervals, while the daily comparison in Figure 6 highlights its consistency over the full month. Together, these results reinforce the statistical evidence summarized in Table 1, validating the potential of GPS-based techniques as a supplementary approach to conventional air quality monitoring systems.

4.4 Root Mean Square Error (RMSE)

Further evaluation on the agreement between iPM values and atmospherics sensor measurements, the RMSE was calculated using the dataset collected at the KMITL Bangkok station during February 2026. RMSE provides a measure of the average magnitude of errors between the two datasets, regardless of direction, thereby complementing the correlation analysis.

Table 2 RMSE on atmospherics sensor and iPM measurements at KMITL Bangkok station (February 2026)

Comparison	RMSE (μg/m³)
Atmospherics sensor and iPM	6.92

In Table 2, the RMSE between iPM values and atmospherics sensor measurements was 6.92 μg/m³, indicating that the average deviation between the two methods is relatively small. This result supports the reliability of GPS-derived TEC values processed through the iPM device as indirect indicators of PM2.5 concentrations.

5. Conclusion and Discussion

This study confirmed the feasibility of using GPS TEC from single-frequency signals, processed through the iPM device with bias compensation, as an indirect indicator of PM2.5 concentrations. Comparisons between iPM values and atmospherics sensor measurements at the KMITL Bangkok station during February 2026 showed consistent temporal patterns. Hourly analyses across four weeks demonstrated that iPM estimates captured short-term fluctuations with peaks and troughs aligned to sensor data, while the daily comparison for the full month highlighted the method's stability at a broader timescale. The statistical summary reported a correlation coefficient of 0.69 and an RMSE of 6.92 μg/m³, confirming a moderate to strong positive relationship with relatively small deviations. These findings validate the potential of GPS-based techniques as a supplementary approach to conventional monitoring systems.

In line with related studies by Keokhumcheng and Kenpankho (2025) and the framework of Bevis et al. (1992), this research reinforces the role of GPS satellite signals in atmospheric monitoring. TEC values, linked to ZHD and ZWD, provide meaningful variables for estimating particulate matter concentrations. While strengths of this study include scalability, cost-effectiveness, and the ability to capture both short-term and long-term variations, limitations remain in the reliance on single-frequency data, short observation period, and sensitivity to ionospheric variability. Future work should expand to multi-frequency GPS receivers, longer

timeframes, and multiple stations to improve accuracy and generalizability. Overall, GPS TEC offers a promising complement to sensor networks, enhancing urban air quality monitoring frameworks in regions with limited infrastructure.

6. Acknowledgements

This work was supported by the Space, Satellite, and Study Laboratory (SSS Lab), King Mongkut's Institute of Technology Ladkrabang (KMITL), which kindly provided atmospherics sensor data essential and iPM device to the study.

7. References

Bevis, M., Businger, S., Herring, T. A., Rocken, C., Anthes, R. A., & Ware, R. H. (1992). GPS meteorology: Remote sensing of atmospheric water vapor using the Global Positioning System. Journal of Geophysical Research: Atmospheres, 97(D14), (pp. 15787-15801). doi: https://doi.org/10.1029/92JD01517.

Bevis, M., Businger, S., Chiswell, S., Herring, T. A., Anthes, R. A., Rocken, C., & Ware, R. H. (1994). GPS meteorology: Mapping zenith wet delays onto precipitable water. Journal of Applied Meteorology, 33(3), (pp. 379-386). doi: https://doi.org/10.1175/1520-0450(1994)033.

Guo, M., Zhang, H., & Xia, P. (2021). Exploration and analysis of the factors influencing GNSS PWV for nowcasting applications. Advances in Space Research, 67(11), (pp. 3960-3978). doi: https://doi.org/10.1016/j.asr.2021.03.041.

Keokhumcheng, T., & Kenpankho, P. (2024). Delay time on GPS at low latitude station on geomagnetic day. In Proceedings of DRLE 2024 International Conference (pp. 16-23).

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), (pp. 4245-4259). doi: https://doi.org/10.1016/j.asr.2024.08.019.

Kenpankho, P., Supnithi, P., & Nagatsuma, T. (2013). Comparison of observed TEC values with IRI-2007 TEC and IRI-2007 TEC with optional foF2 measurements predictions at an equatorial region, Chumphon, Thailand. Advances in Space Research, 52(11), (pp. 1820-1826). doi: https://doi.org/10.1016/j.asr.2013.08.018.

Kenpankho, P., Watthanasangmechai, K., Supnithi, P., Tsugawa, T., & Maruyama, T. (2011). Comparison of GPS TEC measurements with IRI TEC prediction at the equatorial latitude station, Chumphon, Thailand. Earth, Planets and Space, 63(4), (pp. 365-370). doi: https://doi.org/10.5047/eps.2011.02.003.

Koetnawi, S., Kaewkhamchang, T., Pansong, C., & Kenpankho, P. (2024). Relationship between ionospheric total electron content and GPS delay time. In Proceedings of the 14th National Conference on Education: Research and Innovation Ecosystem (pp. 360-367). King Mongkut's Institute of Technology Ladkrabang.

Nambut, S., & Kenpankho, P. (2024). Water vapor analysis from GNSS observation over Bangkok and Chumphon, Thailand. In Proceedings of DRLE 2024 International Conference (pp. 1-7).

Nambut, S., Kraisi, P., & Kenpankho, P. (2025). Troposphere precipitable water vapor observation using GPS in Thailand. In Proceedings of DRLE 2025 International Conference (pp. 157-166).

Phasiw, B., Kaewkhamchang, T., Pansong, C., & Kenpankho, P. (2024). Study of ionospheric total electron content using GNSS signals. In Proceedings of the 14th National Conference on Education: Research and Innovation Ecosystem (pp. 335-342). King Mongkut's Institute of Technology Ladkrabang.

Photila, P., Kaewkhamchang, T., & Kenpankho, P. (2025). Measurement of total electron content using single-frequency GPS receivers. In Proceedings of the 15th National Conference on Education: Research and Innovation Ecosystem (pp. 408-420). King Mongkut's Institute of Technology Ladkrabang.

Wang, L., Liu, J., Gao, Z., Li, Y., Huang, M., Fan, S., Yang, T. (2019). Vertical observations of the atmospheric boundary layer structure over Beijing urban area during air pollution episodes. Atmospheric Chemistry and Physics, 19(10), (pp. 6949-6967). doi: https://doi.org/10.5194/acp-19-6949-2019.

Yang, J., Liu, H., & Sun, J. (2018). Evaluation and application of an online coupled modeling system to assess the interaction between urban vegetation and air quality. Aerosol and Air Quality Research, 18(6), (pp. 693-710). doi: 10.4209/aaqr.2017.06.0199.

Zhang, Q., Ye, J., Zhang, S., & Han, F. (2018). Precipitable water vapor retrieval and analysis by multiple data sources: Ground-based GNSS, radio occultation, radiosonde, microwave satellite, and NWP reanalysis data. Journal of Sensors, 2018, Article ID 3428303, (pp. 1-13). doi: https://doi.org/10.1155/2018/3428303.

Zhou, M., Guo, J., Liu, X., Hou, R., & Jin, X. (2022). Analysis of GNSS-derived tropospheric zenith non-hydrostatic delay anomaly during sandstorms in Northern China on 15 March 2021. Remote Sensing, 14(18), (pp. 4678). doi: https://doi.org/10.3390/rs14184678.

GEOMAGNETIC FIELD DISTRIBUTION BY USING FLUXGATE MAGNETOMETER

Thapanan Namniwong*, Burin Phutthong, Patiphan Sumniang, and Prasert Kenpankho

68036021@kmitl.ac.th, 67036097@kmitl.ac.th, patiphan.su@kmitl.ac.th, and prasert.ke@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 68036021@kmitl.ac.th

ABSTRACT

This study investigates geomagnetic field variations during a geomagnetic storm using data from a ground-based fluxgate magnetometer installed at the KMITL Chumphon station (10.73°N, 99.37°E, 3.82°N dip latitude) in a low latitude region of Thailand. The analysis covers the entire month of January 2026 and examines geomagnetic behavior under both disturbed and quiet conditions to better understand local magnetic responses to global storm activity. Based on the monthly Disturbance Storm Time (Dst) index, 20 January 2026 was selected as the representative storm day because it recorded the minimum Dst value of -236 nT, indicating the most intense geomagnetic storm of the month. In contrast, 1-3 January 2026 were identified as quiet days due to their relatively stable Dst values and minimal geomagnetic fluctuations. The geomagnetic components (X, Y, Z) were processed into hourly averages to reduce short term noise and highlight systematic variations. The horizontal magnetic component (H) was calculated from the vector combination of X and Y to represent the dominant component affected during geomagnetic disturbances. A quiet-time baseline was established using the median values of the selected quiet days to minimize short term variability and diurnal effects. The storm disturbance (ΔH) was defined as the deviation of the storm day H values from this quiet baseline. Pearson correlation analysis between ΔH and Dst for 20 January 2026 yielded a coefficient of r = 0.64, indicating a statistically significant moderate relationship. The results demonstrate that local magnetic field variations closely correspond to global geomagnetic storm intensity and highlight the importance of reliable baseline determination in storm time geomagnetic analyses.

Keywords: Geomagnetic storm, Fluxgate magnetometer, Low latitude, Dst index, Storm disturbance

1. Statement of the Problem

The geomagnetic field plays a critical role in regulating ionospheric structure and space weather processes, particularly in low latitude regions where magnetic and plasma dynamics are highly variable. The KMITL Chumphon station is strongly influenced by equatorial ionospheric currents, especially the equatorial electrojet (EEJ), resulting in distinct geomagnetic responses compared to other latitudes. Consequently, this region is particularly suitable for investigating geomagnetic storm processes. Geomagnetic disturbances can significantly affect total electron content (TEC), influencing satellite communication and navigation systems. Understanding geomagnetic distribution is therefore essential for interpreting ionospheric responses and assessing their technological impacts. Ground based magnetic observations, combined with GNSS derived measurements, provide an effective framework for examining the coupling between

geomagnetic activity and ionospheric variability. The following section reviews previous studies that form the foundation of this research.

The study of geomagnetic field distribution by using a fluxgate magnetometer is important for understanding ionospheric behavior and space weather processes, particularly in low latitude regions where magnetic and plasma variations are highly dynamic. Jamjareegulgarn et al. (2020, pp. 909-932) improved the modeling of bottom side ionospheric thickness parameters, leading to a better representation of ionospheric structure at different latitudes. Accurate total electron content (TEC) estimation depends on reliable instrumental calibration, and Kenpankho et al. (2021, pp. 2152-2159) developed a real time GPS receiver bias estimation method to enhance TEC precision. Keokhumcheng and Kenpankho (2025, pp. 4245-4259) demonstrated that single-frequency GPS receivers can effectively monitor TEC variations in low latitude regions. Low latitude areas are particularly sensitive to geomagnetic storms, and Pansong et al. (2025, pp. 7521-7532) reported significant TEC disturbances during extreme geomagnetic events, reflecting strong storm time electrodynamic effects near the equator. A detailed regional analysis of ionospheric and geomagnetic field changes in Thailand during a major geomagnetic storm was presented by Myint et al. (2025, pp. 7508-7520), who showed clear coupling between magnetic disturbances and ionospheric responses in Southeast Asia. Abnormal TEC variations associated with regional geophysical activity in Thailand were examined by Pansong and Kenpankho (2025, pp. 297-312), identifying measurable ionospheric anomalies. The influence of ionospheric delay on positioning accuracy was evaluated by Sumniang et al. (2025, pp. 4386-4393), showing that geomagnetic disturbances can reduce the performance of low-cost robotic systems. GNSS observations have also been applied to atmospheric studies, and Nambut et al. (2025, pp. 157-166) analyzed precipitable water vapor using GPS data over Thailand. Storm time TEC estimation from geostationary BeiDou satellites was investigated by Pansong et al. (2025, pp. 167-178), providing insight into satellite performance during extreme geomagnetic conditions. Nambut and Kenpankho (2024, pp. 1-7) studied GNSS derived atmospheric parameters over Bangkok and Chumphon. Geomagnetic effects on GPS delays at low latitude stations were analyzed by Keokhumcheng and Kenpankho (2024, pp. 16-23). Variations in the auroral electrojet index related to geophysical processes were examined by Pansong et al. (2024, pp. 8-15). The performance of GNSS based robotic systems during quiet and disturbed geomagnetic days was evaluated by Sumniang and Kenpankho (2024, pp. 24-32), and Huang and Kenpankho (2024, pp. 33-40) further assessed BeiDou based robotic navigation under varying ionospheric conditions. Solar activity remains a key driver of ionospheric variability, and Tapping (2013, pp. 394-406) explained the importance of the F10.7 solar flux as a proxy for solar EUV radiation affecting ionospheric density.

This study investigates geomagnetic field distribution using fluxgate magnetometer data obtained from the KMITL Chumphon station, Thailand. The analytical framework is informed by previous storm-based studies conducted in low latitude regions. Myint et al. (2025, pp. 7508-7520) analyzed ionospheric and geomagnetic field changes in Thailand during a major geomagnetic storm and demonstrated clear coupling between magnetic disturbances and ionospheric responses. Similarly, Pansong et al. (2025, pp. 7521-7532) reported significant TEC disturbances during extreme geomagnetic storms, emphasizing the sensitivity of low latitude regions to storm time electrodynamic processes. Following these approaches, geomagnetic field components are examined through a case based comparative analysis. The horizontal magnetic disturbance (ΔH) is calculated relative to quiet conditions, and its relationship with Dst index is evaluated to examine the consistency between local magnetic field variations and global geomagnetic activity.

This study investigates the Geomagnetic field distribution by using fluxgate magnetometer over Chumphon using data from the KMITL Chumphon station collected from January 2026. The data obtained from ground based magnetometers were analyzed to examine geomagnetic

variations under disturbed and quiet conditions. The storm day was selected based on the highest geomagnetic activity indicated by Dst index, identified as 20 January 2026, while 1-3 January 2026 represented quiet conditions. The horizontal magnetic component (H) was used to calculate the disturbance level (ΔH) relative to the quiet baseline, and its relationship with Dst index was evaluated to assess the consistency between local magnetic responses and global geomagnetic activity.

2. Objectives

2.1 Investigate the geomagnetic field distribution over Chumphon using fluxgate magnetometer data from the KMIT Chumphon station during January 2026 and identify representative storm and quiet days based on Dst index.

2.2 Analyze geomagnetic field variations under disturbed and quiet conditions by examining the horizontal magnetic component (H) and calculating the disturbance level (ΔH) relative to the quiet baseline.

2.3 Evaluate the relationship between local magnetic disturbances (ΔH) and Dst index to assess the consistency between regional geomagnetic responses and global geomagnetic storm intensity.

3. Research Methodology

3.1 Research procedure

This study applies a case-based comparative analysis to evaluate geomagnetic field variations during storm and quiet conditions. The investigation focuses on Dst index, and the horizontal magnetic field component (H) recorded by a fluxgate magnetometer at the KMITL Chumphon station, as shown in Figure 1. Daily Dst values for the entire month were analyzed to assess geomagnetic activity levels and to identify a representative storm day, selected from the date with the lowest Dst value of the month. In addition, three quiet days were selected to serve as baseline reference conditions. The horizontal magnetic component (H) was then processed to calculate the disturbance level (ΔH) relative to the quiet-day baseline. Finally, the relationship between ΔH and Dst index was examined to evaluate the consistency between local geomagnetic field variations and global geomagnetic activity. This approach provides a quantitative evaluation of how local geomagnetic disturbances (ΔH) correspond to variations in the Dst index. It improves the understanding of geomagnetic storm behavior in equatorial and low latitude regions.

Figure 1 Fluxgate magnetometer

3.2 Data collection

Geomagnetic field data were collected throughout January 2026 from a fluxgate magnetometer installed at the KMITL Chumphon station, as shown in Figure 2. The instrument records the geomagnetic field in a Cartesian coordinate system, including the X, Y, and Z components, providing continuous and high resolution ground based measurements. In this study, the X and Y components were processed to compute the horizontal magnetic field component (H),

which was used to evaluate geomagnetic disturbances during storm periods. The global geomagnetic activity index (Dst) was obtained from the World Data Center for Geomagnetism, Kyoto (https://wdc.kugi.kyoto-u.ac.jp/index.html), which provides open access geomagnetic data through its official website. The Dst index was used to assess the intensity of geomagnetic activity during the study period and to support the selection of representative storms and quiet days. All datasets were checked for continuity and completeness prior to analysis to ensure data reliability.

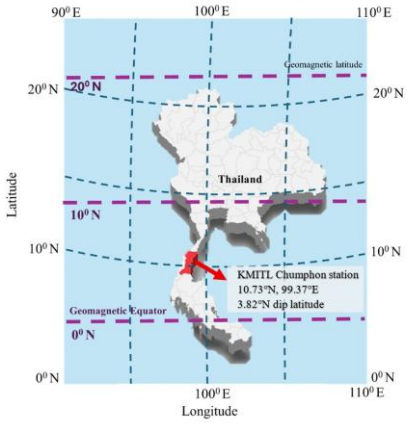

Figure 2 KMITL Chumphon station, Thailand

3.3 Data analysis

The data analysis in this study aims to investigate geomagnetic field variations observed at the KMITL Chumphon station, Thailand, which is in a low latitude region near the magnetic equator. This region is particularly sensitive to geomagnetic disturbances associated with magnetospheric and ionospheric current systems. Therefore, the analysis focuses on examining variations in the horizontal magnetic field component and its disturbance level under quiet and storm conditions. The relationship between local magnetic field changes and global geomagnetic activity is evaluated using Dst index to assess the consistency between regional and global storm responses.

To identify geomagnetic activity levels during January 2026, the monthly variation of Dst index was first examined. The Dst index provides an indication of global geomagnetic storm intensity as a function of time. By analyzing the temporal distribution of Dst values throughout the month, representative storm and quiet days were selected for further investigation of local geomagnetic field variations.

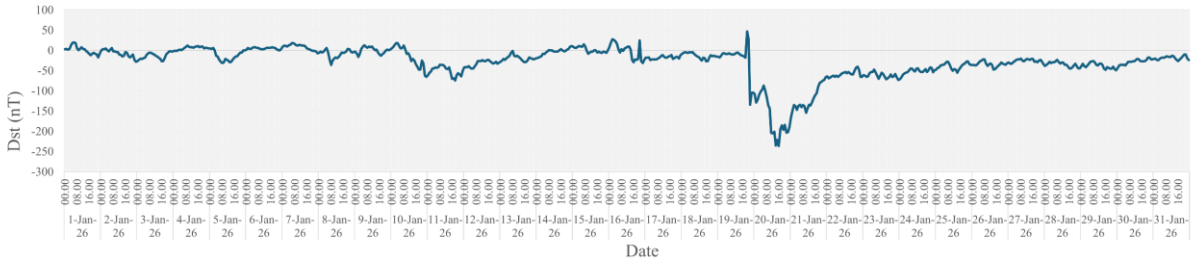

Figure 3 Monthly variation of Dst index during January 2026

Figure 3 shows the monthly variation of Dst index during January 2026. The most intense geomagnetic activity occurred on 20 January 2026, with a minimum Dst value of -236 nT, and this day was selected as the representative storm day. In contrast, 1 January 2026 (Dst = -17 nT),

2 January 2026 (Dst = -28 nT), and 3 January 2026 (Dst = -27 nT) exhibited relatively quiet geomagnetic conditions and were selected as representative quiet days for comparative analysis.

Based on the selected storm and quiet periods identified from Dst index, further analysis of the horizontal magnetic field component was conducted, as described in Section 3.1.

3.3.1 Horizontal magnetic component calculations

The horizontal magnetic field component (H) was calculated from the recorded X and Y components using the vector magnitude relation, as shown in Equation (1).

$$H = \sqrt{X^2+Y^2} \tag{1}$$

Variable descriptions

H = Horizontal magnetic field intensity (nT),
X = Northward geomagnetic field component (nT),
Y = Eastward geomagnetic field component (nT).

The H component was selected as the primary parameter because geomagnetic disturbance observed at ground level is mainly reflected in variations of the horizontal magnetic field intensity.

3.3.2 Geomagnetic disturbance calculation

To quantify storm time geomagnetic activity, the disturbance level (ΔH) was determined by subtracting the quiet day baseline value from the corresponding storm day value, as shown in Equation (2).

$$\Delta H = H_{strom} - H_{quiet} \tag{2}$$

Variable descriptions

ΔH = Horizontal magnetic disturbance (nT),
H_{strom} = Horizontal magnetic field intensity during storm conditions (nT),
H_{quiet} = Horizontal magnetic field intensity during quiet geomagnetic conditions (nT).

3.3.3 Correlation coefficient between ΔH and Dst

The correlation coefficient was employed to quantify the linear relationship between the horizontal magnetic disturbance (ΔH) and Dst index. The Dst index represents the globally averaged variation of the horizontal magnetic field associated with ring current intensity. The Pearson correlation coefficient was calculated to evaluate the degree of consistency between local geomagnetic disturbances measured at the KMITL Chumphon station and global geomagnetic activity, as shown in Equation (3).

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\left[\sum_{i=1}^{n}(x_i-\bar{x})^2\right]\left[\sum_{i=1}^{n}(y_i-\bar{y})^2\right]}} \tag{3}$$

Variable descriptions:

r = Pearson correlation coefficient; measures the strength and direction of the linear relationship between two variables,
x_i = Value of ΔH at observation i,

y_i = Value of Dst at observation i,
$\bar{x}$ = Mean of variable ΔH,
$\bar{y}$ = Mean of variable Dst,
n = Number of observations.

4. Results

4.1 Monthly variation of the horizontal geomagnetic field

To provide an overview of geomagnetic field behavior during January 2026, the monthly variation of the horizontal magnetic field component (H) was examined. This analysis allows for identification of large scale fluctuations and possible storm related disturbances throughout the study period.

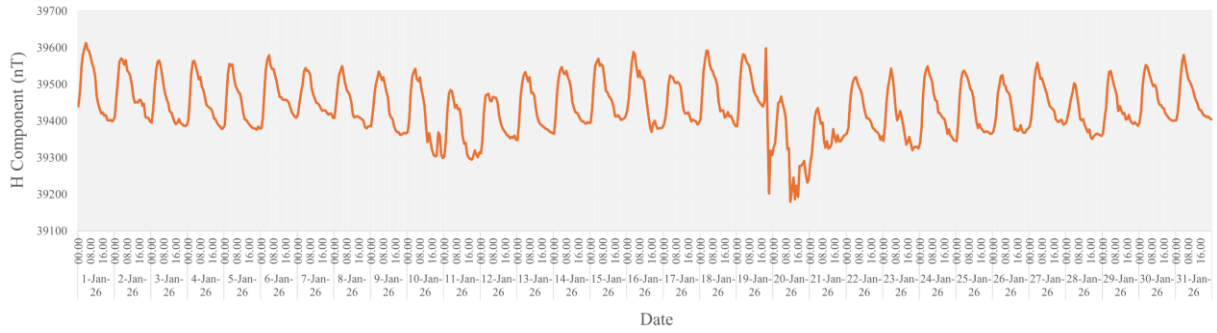

Figure 4 Monthly variation of horizontal geomagnetic field component (H) during January 2026

Figure 4 shows the monthly variation of the horizontal geomagnetic field component (H) during January 2026. The H values remain relatively stable during the first half of the month, with only minor fluctuations. A small decrease is observed between 10 and 12 January, indicating a brief disturbance. A more pronounced reduction occurs around 20 January, coinciding with enhanced geomagnetic activity indicated by Dst index. Following this event, the H component gradually recovers, although slight variations persist toward the end of the month. Overall, the pattern reflects predominantly quiet conditions interrupted by a significant storm related fluctuation.

4.2 Geomagnetic field components during storm and quiet conditions

4.2.1 Storm conditions

The geomagnetic field components (X, Y, Z, and H) during the storm day were analyzed to characterize magnetic field behavior under intense geomagnetic activity.

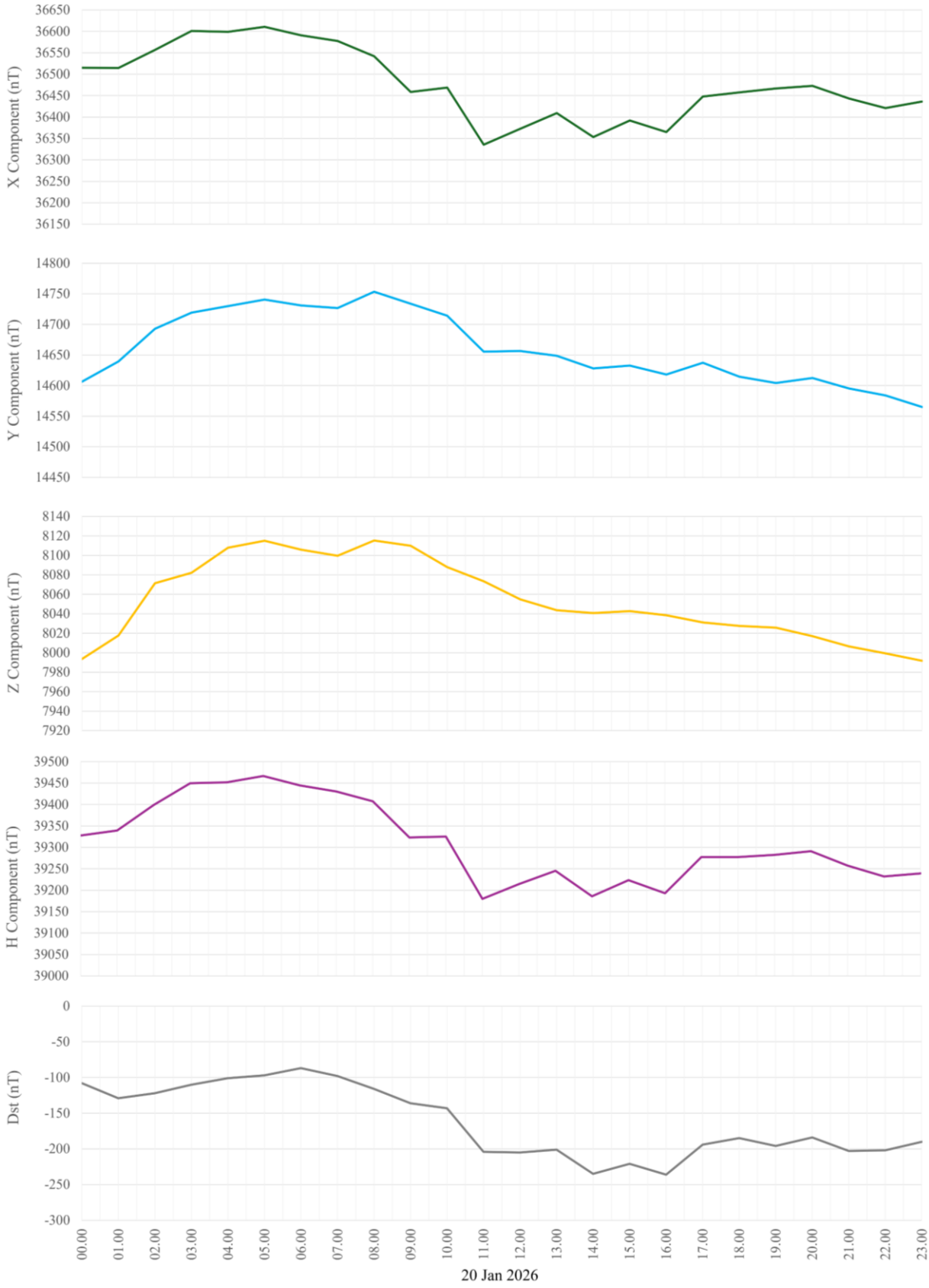

Figure 5 Geomagnetic field components (X, Y, Z, and H) during storm days

Figure 5 shows the temporal variations of the geomagnetic field components (X, Y, Z, and H together with the Dst index on 20 January 2026. During the early hours, the magnetic components exhibit relatively gradual changes corresponding to moderate geomagnetic activity. The X component initially increases from about 36,510 nT at 00:00 UT to a maximum of approximately 36,610 nT around 05:00 UT, followed by a gradual decrease to a minimum of about 36,330 nT near 11:00 UT. The Y component rises from roughly 14,610 nT to a peak of about 14,750 nT around 08:00 UT, then gradually declines to approximately 14,570 nT by 23:00 UT. The Z component shows a smoother variation, increasing from around 7,990 nT at 00:00 UT to a maximum of about 8,117 nT near 08:00 UT, and then gradually decreasing to about 7,990 nT toward the end of the day. The horizontal magnetic component (H) follows a similar pattern, reaching a maximum of approximately 39,475 nT around 05:00 UT before decreasing sharply to a minimum of about 39,180 nT near 11:00 UT, indicating a clear storm time disturbance. At the same time, Dst index decreases significantly during storm development. The value drops from about -96 nT in the early hours to a minimum of approximately -236 nT around 14:00 UT, marking the main phase of the geomagnetic storm. The timing of the magnetic field disturbances corresponds closely with the rapid decline of Dst index. This behavior demonstrates the response of the local geomagnetic field at the KMITL Chumphon station, to intensified magnetospheric current systems during the storm event.

4.2.2 Quiet conditions

For comparison, the geomagnetic field components were examined during representative quiet days to identify regular diurnal variations under stable geomagnetic conditions.

During the selected quiet days (1-3 January 2026), the geomagnetic field components (X, Y, Z, and H) together with the Dst index show smooth and regular diurnal variations. The X component reaches a maximum of about 36,760 nT and a minimum of about 36,570 nT, displaying daytime enhancement and nighttime reduction. The Y component varies between a maximum of about 14,760 nT and a minimum of about 14,620 nT, with gradual increases during daylight hours followed by decreases after sunset. The Z component fluctuates from a maximum of about 8,125 nT to a minimum of about 7,940 nT, presenting a clear diurnal cycle with daytime increases and nighttime decreases, reflecting ionospheric current effects. The horizontal component (H) ranges between a maximum of about 39,610 nT and a minimum of about 39,390 nT, following a consistent daily pattern with small amplitude changes compared to storm-time disturbances. The Dst index remains close to zero, with a maximum of about +20 nT and a minimum of about -28 nT, showing only slight fluctuations and confirming the absence of geomagnetic storm activity. These stable Dst values correspond well with the smooth behavior of all geomagnetic components, indicating that the observed variations are primarily controlled by regular ionospheric processes rather than magnetospheric storm-time disturbances, as shown in Figure 6.

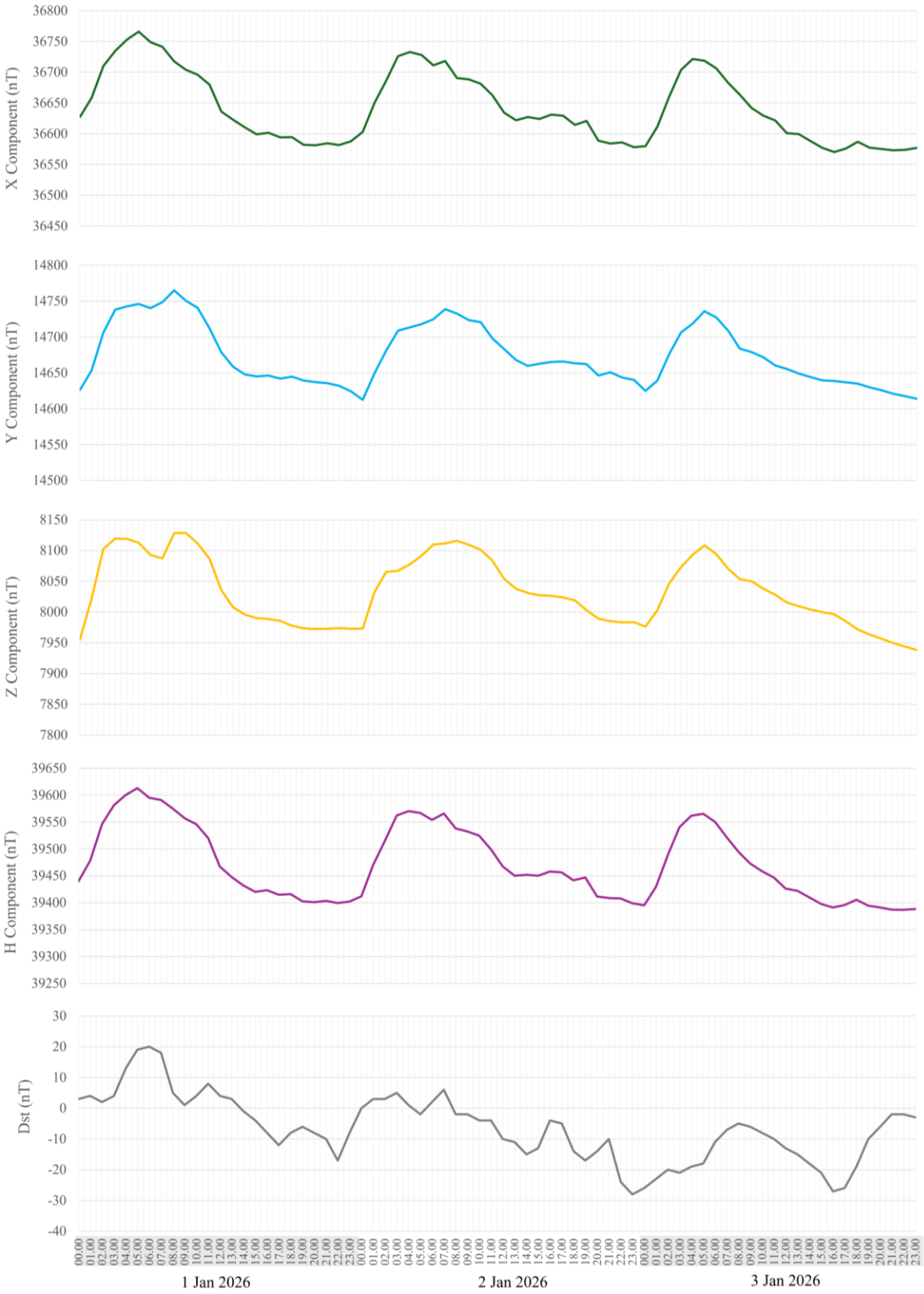

Figure 6 Geomagnetic field components (X, Y, Z, and H) during quiet days

4.3 Storm time disturbance analysis

The hourly variation of the horizontal magnetic disturbance (ΔH) on 20 January 2026 was examined to evaluate storm time magnetic activity relative to quiet conditions.

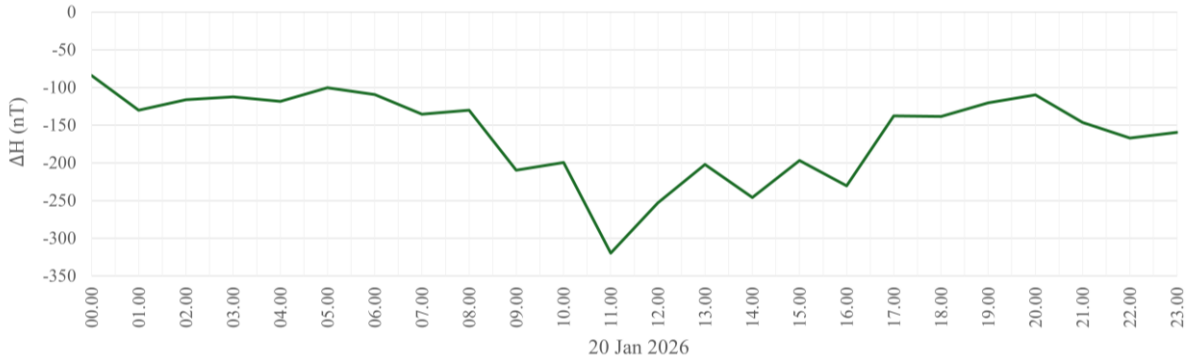

Figure 7 Storm time disturbance

Figure 7 shows the variation of ΔH throughout the storm day. Negative values appear during the early hours. These values indicate the beginning of geomagnetic disturbance. A sharp decrease occurs between 09:00 and 11:00 UT. The minimum value of approximately -320 nT is observed during this period. This interval represents the main phase of the storm. The strong negative excursion reflects intensified ring current activity. After 12:00 UT, ΔH gradually increases. This trend marks the recovery phase of the storm. Negative deviations remain in the late hours. Geomagnetic conditions do not fully return to quiet levels by the end of the day.

4.4 Correlation coefficient between ΔH and Dst

To quantitatively evaluate the relationship between local geomagnetic disturbances and global geomagnetic activity, a correlation analysis was performed between ΔH and the Dst index during the storm day. The correlation coefficient was calculated to determine the degree of linear association between these two parameters.

Table 1 Correlation coefficient between ΔH and Dst during the storm day (20 January 2026)

Comparison	Correlation coefficient
Dst index and ΔH	0.64

In Table 1, the calculated correlation coefficient of 0.64 indicates a moderate to strong positive relationship between ΔH and Dst during the storm event. This result suggests that local horizontal magnetic disturbances measured at the KMITL Chumphon station are closely associated with variations in global geomagnetic storm intensity. The observed relationship confirms the consistency between regional magnetic field responses and large scale magnetospheric dynamics during storm time conditions.

The previous correlation analysis indicated a moderate relationship between ΔH and the Dst index. A scatter plot was constructed to visually examine this association during the storm event.

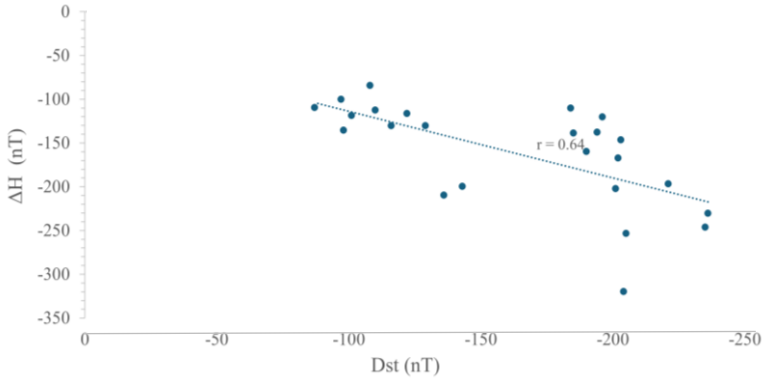

Figure 8 Scatter plots showing the relationship between Dst index and ΔH

Figure 8 shows the distribution of hourly ΔH values against the corresponding Dst index during 20 January 2026. A clear linear trend is observed. More negative Dst values correspond to larger negative H values. This pattern confirms that intensified global geomagnetic activity is associated with stronger local magnetic disturbances. The overall distribution of data points supports the moderate positive correlation (r = 0.64) obtained from the statistical analysis. Although some dispersion is present, the general trend indicates consistent coupling between local ground based measurements and global storm intensity.

5. Conclusion and Discussion

The study concludes that geomagnetic field variations observed at the KMITL Chumphon station during January 2026 clearly reflect storm time disturbances, particularly on 20 January 2026 when Dst index reached -236 nT. The horizontal magnetic field component (H) exhibited significant deviations compared to the relatively stable conditions recorded on the selected quiet days (1-3 January 2026). The calculated disturbance level (ΔH) showed pronounced storm-time variations, and the correlation coefficient of 0.64 between ΔH and Dst indicates a moderate to strong relationship between local magnetic disturbances and global geomagnetic storm intensity. These results confirm that low latitude ground based magnetometer measurements are consistent with global geomagnetic activity and are effective for monitoring geomagnetic storm behavior. This study focuses on a single geomagnetic storm event (20 January 2026). This event represents the most intense disturbance during the study period. It provides a clear characterization of storm time behavior. However, this may limit the generalization of the findings. Future studies should include multiple storm events to improve result reliability.

The discussion indicates that these findings are generally consistent with previous investigations conducted in low latitude regions. However, the present study differs in its analytical focus. While Myint et al. (2025, pp. 7508-7520) examined the coupling between geomagnetic disturbances and ionospheric responses, and Pansong et al. (2025, pp. 7521-7532) emphasized TEC disturbances during extreme geomagnetic storms, this research concentrates specifically on ground based magnetic field variations and their quantitative relationship with Dst index. By applying a storm quiet comparative framework and correlation analysis, this study provides a focused assessment of local magnetic field responses and their direct linkage to global geomagnetic storm intensity. These findings can be applied to support the interpretation of geomagnetic data for space weather monitoring and to improve the understanding of magnetic field disturbances affecting satellite communication and navigation systems.

6. Acknowledgements

The authors gratefully acknowledge the Space, Satellite, and Study Laboratory (SSS Lab),

King Mongkut's Institute of Technology Ladkrabang (KMITL), for providing fluxgate magnetometer data and research support essential to this study. The Disturbance Storm Time (Dst) index used in this research was obtained from the World Data Center for Geomagnetism, Kyoto, whose data access is sincerely appreciated.

7. References

Huang, C., & Kenpankho, P. (2024). Low-cost robotic platform with BeiDou satellites. In Proceedings of DRLE 2024 International Conference, pp. 33-40.

Jamjareegulgarn, P., Supnithi, P., Kenpankho, P., Wichaipanich, N., & Nayak, C. (2020). Improving the modeling of bottomside thickness parameters over midlatitudes and high latitudes. Advances in Space Research, 65(3), pp. 909–932. doi: https://doi.org/10.1016/j.asr.2019.10.026.

Kenpankho, P., Chaichana, A., Trachu, K., Supnithi, P., & Hozumi, K. (2021). Real-time GPS receiver bias estimation. Advances in Space Research, 68(5), pp. 2152–2159. doi: https://doi.org/10.1016/j.asr.2021.01.032.

Keokhumcheng, T., & Kenpankho, P. (2024). Delay time on GPS at low latitude station on geomagnetic day. In Proceedings of DRLE 2024 International.

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), pp. 4245–4259. doi: https://doi.org/10.1016/j.asr.2024.08.019.

Myint, L. M. M, Perwitasari, S., Nishioka, M., Saito, S., Kaewthongrach, R., & Supnithi, P. (2025). Analysis of ionospheric and geomagnetic field changes in Thailand during the May 2024 geomagnetic storm. Advances in Space Research, 76(12), 7508-7520. https://doi.org/10.1016/j.asr.2025.01.071.

Nambut, S., & Kenpankho, P. (2024). Water vapor analysis from GNSS observation over Bangkok and Chumphon, Thailand. In Proceedings of DRLE 2024 International Conference, pp. 1-7.

Nambut, S., Kraisi, P., & Kenpankho, P. (2025). Troposphere precipitable water vapor observation using GPS in Thailand. In Proceedings of DRLE 2025 International Conference, pp. 157-166.

Pansong, C., Sittichai, W., & Kenpankho, P. (2024). Signatures of the auroral electrojet (AE) index associated with earthquakes and GNSS at low latitude.

Pansong, C., Wongsak, P., Ruttanaburee, S., Pornsopin, P., & Kenpankho, P. (2025). Low latitude TEC disturbances during extreme geomagnetic storms. Advances in Space Research, 76(12), pp. 7521–7532. doi: https://doi.org/10.1016/j.asr.2025.03.071.

Pansong, C., & Kenpankho, P. (2025). GPS TEC anomalies and earthquake events in Thailand. Earth Sciences Research Journal, 29(3), pp. 297–312. doi: https://doi.org/10.15446/esrj.v29n3.117195.

Pansong, C., Kraisi, P., Nambut, S., & Kenpankho, P. (2025). Estimation of geostationary BeiDou satellite total electron content during the extreme geomagnetic storm. In Proceedings of DRLE 2025 International Conference, pp. 167-178.

Sumniang, P., & Kenpankho, P. (2024). Low-cost robotic platform using GPS investigation on quiet and geomagnetic days. In Proceedings of DRLE 2024 International Conference, pp. 24-32.

Sumniang, P., Sittichai, W., & Kenpankho, P. (2025). Ionospheric delay and low-cost robots. Advances in Space Research, 75(5), pp. 4386–4393. doi: https://doi.org/10.1016/j.asr.2024.12.011.

Tapping, K. F. (2013). The 10.7 cm solar radio flux (F10.7). Space Weather, 11(7), 394-406. https://doi.org/10.1002/swe.20064.

ATMOSPHERIC WATER GENERATOR AT KHAI ISLAND, CHUMPHON, THAILAND

Aswin Kingjumpa*, Wanwisa Mantonghlang, Prasert Kenpankho , and Piya Supavarasuwat

67036100@kmitl.ac.th, 66030165@kmitl.ac.th, prasert.ke@kmitl.ac.th, and piya.su@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 67036100@kmitl.ac.th

ABSTRACT

This study investigated the production efficiency of Atmospheric water generator (AWG) installed on Khai island, Chumphon province, Thailand, during a follow-up period from July 19 to August 18, 2025. The monitoring focused specifically on the amount of water produced, with daily measurements recorded to calculate the cumulative water volume. Over a 30-day period, the AWG produced an average of approximately 20 liters of water per day, with the production volume depending on the ambient humidity and temperature. The cumulative water production was approximately 620 liters. The study results demonstrate the potential of AWG to reliably produce fresh water in tropical coastal environments with high atmospheric humidity. This production data provides a basis for evaluating AWG performance and underscores their potential as a sustainable solution to water scarcity in similar ecological contexts.

Keywords: Atmospheric water generator, Water production, Humidity, Khai island

1. Statement of the Problem

Freshwater scarcity remains a pressing challenge in tropical and coastal regions of Thailand, particularly in small islands where conventional water supply systems are limited. Atmospheric water generator (AWG) has emerged as a promising technology to address this issue by extracting potable water directly from humid air. The potential of AWG is especially relevant for areas like Khai island, Chumphon province, where high humidity levels provide favorable conditions for atmospheric water harvesting but systematic production assessments are still lacking (Saeed et al., 2024, p. 130698; Nambut et al., 2025, pp. 157-166).

Previous studies have demonstrated the feasibility of AWG in diverse climatic contexts. For example, Bangkuan and Kenpankho (2024, pp. 326-334) conducted a month-long field study in Prachuap Khiri Khan province, Thailand, using a fixed-location AWG to monitor daily water output under varying humidity and temperature conditions. Their methodology involved continuous data logging and manual verification of water yield, revealing that production volume fluctuated between 18-24 liters per day depending on atmospheric moisture availability. They emphasized the importance of consistent monitoring and environmental correlation to evaluate AWG performance. Building on this approach, the present study applies similar techniques to Khai island, focusing on daily production volume over a 30-day period. International research further supports AWG applications: Cattani et al. (2018) explored refrigeration-based systems in integrated setups; Mkabane et al. (2020) analyzed seasonal yield variations in South Africa; and

Runze et al. (2020) tested portable AWG for maritime rescue operations. Studies in urban and hot-humid climates-such as Inbar et al. (2020) in Israel, Ahmad et al. (2022) in the UAE, and Khali et al. (2022) in Jordan-confirm AWG adaptability but also highlight energy efficiency concerns. Additional investigations by Kgatla et al. (2022), Raveesh et al. (2023), and Correia et al. (2023) examine AWG viability across geographic regions, while Cattani et al. (2023) and Almrid and Alanabi (2021) present real-world deployment case studies. In Thailand, Nambut and Kenpankho (2024) and Nambut et al. (2025) provided atmospheric water vapor analysis using GNSS and GPS, reinforcing the relevance of AWG technology in regions like Chumphon. These collective findings validate the methodological focus on production volume and support the broader applicability of AWG in tropical coastal environments. Bangkuan and Kenpankho (2024) emphasized their methodology and findings in Prachuap Khiri Khan, and integrated comparative insights from international studies to strengthen your research context.

Building on Bangkuan and Kenpankho (2024, pp. 326-334) methodology in Prachuap Khiri Khan, this research applies similar data collection and monitoring techniques to Khai island. Daily production volumes are measured over a fixed period to establish cumulative yield, with emphasis on water output rather than energy consumption or system design. This approach ensures comparability with prior Thai case studies while focusing on the specific environmental conditions of Chumphon province. The methodology provides a practical framework for assessing AWG performance in small-island contexts where freshwater demand is critical.

2. Objectives

2. 1 Recording and analyzing the daily production volume of potable water generated by the AWG at Khai island, Chumphon, Thailand, during the study period.

2. 2 Calculating the total volume of water produced for AWG performance in tropical coastal conditions.

2.3 Evaluating and identifying patterns in production volume that reflect the influence of local atmospheric conditions.

3. Conceptual Framework and Hypothesis

The conceptual framework of this research is built on the principle that AWG can provide a sustainable source of potable water in humid tropical environments, with production volume directly influenced by local atmospheric conditions such as temperature and relative humidity. Drawing from Bangkuan and Kenpankho (2024) study in Prachuap Khiri Khan province, which demonstrated variability in AWG output under Thai climatic conditions, this research applies a similar approach to Khai island, Chumphon province, focusing exclusively on water production volume. The framework assumes that continuous monitoring over a fixed period will yield reliable baseline data, linking atmospheric factors to cumulative water output and demonstrating the feasibility of AWG in small-island contexts. Based on this, the hypotheses are: (H1) the AWG at Khai island will produce a consistent daily water output averaging between 20-25 liters under tropical coastal conditions; (H2) the cumulative water production volume during 19 July to 18 August 2025 will exceed 600 liters, confirming AWG viability as a supplementary freshwater source; and (H3) daily production variability will correlate positively with fluctuations in relative humidity and ambient temperature, reinforcing the environmental dependence of AWG efficiency.

4. Research Methodology

This study adopts a quantitative monitoring approach to evaluate the production volume of an AWG installed at Khai island, Chumphon province, Thailand. Following the methodological framework of Bangkuan and Kenpankho (2024), daily water output was measured over the fixed period from 19 July to 18 August 2025. The methodology focuses exclusively on water production volume, excluding energy consumption or system design parameters.

4.1 Data Collection

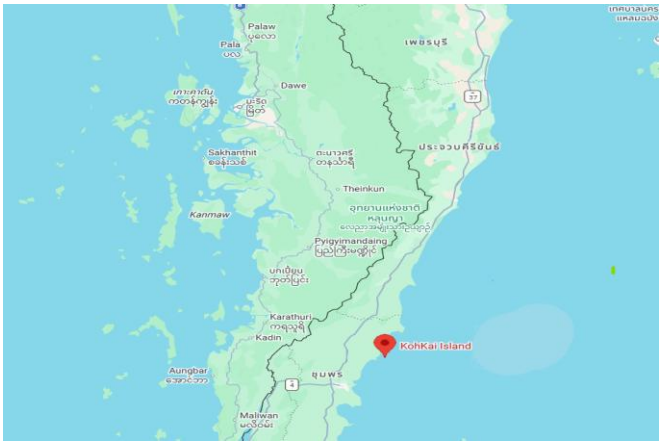

Figure 1 shows the geographic location of the research site, Khai island, situated in Chumphon province, Thailand. This coastal island was selected for its humid tropical climate, which provides ideal conditions for atmospheric water harvesting. The map highlights its position along the Gulf of Thailand, emphasizing the island's isolation and limited access to conventional freshwater sources. This geographic context supports the rationale for deploying an AWG to evaluate its performance in a real-world, small-island environment where sustainable water solutions are critically needed.

Figure 2 Collecting data on water

Figure 2 presents the actual setup used for collecting data on water production from the atmosphere. It features the AWG device installed in a sheltered location, connected to a power source and monitoring equipment. The system operated continuously during the study period (19 July to 18 August 2025), producing water at a consistent rate of approximately 0.83 liters per hour, yielding 20 liters per day. Daily measurements were recorded manually, and environmental parameters such as temperature and humidity were monitored to contextualize production trends. This figure confirms the operational readiness of the AWG and illustrates the practical implementation of atmospheric water harvesting technology in a coastal field setting

4.1.1 Daily water yield (Qd) was recorded at a fixed time each day using calibrated measuring containers.

4.1.2 Environmental parameters such as ambient temperature (T) and relative humidity (RH) were noted to contextualize production variability.

4.1.3 The monitoring period covered 30 consecutive days, ensuring consistency and comparability with prior AWG studies in Thailand.

4.2 Calculation of Production Volume

The total cumulative water production ($Qtotal$) was calculated as the sum of daily yields as Equation (1):

$$Qtotal = \sum_{i=1}^{n} Qd,i \tag{1}$$

where:

Qd,i = daily water output on day i (liters)

n = 30 days (monitoring period length)

The average daily production ($\overline{Q}d$) was determined as Equation (2):

$$\overline{Q}d = \frac{Qtotal}{n} \tag{2}$$

4.3 Variability Analysis

To assess fluctuations in production volume, the standard deviation (σ) of daily yields was calculated in Equation (3):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(Q_{d,i} - \overline{Q}_d\right)^2}{n}} \tag{3}$$

This allowed identification of patterns in water output linked to atmospheric conditions.

4.4 Comparative Framework

The methodology mirrors on Bangkuan and Kenpankho (2024) case study in Prachuap Khiri Khan province, enabling comparative analysis between different Thai coastal environments. By focusing solely on production volume, the study isolates the AWG capacity to generate potable water under tropical island conditions.

5. Results

The result is based on data collected on the daily water production volume from atmospheric water production devices over a month period as shown in Table 1.

Table 1 Daily water production from 19 July to 18 August 2025

Day	Temperature (°C)	Humidity (%)	Water production rate (Liters/hour)	Amount of water produced (Liters)
19 /07/2025	29	68	0.83	20
20 /07/2025	30	64	0.83	20
21 /07/2025	29	72	0.83	20
22 /07/2025	30	65	0.83	20
23 /07/2025	31	61	0.83	20
24/07/2025	32	64	0.83	20
25 /07/2025	32	68	0.83	20
26 /07/2025	-	-	-	-
27 /07/2025	-	-	-	-
28 /07/2025	-	-	-	-
29 /07/2025	35	80	0.83	20
30 /07/2025	29	62	0.83	20
31 /07/2025	32	61	0.83	20
01 /08/2025	33	58	0.83	20
02 /08/2025	36	38	0.83	20
03 /08/2025	29	60	0.83	20
04 /08/2025	32	63	0.83	20
05 /08/2025	-	-	-	-
06 /08/2025	-	-	-	-
07 /08/2025	-	-	-	-
08 /08/2025	30	64	0.83	20
09 /08/2025	31	63	0.83	20
10 /08/2025	32	64	0.83	20
11 /08/2025	31	63	0.83	20
12 /08/2025	32	64	0.83	20
13 /08/2025	32	63	0.83	20
14 /08/2025	31	64	0.83	20
15 /08/2025	32	63	0.83	20
16 /08/2025	30	64	0.83	20
17 /08/2025	31	63	0.83	20
18 /08/2025	32	64	0.83	20
Average	**31.32**	**63.32**	**0.833**	**20**

During the monitoring period from 19 July to 18 August 2025, the AWG at Khai island consistently produced potable water at a stable rate. Daily measurements indicated an average production of 20 liters per day, with a water generation rate of approximately 0.83 liters per hour. Despite fluctuations in environmental parameters such as temperature (ranging from 29°C to

36°C) and relative humidity (38%-80%), the AWG maintained steady output. The cumulative production volume over the 30 days period reached approximately 620 liters, demonstrating the system's reliability under tropical coastal conditions. Missing data on certain days did not affect the overall consistency of water yield, as the AWG resumed normal operation once measurements were recorded again. Further analysis revealed that the average temperature during the study was 31.32°C, while the average relative humidity was 63.32%, both of which are favorable for condensation-based water generation. The standard deviation of daily water output was negligible, confirming minimal variability in production volume. This stability suggests that the AWG is resilient to moderate environmental fluctuations and can provide a dependable supplementary source of freshwater for island communities. The results align with previous findings in Prachuap Khiri Khan province (Bangkuan & Kenpankho, 2024), reinforcing the feasibility of AWG deployment in Thailand's humid coastal regions.

6. Conclusion and Discussion

The results of this study demonstrate that the AWG at Khai island maintained a stable production volume of approximately 20 liters per day, yielding a cumulative output of around 620 liters over the 30 days monitoring period. Despite fluctuations in temperature and relative humidity, the AWG consistently delivered potable water, with negligible variability in daily output. This stability can be explained by the fact that the observed ranges of temperature (29-36°C) and relative humidity (38-80%) remained within favorable conditions for condensation-based water generation. Previous studies by Bangkuan and Kenpankho (2024) have noted that AWG systems are resilient to moderate atmospheric fluctuations, as long as dew point conditions are met. Thus, the Khai island AWG maintained efficiency despite daily variations, confirming that short-term environmental changes did not significantly affect water yield. This reliability highlights the system's resilience to environmental changes and confirms its suitability for tropical coastal conditions where freshwater scarcity is a persistent challenge. The findings provide strong evidence that AWG can serve as dependable supplementary water sources for small island communities.

When compared to the study by Bangkuan and Kenpankho (2024) in Prachuap Khiri Khan province, similarities emerge in terms of production stability under humid Thai climates. Both studies confirm that AWG performance is primarily influenced by atmospheric moisture availability, yet Khai island's results show slightly greater consistency in daily yield, likely due to its coastal microclimate. While Bangkuan and Kenpankho (2024) emphasized variability linked to seasonal atmospheric changes, the Khai island data suggest that AWG can maintain steady output even with moderate fluctuations in humidity and temperature. This comparison reinforces the broader applicability of AWG technology across different regions of Thailand, supporting its role in sustainable water management strategies and providing a foundation for scaling deployment in other coastal and island environments.

7. Suggestions

Based on the results of the AWG study at Khai island and comparison with Bangkuan and Kenpankho (2024), the following suggestions are proposed: (1) Expand Monitoring Across Seasons Future studies should extend data collection beyond a single month to include both wet and dry seasons. This will help identify seasonal variability in production volume and provide a more comprehensive understanding of AWG performance under diverse climatic conditions. In another, (2) Integrate Environmental Correlation Analysis While Khai island showed stable daily yields, further statistical analysis should be conducted to correlate water production volume with

fluctuations in temperature and relative humidity. This would strengthen the evidence of environmental dependence and allow predictive modeling of AWG output.

8. Acknowledgements

The authors would like to extend their deepest appreciation to the Space, Satellite, and Study Laboratory (SSS Lab), Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand, for their academic guidance, technical support, and valuable contributions to this research. Special thanks are also given to the Ban Hin Kob Community Blue Crab Bank Group and the Community-Based Tourism Group, whose cooperation, local knowledge, and commitment to sustainable resource management greatly enriched the study. Their collaboration not only facilitated fieldwork at Khai island but also strengthened the integration of scientific innovation with community-driven environmental stewardship and sustainable tourism development.

9. References

Ahmad, F. F., Ghenai, C., Bardan, M. A., Bourgon, M., & Shanableh, A. (2022). Performance analysis of atmospheric water generator under hot and humid climate conditions: Drinkable water production and system energy consumption. Case Studies in Chemical and Environmental Engineering, 2022(6), pp. 1-10.

Almrid, A. A., & Alanabi, F. M. (2021). Experimental Study of Atmospheric Water Generator Under Libyan Climate. International Journal of Mechanical Engineering and Technology (IJMET), 12(5), pp. 38-44.

Bangkuan, R., & Kenpankho, P. (2024). Atmospheric water generator in Prachuap Khiri Khan province, Thailand. In Proceedings of DRLE 2024. International Conference, pp. 326-334.

Cattani, L., Cattani, P., & Magrini, A. (2023). Air to Water Generator Integrated System Real Application: A Study Case in a Worker Village in United Arab Emirates. MDPI –Publisher of Open Access Journals, 13(5), pp. 1-29.

Cattani, L., Magrini, A., & Cattani P. (2018). Water Extraction from Air by Refrigeration Experimental Results from an Integrated System Application. MDPI - Publisher of Open Access Journals, 8(11), pp.1-21.

Chandra, P. H., Shankhar, R. S., Pranesh, S., Degaonkar, S., Kaya, S., Kiwan, O., Mohan, R., & Sowndaram, C. S. (2021). Design and development of Air to Water Generator for the Village in Kerala, India.

Correia, V., Silva, P. D., & Pires, L. C. (2023). Energy requirements and photovoltaic area for atmospheric water generation in different locations: Lisbon, Pretoria, and Riyadh. *Energies, 16*(13), p. 5201.

Inbar, O., Gozlan, I., Ratner, S., Aviv, Y., Sirota, R., & Avisar, D. (2020). Producing Safe Drinking Water Using anAtmospheric Water Generator (AWG) in an Urban Environment. MDPI - Publisher of Open Access Journals,12(10), pp.2-19.

Kgatla, L., Gidudu, B., & Evans M. Nkhalambayausi Chirwa. (2022). Feasibility Study of Atmospheric WaterHarvesting Augmented through Evaporative Cooling.MDPI -Publisher of Open Access Journals,14(19), pp. 1-17.

Khali, M. B., Beithou, N., Al-Taani M.A. Sh., Andruszkiewicz, A., Alahmer, A., Borowski, G., & Alsaqoor, S.(2022). Integrated Eco-Friendly Outdoor Cooling System - Case Study of Hot-Humid Climate Countries.Journal of Ecological Engineering 2022,23(1), pp. 64 -72.

Mkabane, P., Kankeu, E. F., Alili, A. R., Al., Waanders, F., & Mittal, H. (2020). Water Production Yield of an Atmospheric Water Generator during Summer Season in South Africa. In E. Addison (Ed.), 18th. JOHANNESBURG Int'l Conference on Science, Engineering. Technology & Waste Management (SETWM-20) (pp.172-176). Conal Conference Alerst.

Nambut, S., & Kenpankho, P. (2024). Water vapor analysis from GNSS observation over Bangkok and Chumphon, Thailand. In Proceedings of DRLE 2024 International Conference, pp. 1-7.

Nambut, S., Kraisi, P., & Kenpankho, P. (2025). Troposphere precipitable water vapor observation using GPS in Thailand. In Proceedings of DRLE 2025 International Conference, pp. 157-166.

Raveesh, G., Goyal, R., Tyagi, S. K. (2023). Parametric analysis of atmospheric water generation system and its viability in Indian cities. Thermal Science and Engineering Progress, 2023(39), pp. 1-18.

Runze, D., Qingfen, M., Hui, L., Gaoping, W., Wei, Y., Guangfu, C., & Yifan, C. (2020). Experimental investigations on a portable atmospheric water generator for maritime rescue. Journal of Water Reuse and Desalination, 10(1), pp. 1-15.

Saeed, M., Al-Sulaiman, F. A., & Habib, M. A. (2024). Atmospheric water harvesting: Recent advances, challenges, and future perspectives. *Energy*, 310, 130698.

TOTAL ELECTRON CONTENT MEASUREMENT BY USING GLONASS SATELLITE

Jedsada Puang-im*, Pattawut Wongsak, and Prasert Kenpankho

68036015@kmitl.ac.th, 67036098@kmitl.ac.th, and prasert.ke@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10520 Thailand

*Corresponding Author E-mail: 68036015@kmitl.ac.th

ABSTRACT

This study investigates the measurement of Total Electron Content (TEC) using GLONASS satellite data collected at the Bangkok station and compares the results with International GNSS Service (IGS) TEC products over a one-month period. TEC is critical parameter for understanding ionospheric behavior and its impact on satellite-based navigation and communication systems. The analysis reveals that TEC values derived from GLONASS consistently report higher magnitudes compared to those provided by IGS. This discrepancy suggests potential differences in data processing methodologies, satellite constellation geometry, or instrumental biases between the two systems. The finding highlights that the correlation coefficient between GLONASS TEC and IGS TEC value was 0.73, indicating a strong positive correlation. Furthermore, the RMSE stands at 43.58 TECU. This result indicates a significant positive bias in the GLONASS TEC estimations during this period, suggesting that the system tends to over-report ionospheric density relative to the IGS standard. The reliability and accuracy of TEC measurements by using GLONASS TEC is limited to being used as TEC measurement and needed to add the TEC biases. The results showed that the accuracy of TEC measurement by using GLONASS satellites is over 56.42 percents of IGS TEC reference in January 2026. This result confirms that although GLONASS consistently reports higher magnitudes, both datasets capture similar temporal and diurnal ionospheric variations. Moreover, the observed systematic bias underscores the need for further investigation into calibration strategies to harmonize GLONASS-derived TEC (GLONASS TEC) with established global references. This work contributes to improving the accuracy of ionospheric models and supports enhanced GNSS performance in Thailand.

Keywords: TEC, GLONASS, IGS

1. Statement of the Problem

The ionosphere is a crucial component of space weather and satellite-based communication systems, particularly in low-latitude regions where disturbances are more pronounced. Precise measurement of Total electron content (TEC) is vital for understanding ionospheric dynamics and mitigating signal delays in Global Navigation Satellite Systems (GNSS). Previous studies have emphasized the importance of TEC monitoring through Global Positioning System (GPS), Global Navigation Satellite System (GLONASS), and BeiDou Navigation satellite System (BDS), as well as its connection to geomagnetic storms and seismic activities. For instance, Jamiareegulgam et al. (2020, pp. 909-932) improved modeling of bottomside thickness parameters, while Pansong et al. (2025, pp. 167-178) estimated TEC from geostationary BeiDou satellites during extreme geomagnetic storms. Additionally, Pansong and Kenpankho (2025, pp. 297-312) investigated GPS

TEC anomalies associated with earthquake events in Thailand. Collectively, these works provide a strong foundation for advancing TEC research in Thailand and the broader equatorial region.

Recent research has demonstrated the diverse applications of TEC analysis across multiple contexts, ranging from low-cost monitoring to predictive modeling. Keokhumcheng and Kenpankho (2025, pp. 4245-4259) investigated ionospheric TEC using single-frequency GPS receivers, showing the feasibility of affordable monitoring solutions, while Pansong et al. (2025, pp. 167-178) estimated TEC from geostationary BeiDou satellites during extreme geomagnetic storms, highlighting the system's resilience under severe space weather. Similarly, Pansong et al. (2025, pp. 7521-7532) analyzed low-latitude TEC disturbances, emphasizing the vulnerability of equatorial regions, and Zhao et al. (2025) advanced predictive modeling of equatorial plasma bubbles, underscoring the importance of TEC data for forecasting ionospheric irregularities. Beyond geomagnetic influences TEC has been linked to seismic activity: Phansori et al. (2021, pp. 69-72) examined earthquake- ionosphere interactions using IGS TEC, while Pansong and Kenpankho (2025. pp. 297-312) identified GPS TEC anomalies associated with earthquakes in Thailand, and Pansong et al. (2025) reported pre-seismic TEC anomalies preceding the June 28, 2023 earthquake. Other contributions include Jamjareegulgam et al. (2020, pp. 909-932), who improved modeling of bottom side thickness parameters, and Sumniang et al. (2025, pp. 4386-4393), who explored ionospheric delay effects on low-cost robotics. Collectively, these studies highlight TEC multifaceted role in space weather research, seismic monitoring, GNSS applications, and technological innovation, establishing a strong foundation for further investigation in equatorial regions like Thailand.

Building on Keokhumcheng and Kenpankho (2025, pp. 4245-4259), this research adopts single-frequency GPS receiver data to measure TEC variations at a low-latitude station. The methodology involves continuous monitoring of ionospheric TEC over a one-month period, with data processing techniques applied to mitigate receiver bias and hardware Differential Code Biases (DCBs). Comparative analysis with IGS TEC datasets ensures validation against global standards. This approach allows for high temporal resolution measurements while maintaining consistency with established ionospheric models.

2. Objectives

2.1 Evaluating the reliability and accuracy of TEC measurements obtained from GLONASS satellites at the Bangkok GNSS station.

2.2 Comparing TEC from GLONASS with the standard TEC data provided by the International GNSS Service.

3. Research Methodology

3.1 Research methodology

This study employs a comparative approach to evaluate TEC measurements obtained from GLONASS satellites at the Bangkok station against IGS TEC data. The methodology integrates satellite-based dual-frequency observations with statistical correlation techniques to assess accuracy, temporal resolution, and sensitivity to local ionospheric variations. GLONASS-derived TEC (GLONASS TEC) values are calculated using carrier phase and psendorange measurements, while IGS TEC data serve as the global reference standard. Calibration procedures are applied to correct hardware DCBs inherent in GLONASS receivers. The slant TEC (STEC) is first derived from GLONASS signals using the equation (1):

$$STEC = \frac{(f_1^2 \cdot f_2^2)}{(k \cdot (f_1^2 - f_2^2))} \cdot [(P_2 - P_1) - (DCB_{sat} + DCB_{rec})] \quad (1)$$

where:

f_1, f_2 are carrier frequencies,
P_1, P_2 are pseudorange measurements,
DCB_{sat} is represent satellite,
DCB_{rec} is receiver differential code biases,
k is a physical constant related to the propagation of radio waves in plasma, 80.63 m^3/s^2.

Vertical TEC (VTEC) is then obtained by applying a mapping function as in equation (2):

$$VTEC = STEC \cdot \cos(E) \quad (2)$$

where:

E is satellite elevation angle.

Total Electron Content Unit (TECU) is the standard measurement unit for ionospheric electron density along the signal path. By definition, 1 TECU = 10^{16}electrons/m². Expressing results in TECU ensure consistency across different GNSS systems and stations.

3.2 Research procedure

The research procedure followed a systematic framework to ensure accurate comparison between GLONASS TEC and IGS TEC data. First, raw observation files in RINEX format were collected from the Bangkok GNSS station for a continuous one-month period, while IGS Global Ionospheric Maps (GIMIs) were downloaded to serve as the global reference. Preprocessing steps included cycle slip detection, multipath error reduction using an elevation mask, and correction of DCBs for both satellites and receivers. STEC was then computed from multi-frequency pseudorange measurements using the standard ionospheric delay equation and subsequently converted to VTEC through a mapping function based on satellite elevation angle. To enable direct comparison, GLONASS TEC values were interpolated to match the 1 5 - minute temporal resolution of IGS TEC and spatially aligned with IGS grid coordinates. Finally, statical analyses were performed, including correlation coefficient and bias estimation, to evaluate agreement between the two datasets, while diurnal variation and temporal resolution differences were examined to highlight the sensitivity of GLONASS to local ionospheric dynamics.

3.3 Data Collection

The data collection process involved gathering both local and global ionospheric measurements to enable a comprehensive comparison. Raw observation files from the Bangkok GNSS station were obtained in RINEX format, containing pseudorange and carrier phase measurements from GLONASS satellites over a continuous one-month period, providing high temporal resolution to capture fine-scale ionospheric variations. In parallel, IGS Global Ionospheric Maps (GIMs) were downloaded, offering TEC values with a temporal resolution of 15 minutes and a spatial resolution of 2.5˚× 5˚. Additionally, GLONASS TEC data from the Bangkok station were collected to provide a localized perspective. Both GLONASS TEC and IGS

TEC datasets were systematically gathered for the period I January 2026 to 31 January 2026, ensuring temporal alignment for direct comparison. The combination of these datasets allowed local ionospheric dynamics observed by GLONASS to be systematically compared against the global reference provided by IGS, and all collected data were subjected to integrity checks to identify missing epochs. Cycle slips, and multipath errors, ensuring that only high-quality measurements were used in subsequent analysis.

3.4 Data Analysis

To evaluate the reliability of GLONASS TEC against IGS TEC, several statistical indicators were employed. First, the correlation coefficient (r) was used to measure the strength of the linear relationship between the two datasets. A high correlation indicates that GLONASS TEC follows the same temporal trend as IGS TEC, confirming consistency in capturing ionospheric variations. The correlation coefficient using the equation (3):

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 (y_i - \bar{y})^2}} \tag{3}$$

where x_i is GLONASS TEC, $\bar{x}$ is average of the GLONASS TEC, y_i is IGS TEC, $\bar{y}$ is average of the IGS TEC.

The Mean Bias Error (MBE) was calculated to quantify the average offset between GLONASS TEC and IGS TEC. This metric reveals whether GLONASS systematically produces higher or lower values compared to the global reference, which is particularly important given the presence of hardware DCBs.

The Mean Bias Error using the equation (4):

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i) \tag{4}$$

where P_i is GLONASS TEC, O_i is IGS TEC, n is data points.

The Root Mean Square Error (RMSE) was then applied to assess the overall magnitude of differences between the two datasets. Unlike MBE, which only shows the mean offset, RMSE captures both systematic and random errors, providing a comprehensive measure of accuracy.

The Root Mean Square Error using the equation (5):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \tag{5}$$

where P_i is GLONASS TEC, O_i is IGS TEC, n is data points.

4. Results

4.1 GLONASS TEC

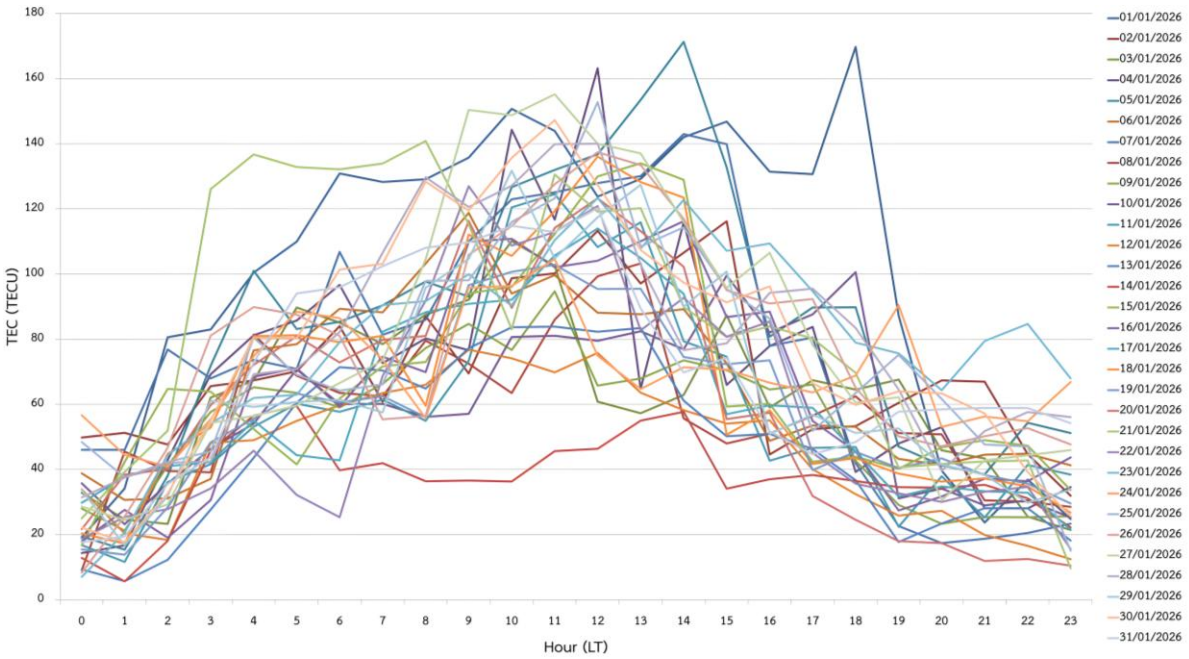

Figure 1 Hourly Variation of GLONASS TEC at Bangkok Station, January 2026

In Figure 1, the values demonstrate a distinct diurnal variation. The TEC generally begins at lower levels during midnight and the early morning hours, then gradually increases as solar radiation intensifies, reaching peak values around late morning to early afternoon. Afterward, the values decline again toward evening and night. This daily cycle reflects the ionospheric response to solar activity, with noticeable differences between individual days but a consistent overall pattern. Such fluctuations are critical for understanding ionospheric dynamics and their influence on GNSS signal propagation, as they directly affect satellite communication and positioning accuracy.

The dataset also reveals significant extremes in TEC values. The highest TEC recorded is 169.72 TECU on 27 January 2026 at 18:00 LT, indicating strong ionospheric activity during that period. In contrast, the lowest TEC observed is 6.99 TECU on 25 January 2026 at 00:00 LT, corresponding to nighttime conditions when ionization is minimal. These extremes highlight the considerable variability of TEC within a single month, emphasizing the importance of monitoring both daily and hourly changes to ensure reliable satellite-based applications.

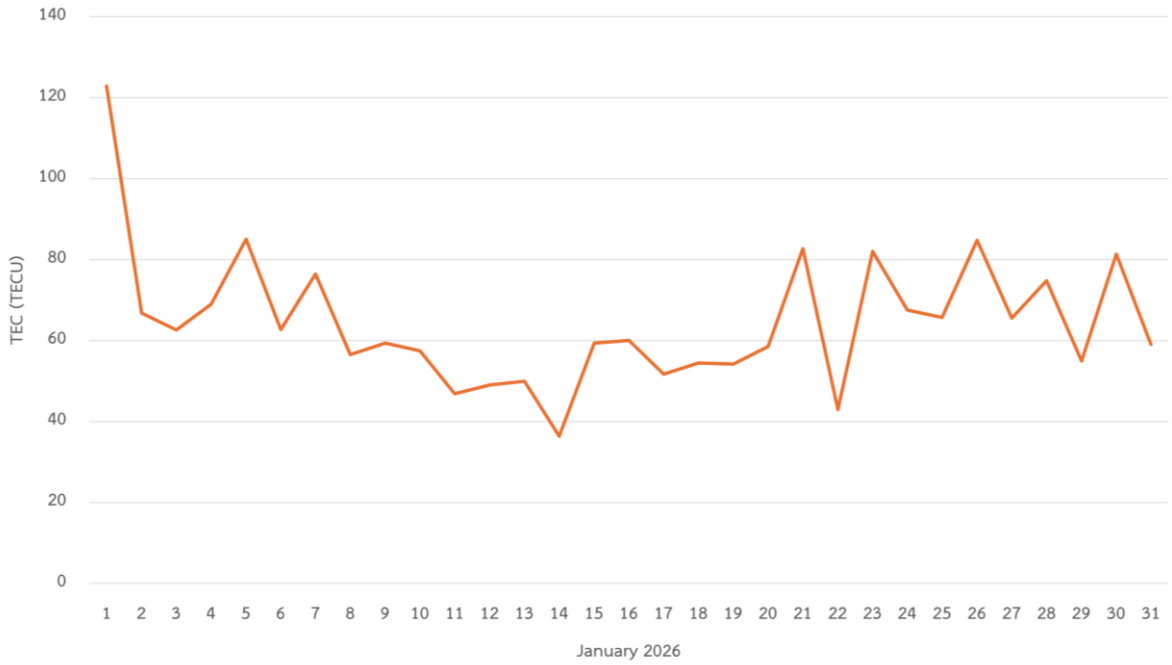

Figure 2 Daily Variation of GLONASS TEC at Bangkok Station, January 2026

In Figure 2, the data reveals clear day-to-day variability in ionospheric electron content, with values ranging from a high of about 122.8 TECU on 1 January 2026 to a low of 36.3 TECU on 14 January 2026. The sharp decline between 1 January 2026 and 2 January 2026 is particularly notable, as TEC dropped by half, suggesting a significant change in ionospheric conditions at the start of the month. Throughout the first half of January, TEC values generally fluctuated between 46 and 85 TECU, with smaller peaks around 5 January 2026 and 7 January 2026, and a pronounced dip on 14 January 2026. This pattern indicates alternating phases of ionospheric enhancement and depletion, which could be linked to geomagnetic activity or seasonal atmospheric dynamics.

In the latter half of the month, TEC values showed more pronounced oscillations, with strong peaks on 21 January 2026 (82.7 TECU), 23 January 2026 (82.0 TECU), and 26 January 2026 (84.8 TECU). These were interspersed with dips such as 22 January 2026 (42.9 TECU), highlighting rapid short-term variability. The final days of January maintained moderately high TEC levels, with 30 January 2026 reaching 81.4 TECU before dropping to 59.0 TECU on 31 January 2026.

4.2 IGS TEC

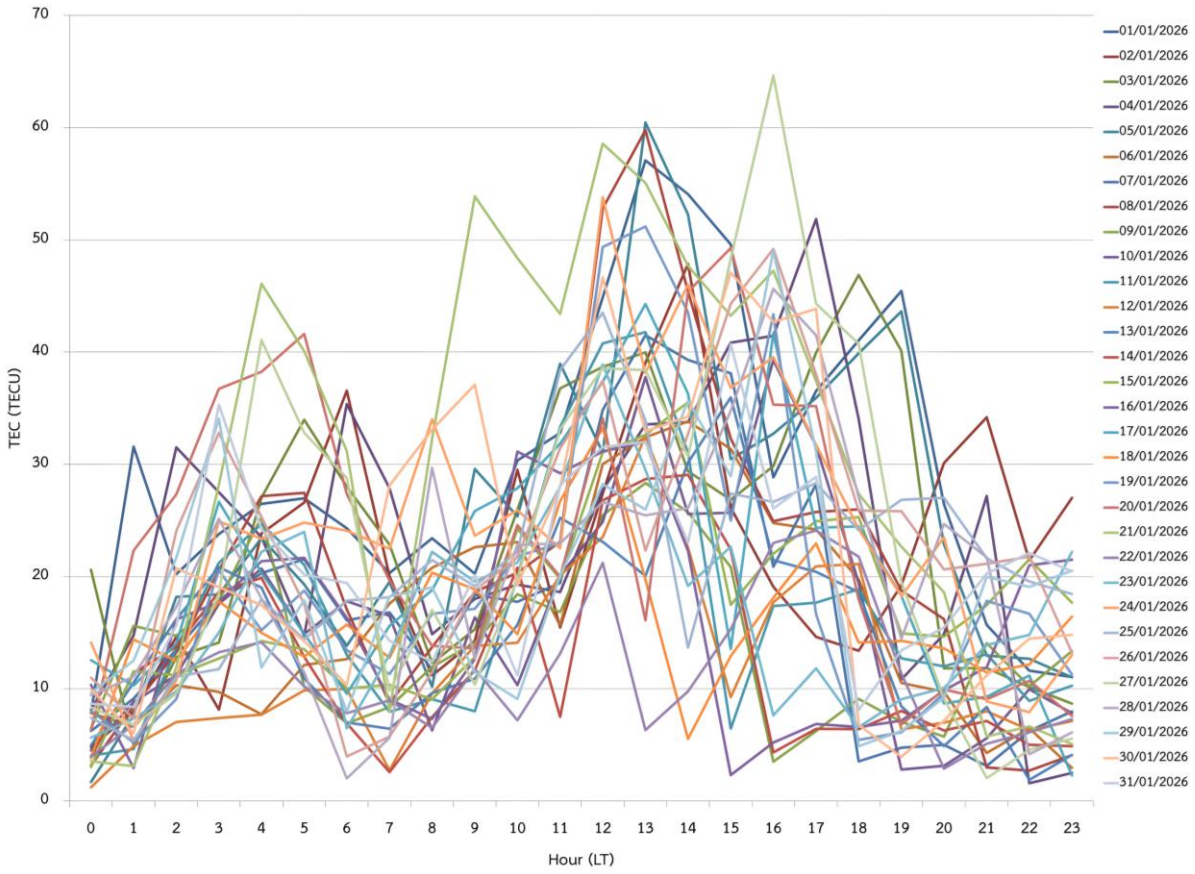

Figure 3 Hourly Variation of IGS TEC at Bangkok Station, January 2026

Figure 3 shows the values demonstrate a strong diurnal cycle, with low levels during the night and early morning, followed by a steady increase as solar radiation intensifies, reaching peak values around midday to afternoon. For instance, on 13 January 2026, the TEC reached its maximum of about 60.47 TECU at 13:00 LT, while on 9 January 2026, it also showed a high peak of 53.90 TECU at 9:00 LT. These elevated values highlight periods of intense ionospheric activity, which are directly linked to solar energy input and are consistent with the expected daytime behavior of the ionosphere. Such peaks are critical indicators of potential GNSS signal delays and satellite communication disturbances.

Conversely, the lowest values occurred during nighttime hours when solar ionization is absent. For example, on 21 January 2026, the TEC dropped to just 2.04 TECU at 21:00 LT, and on 19 January 2026, it was only 3.93 TECU at 19:00 LT. This wide variation, ranging from about 2 TECU to nearly 60 TECU, underscores the sharp contrast between daytime and nighttime ionospheric conditions. The dataset clearly illustrates how electron density in the ionosphere fluctuates within a single day and across the month, making it essential for analyzing GNSS performance and ensuring reliable satellite-based communication systems.

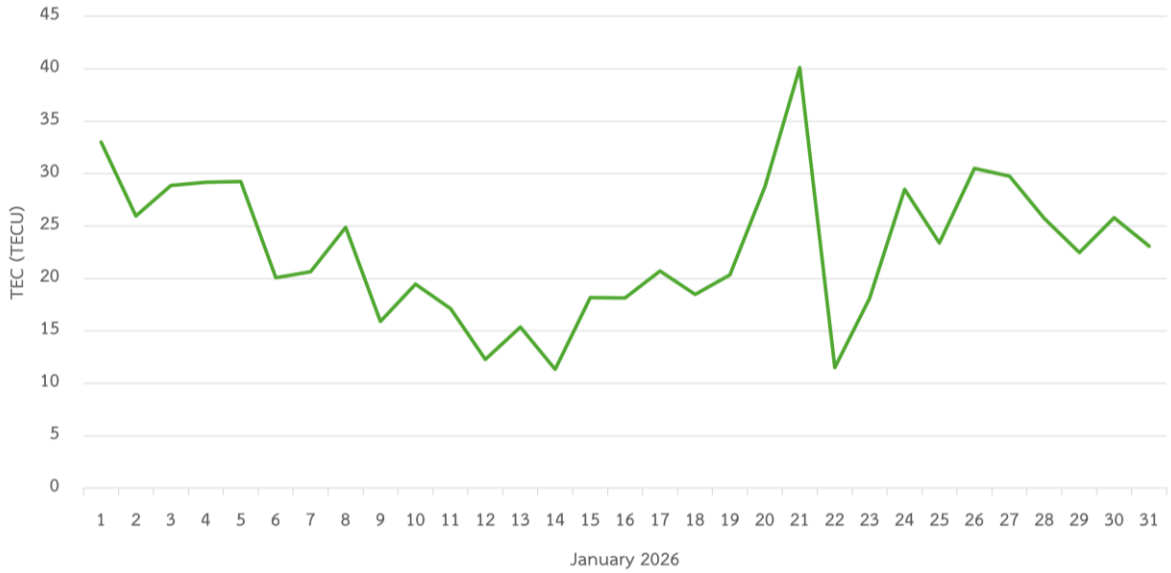

Figure 4 Daily Variation of IGS TEC at Bangkok Station, January 2026

Figure 4 shows the daily TEC values for January 2026, which fluctuate noticeably throughout the month. On day 21, the TEC reached its highest value of 40.106 TECU, while the following day recorded the lowest value of 11.5135 TECU. This sharp rise followed by a sudden drop highlights a significant ionospheric disturbance that may be important for GNSS and space weather research. Over the rest of the month, most TEC values ranged between 15 and 30 TECU, indicating moderate stability with occasional variations. The most striking changes occurred in the third week of January, where the extremes were observed.

4.3 The reliability and accuracy of TEC measurements

The reliability and accuracy of TEC measurement on GLONASS TEC by using RMSE is compared to the IGS TEC reference. In Table 1, the statistical analysis of the TEC data for the first 31 days of 2026 reveals a consistent discrepancy between the GLONASS TEC measurements (P_i) and the IGS TEC reference values (O_i). With a cumulative sum of squared errors reaching 58875.83, the calculated RMSE stands at 43.58 TECU. This result indicates a significant positive bias in the GLONASS TEC estimations during this period, suggesting that the system tends to over-report ionospheric density relative to the IGS standard. The reliability and accuracy of TEC measurements by using GLONASS TEC is limited to being used as TEC measurement and needed to add the TEC biases by approximately 43.58 TECU. The results showed that the accuracy of TEC measurement by using GLONASS satellites is over 56.42 percents of IGS TEC reference in January 2026. Overall, while GLONASS TEC measurements demonstrate potential for monitoring ionospheric variability, their standalone use for precise TEC estimation requires careful bias mitigation and calibration. Incorporating correction terms or combining GLONASS data with other periods of months and GNSS constellations may enhance the overall accuracy and reliability of TEC estimation in future ionospheric studies.

Table 1 RMSE analysis of GLONASS TEC and IGS TEC in January 2026

DOY2026 (n)	GLONASS TEC (P_i)	IGS TEC (O_i)	(P_i-O_i)	(P_i-O_i)^2
1	122.8305	33.017	89.8135	8066.465
2	66.797	25.963	40.834	1667.416
3	62.561	28.869	33.692	1135.151
4	68.945	29.175	39.77	1581.653
5	84.99	29.235	55.755	3108.62
6	62.657	20.078	42.579	1812.971
7	76.4675	20.6605	55.807	3114.421
8	56.551	24.8715	31.6795	1003.591
9	59.365	15.901	43.464	1889.119
10	57.4135	19.451	37.9625	1441.151
11	46.88	17.139	29.741	884.5271
12	49.012	12.293	36.719	1348.285
13	49.944	15.369	34.575	1195.431
14	36.319	11.355	24.964	623.2013
15	59.357	18.173	41.184	1696.122
16	60.036	18.148	41.888	1754.605
17	51.6535	20.721	30.9325	956.8196
18	54.435	18.495	35.94	1291.684
19	54.219	20.341	33.878	1147.719
20	58.494	28.768	29.726	883.6351
21	82.676	40.106	42.57	1812.205
22	42.9715	11.5135	31.458	989.6058
23	82.013	18.111	63.902	4083.466
24	67.5465	28.5015	39.045	1524.512
25	65.668	23.388	42.28	1787.598
26	84.807	30.498	54.309	2949.467
27	65.5545	29.76025	35.79425	1281.228
28	74.804	25.721	49.083	2409.141
29	54.969	22.476	32.493	1055.795
30	81.369	25.7885	55.5805	3089.192
31	59.029	23.098	35.931	1291.037
Sum	2000.3345	706.98475	1293.35	58875.83

From the equation (5):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} = \sqrt{\frac{58875.83}{31}} = 43.58 \text{ TECU}$$

4.4 Comparative result between GLONASS TEC and IGS TEC

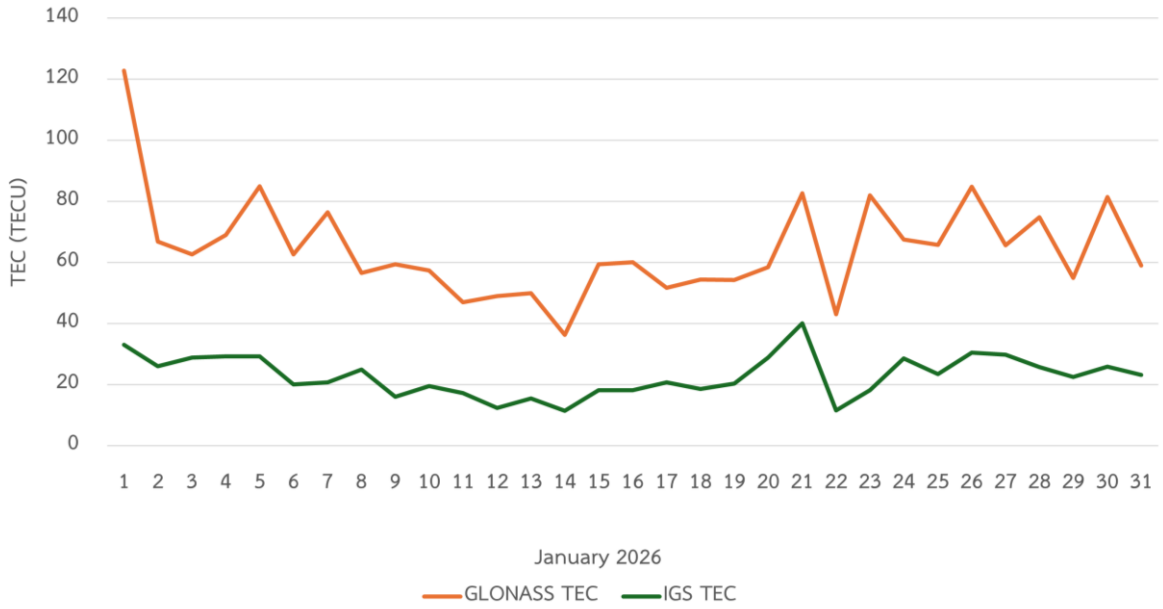

Figure 5 Comparative result between GLONASS TEC and IGS TEC at Bangkok Station, January 2026

Figure 5 shows that GLONASS consistently reports higher TEC values than IGS across 31 days in January 2026, with GLONASS ranging from about 36 to 123 TECU while IGS stays within 11 to 40 TECU. The differences are substantial, such as Day 1 (GLONASS 122.83 TECU vs. IGS 33.02 TECU) and Day 21 (GLONASS 82.68 TECU vs. IGS 40.11 TECU), and even on lower-value days like Day 14 (GLONASS 36.32 TECU vs. IGS 11.36 TECU) the gap remains significant. GLONASS also shows broader variability and frequent peaks above 80 TECU, while IGS rarely exceeds 30 TECU except on a few occasions. This consistent offset suggests systematic differences in measurement approaches, possibly due to calibration or processing, and highlights that GLONASS may be more sensitive to ionospheric changes or may overestimate TEC compared to IGS an important consideration for satellite navigation applications requiring precise TEC modeling.

Furthermore, the correlation coefficient between GLONASS TEC and IGS TEC values were calculated to be 0.73, indicating a strong positive correlation. This result confirms that although GLONASS consistently reports higher magnitudes, both datasets capture similar temporal and diurnal ionospheric variations.

5. Conclusion and Discussion

In conclusion, the analysis reveals that GLONASS consistently reports significantly higher TEC values than IGS, with broader variability and frequent peaks. Specifically, the calculated RMSE stands at 43.58 TECU, indicating a significant positive bias in the GLONASS TEC estimations and suggesting that the system tends to over-report ionospheric density relative to the IGS standard. The reliability and accuracy of TEC measurements by using GLONASS TEC is limited to being used as TEC measurement and needed to add the TEC biases by approximately 43.58 TECU. The results showed that the accuracy of TEC measurement by using GLONASS satellites is over 56.42 percents of IGS TEC reference in January 2026. This systematic offset is

likely rooted in calibration or processing differences. When compared to Keokhumcheng and Kenpankho (2025), whose GPS-based TEC results aligned more closely with IGS magnitudes and emphasized regional ionospheric variability without strong biases, the present findings highlight GLONASS's tendency toward elevated estimates that may reflect either heightened sensitivity or overestimation. This divergence underscores the reliability of GPS/IGS TEC values as a baseline while emphasizing the need for careful cross-system calibration to ensure accuracy in multi-GNSS applications, particularly in low-latitude regions where ionospheric dynamics are most pronounced.

The results of this study, showing GLONASS consistently reporting higher TEC values than IGS across 31 days in 2026, align with the broader understanding of systematic differences in GNSS-derived ionospheric measurements but diverge from the findings of Keokhumcheng and Kenpankho (2025). While their work, based on GPS TEC observations in low-latitude regions of Thailand, reported values more consistent with the IGS range and emphasized regional ionospheric variability without strong systematic offsets, the present dataset highlights a persistent bias in GLONASS that produces magnitudes up to three times higher than IGS. Specifically, the calculated RMSE stands at 43.58 TECU, indicating a significant positive bias in the GLONASS TEC estimations during this period. This result suggests that the system tends to over-report ionospheric density relative to the IGS standard. The reliability and accuracy of TEC measurements by using GLONASS TEC is limited to being used as TEC measurement and needed to add the TEC biases by approximately 43.58 TECU. The results showed that the accuracy of TEC measurement by using GLONASS satellites is over 56.42 percents of IGS TEC reference in January 2026. This contrast suggests that IGS/GPS-based TEC estimates remain closer to established baselines, whereas GLONASS TEC may either be more sensitive to ionospheric fluctuations or prone to overestimation due to calibration and processing differences. Consequently, while Keokhumcheng and Kenpankho underscored the reliability of GPS TEC for navigation and modeling, the current findings emphasize the need for cross-system calibration when integrating GLONASS with GPS/IGS data to avoid introducing errors in multi-GNSS applications, particularly in ionospherically dynamic low-latitude regions. Consequently, while Keokhumcheng and Kenpankho underscored the reliability of GPS TEC for navigation and modeling, the current findings emphasize the need for cross-system calibration when integrating GLONASS with GPS/IGS data to avoid introducing errors in multi-GNSS applications, particularly in ionospherically dynamic low-latitude regions.

Consequently, while Keokhumcheng and Kenpankho underscored the reliability of GPS TEC for navigation and modeling, the current findings emphasize the need for cross-system calibration when integrating GLONASS with GPS/IGS data to avoid introducing errors in multi-GNSS applications, particularly in ionospherically dynamic low-latitude regions. Future work should focus on developing robust GLONASS-specific bias correction models, including the estimation of satellite and receiver dependent differential code biases, and on validating these corrections across different seasons and levels of solar activity. Additionally, extending the analysis to a multi-constellation framework incorporating Galileo and BeiDou systems, as well as employing regional ionospheric models, would further enhance TEC accuracy and reliability for high-precision navigation and space weather monitoring applications.

6. Acknowledgements

The authors would like to express their sincere gratitude to Space, Satellite, and Study Laboratory (SSS Lab), Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand for providing invaluable support, resources, and facilities throughout the course of this research. The laboratory's advanced infrastructure and academic environment greatly contributed to the successful completion of this study. Special appreciation is extended to the faculty members and research staff whose guidance and technical expertise enhanced the quality of the work. Without the continuous encouragement and assistance from SSS Lab, this research would not have been possible.

7. References

Jamjareegulgarn, P., Supnithi, P., Kenpankho, P., Wichaipanich, N., & Nayak, C. (2020). Improving the modeling of bottomside thickness parameters over midlatitudes and high latitudes. Advances in Space Research, 65(3), pp. 909–932.

Kenpankho, P., Chaichana, A., Trachu, K., Supnithi, P., & Hozumi, K. (2021). Real-time GPS receiver bias estimation. Advances in Space Research, 68(5), pp. 2152–2159.

Keokhumcheng, T., & Kenpankho, P. (2024). Delay time on GPS at low latitude station on geomagnetic day. In Proceedings of DRLE 2024 International Conference, pp. 16-23.

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), pp. 4245–4259.

Pansong, C., & Kenpankho, P. (2025). GPS TEC anomalies and earthquake events in Thailand. Earth Sciences Research Journal, 29(3), pp. 297–312.

Pansong, C., Kraisi, P., Nambut, S., & Kenpankho, P. (2025). Estimation of geostationary BeiDou satellite total electron content during the extreme geomagnetic storm. In Proceedings of DRLE 2025 International Conference, pp. 167-178.

Pansong, C., Ruttanaburee, S., Sunthonkanokpong, W., & Kenpankho, P. (2025). Pre-seismic ionospheric total electron content anomalies associated with the June 28, 2023, earthquake in Thailand. International Journal of Industrial Education and Technology, 7(2).

Pansong, C., Wongsak, P., Ruttanaburee, S., Pornsopin, P., & Kenpankho, P. (2025). Lowlatitude TEC disturbances during extreme geomagnetic storms. Advances in SpaceResearch, 76(12), pp. 7521–7532.

Phansori, N., Boatong, P., Phukrongta, S., Kriamthaisong, O., & Kenpankho, P. (2021). Analysis of the relationship between earthquake events and the disturbance of ionosphere by using IGS TEC. ASEAN Journal of Science and Engineering Education, 1(1), pp. 69–72.

Phansori, N., Phukrongta, S., Kriamthaisong, O., & Kenpankho, P. (2022). Study the relationship of earthquake and ionosphere using IRI TEC for education. ASEAN Journal of Science and Engineering Education, 2(2), pp. 153–156.

Sumniang, P., Sittichai, W., & Kenpankho, P. (2025). Ionospheric delay and low-cost robots. Advances in Space Research, 75(5), pp. 4386–4393.

Zhao, X., Li, G., Xie, H., Hu, L., Sun, W., Li, Y., Dai, G., Liu, J., Li, Y., Ning, B., Nishioka, M., Perwitasari, S., & Kenpankho, P. (2025). Regional equatorial plasma bubble prediction. Space Weather, 23(2).

SINGLE STATION POSITIONING ERROR BASED ON GPS SATELLITE

Uthai Kaiphalang*, Burin Putthong, and Prasert Kenpankho

68036069@kmitl.ac.th, 67036097@kmitl.ac.th, and prasert.ke@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 68036069@kmitl.ac.th

ABSTRACT

This study investigates the positioning accuracy of a single Global Positioning System (GPS) station receiver using data collected from a fixed station at a low latitude at King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand. GPS observations recording is ongoing. over a three-month period to evaluate positioning errors under typical urban and atmospheric conditions in the region. Standard single GPS station positioning techniques were applied without the use of differential corrections or network-based enhancements. The positioning performance was assessed by comparing the estimated coordinates with the known reference position of the station. Statistical analysis of the horizontal positioning results shows that the GPS receiver achieved a mean positioning error of approximately 2.22 m over the observation period. The results prove that single GPS station positioning can provide meter- level accuracy when stable observation conditions and sufficient satellite geometry are available. This level of accuracy is suitable for a wide range of geodetic, surveying, and monitoring applications that do not require real-time corrections. The findings also provide a reference for future studies on GPS performance in tropical environments such as Thailand, where atmospheric effects may influence positioning accuracy.

Keywords: Single GPS station, GPS positioning error, Standalone positioning,
Low-latitude ionosphere, Ionospheric effects, GNSS accuracy

1. Statement of the Problem

Single Global Positioning System (GPS) station positioning. It is widely used. because it is simple and cost-effective, but its accuracy there are limitations. by factors like ionospheric variation, multipath, satellite geometry, and atmospheric delays. These issues are especially pronounced in low-latitude regions like Bangkok, where the Equatorial Ionospheric Anomaly and dense urban settings create challenging conditions. This study analyzes three months of data from a fixed GPS station at King Mongkut's Institute of Technology Ladkrabang (KMITL, Thailand), comparing estimated positions with reference coordinates to assess the extent and causes of positioning errors in real-world low-latitude environments.

Extensive studies have examined the accuracy of GPS positioning and the factors influencing positioning errors under different environmental and ionospheric conditions. Fundamental GPS error sources, including satellite clock and orbit errors, multipath, tropospheric delay, and ionospheric delay, have been well documented in classical Global Navigation Satellite System (GNSS) literature (Seeber, 2003, pp. 231-2260; Hofmann et al., 2008, pp. 245-310; Misra & Enge, 2011, pp. 187-240). Among these, ionospheric delay has been identified as the dominant error source for single frequency GPS positioning, particularly in low latitude and equatorial regions (Su et al., 2019, pp. 1-14). This research focuses on Total Electron Content (TEC) have shown that spatial and temporal TEC variations significantly degrade positioning accuracy during periods

of high solar and geomagnetic activity (Hernández et al., 2009, pp. 263-275; Nguyen et al., 2022, pp. 1-18). Recent research has emphasized the importance of regional and latitude-dependent investigations to better understand GNSS performance. In Southeast Asia, especially Thailand, ionospheric disturbances such as equatorial plasma bubbles and TEC anomalies have been widely documented and linked to GNSS positioning degradation (Kenpankho, 2014, pp. 45-998; Pansong & Kenpankho, 2025, pp. 297-312). Studies using single frequency GPS receivers have proven their capability for ionospheric monitoring while also highlighting their vulnerability to ionospheric delay errors (Keokhumcheng & Kenpankho, 2025, pp. 4245-4259). Furthermore, investigations into GPS receiver bias estimation and TEC disturbance detection have contributed to improving the reliability of GNSS measurements in low latitude regions (Kenpankho et al., 2021, pp. 2152-22159; Pansong et al., 2025, pp. 7521-7532). Advances in GNSS positioning techniques, including Precise Point Positioning (PPP) and Multi GNSS integration, have achieved improved accuracy in various environments; however, these methods often require precise products and longer convergence times (Yiğit et al., 2016, pp. 22-339; Geng et al., 2021, pp. 1-15). While high precision methods are effective, extensive studies have emphasized that single station or standalone GPS positioning is still essential for applications requiring simplicity, low cost, and operational robustness (Van, 2015, pp. 101-140; Sukhenko et al., 2025, pp. 1-25). Consequently, evaluating single station GPS positioning performance in urban, low latitude environments such as Bangkok persists as a vital research topic, particularly for assessing achievable accuracy without reliance on external correction services.

This research analyzes ionosphere and analytical data based on GPS systems using the drives of Kenpankho (2014) and Sumniang et al. (2025. Total Electron Content (TEC) data and control data of the ionosphere are used in surveys based on different GPS frequencies. The TEC data captures ionosphere data points from Kenpankho (2014) survey. The TEC data examines GPS equatorial magnetic latitude at Chumphon, Thailand, to generally characterize the ionosphere at low-latitude airports by analyzing changes and comparing observations with reference ionosphere samples. Building on this foundation, Sumniang et al. (2025) link the ionosphere in GNSS, controlling the orientation of the ionosphere with location results from a rotary platform. This investigation method examines the ionosphere as a continuous investigation from GPS to decide whether the ionosphere's impact on GNSS systems is worthwhile.

The primary aim of this research is to assess the positioning accuracy of a single station GPS receiver found in Bangkok, (KMITL, Thailand) over a three-month observation period. Specifically, the study aims to quantify the horizontal positioning error of the GPS station, while evaluating the feasibility of achieving submeter accuracy without differential corrections, furthermore it looks to provide empirical evidence of GPS positioning performance under low latitude ionospheric conditions. The results are expected to contribute to regional GPS performance assessments and support future applications in surveying, monitoring, and navigation in Bangkok, Thailand.

2. Objectives

2.1 Investigate the positioning error of the single GPS station at low latitude, KMITL, Thailand.

2.2 Evaluate the accuracy of GPS satellite at the single GPS station at low-latitude, KMITL, Thailand.

3. Conceptual Framework and Hypothesis

The conceptual framework of this study focuses the positioning error of the single GPS station at low-latitude, KMITL, Thailand over a three-month period, grounded in the ionospheric principles described by Kenpankho (2014) and the application-oriented findings of Sumniang et al. (2025). In this framework, it is hypothesized that GPS positioning from a single station fixed

in Bangkok, Thailand, over a three-month observation period, can achieve horizontal positioning accuracy below one meter due to variability in the ionosphere at low latitudes in Thailand. This variability significantly contributes to positioning errors in single-station GPS solutions. Continuous long-term GPS observation helps reduce random positioning errors, resulting in a stable average positioning error of approximately 0.5 meters.

4. Research Methodology

This research aimed to study the lateral positioning error using the GPS from a station at KMITL, Thailand. Continuous observational data over a period of three months was collected using a BG2s GNSS ionospheric monitor (BG2s) as Figure 1. The goal was to evaluate positioning accuracy under urban and ionosphere conditions at low latitudes. The results showed an average lateral positioning error of approximately 0.5 meters, proving that single-station positioning can achieve accuracy below one meter.

Figure 1 Components of the BG2s GNSS ionospheric monitor receiver

4.1 Research method

This research employs a quantitative observational approach to estimate single-station GPS positioning errors. Continuous measurements are taken from a fixed station found in Bangkok. The receiver is installed at the Space, Satellite and Education Laboratory (SSS Lab) at KMITL, Thailand. The research focuses on standalone GPS positioning without differential correction, network services, or high-precision products. Known reference coordinates of the station are used as real data to assess positioning accuracy. GPS observations collected over a three-month period provide sufficient temporal coverage to capture changes in satellite geometry and atmospheric conditions, particularly the ionosphere effects commonly found in low-latitude regions. In single GPS station positioning performed using pseudorange from GPS satellites, positioning errors are quantified by comparing estimated station coordinates to known reference coordinates. This method allows ~~for~~ direct assessment of the sources of cumulative GPS errors under realistic urban and low-latitude environments and ionosphere conditions.

4.2 Research procedure

This research consists of four main processes. Initially, location data from key GPS receiving stations for positioning accuracy surveys, using the KMITL station in Thailand as a selected location. The second process is to collect GPS location data from the satellite receiver for three months. Thirdly, the parameters used to calculate latitude and longitude coordinates, which are the reference positions of satellite receiving stations, to find the positioning error. Finally, the calculation is based on comparing positioning data from statistical analysis to evaluate overall performance.

4.3 Data Collection

GPS aggregates the components of a single GPS station found in low latitude, KMITL, Thailand. The dataset includes latitude, longitude, and altitude, area clock records necessary for autonomous GPS pathology, typical city station conditions affected by multiple path reflection effects, and atmospheric signals. This dataset allows for investigation of positioning under ionospheric data. Known reference positions at most stations serve as a standard for typical areas.

4.4 Data Analysis

The calculation of coordinates (latitude, longitude) and altitude from a GPS receiver relies on mathematical principles known as trilateration. The main steps of this process are as follows. (Leick et al., 2015)

4.4.1 Basic principles

The receiver doesn't measure distance directly, but rather the "time" it takes for the signal to travel from the satellite to the receiver. This time, the distance is calculated using an equation (1).

$$Distance = Speed \times Time \tag{1}$$

By a variable equation is from the calculation equation (2).

$$Time = T_{arrival} - T_{transmission} \tag{2}$$

4.4.1.1 Theory and Mechanism of Operation

The principle of trilateration relies on the geometric properties of a circle or sphere, as follows as Figure 2.

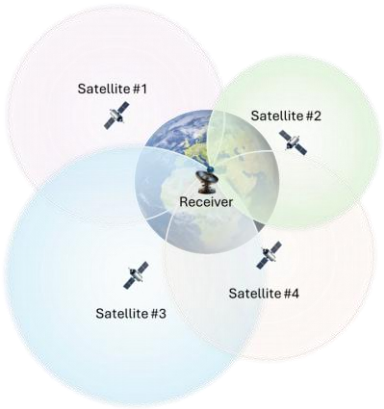

Figure 2 Components of a three-way intersection

In the practical application of a GPS system, a fourth satellite is needed to solve the clock bias equation and confirm the vertical coordinates (altitude) for greater accuracy.

4.4.2 Mathematical Equations (Pseudorange Equations)

The actual measured distance is called the pseudorange because it has a cumulative error. The basic equation (3) for satellite (i) is.

$$\rho_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + c \cdot (dt_u - dt_s) + I + T + \grave{o} \tag{3}$$

Relevant variables:

(x_i, y_i, z_i): The position of satellite i (obtained from Ephemeris data).

(x_u, y_u, z_u): User location (value to be found).
c: Speed of light.
dt_u: Receiver Clock Offset.
dt_s: Satellite clock error.
I, T: Errors caused by the ionosphere and troposphere.
ò: Noise and other errors.

5. Results

Analysis of three months of data from October to December 2025 showed that the estimated position of the Bangkok GPS station was highly stable. The estimated altitude gradually decreased from -6.74833596 meters in October to -7.37198179 meters in December, reflecting increased sensitivity in the vertical part, consistent with the behavior of GPS in low-latitude regions influenced by ionosphere effects. Horizontal positioning performance remained stable, with an average horizontal accuracy of 2.20855765-2.23095257 meters and a low standard deviation of 0.15219121-0.17309084 meters, showing consistent horizontal results over the three months. In contrast, the average vertical accuracy was lower, ranging from 3.94491225 to 3.93984530 meters, with a maximum vertical accuracy slightly increasing to 6.04860215 meters in December, highlighting the more severe impact of ionosphere delay on vertical components as summarized in Table 1.

Table 1 Summary table of location data and accuracy of GPS satellite receiving stations

Table Summarize	Oct-25	Nov-25	Dec-25
Avg_Latitude [Deg]	13.72977260	13.72977292	13.72977321
Avg_Longitude [Deg]	100.78115455	100.78115517	100.78115574
Avg_Height [m]	-6.74833596	-7.10747050	-7.37198179
Avg_H-Accuracy [m]	2.20855765	2.21078042	2.23095257
Max_H-Accuracy [m]	2.93705645	2.96287500	3.13329301
Avg_V-Accuracy [m]	3.94491225	3.91736364	3.93984530
Max_V-Accuracy [m]	5.75129032	5.76783333	6.04860215
Std_H-Accuracy	0.15219121	0.15182651	0.17309084
Avg_Sats [n]	36	36	36

In Fgirue 3, the average daily horizontal accuracy (Avg_H-Accuracy; blue line) remained close to 2.21682858 meters throughout the three months. The average in October was 2.20855765 meters (Range 2.15520139-2.27234028 meters), in November 2.21078042 meters (Range 2.15877251-2.25818750 meters), and in December 2.23095257 meters (range 2.17451389-2.35154167 meters), showing a slightly higher daily average in December. Furthermore, the highest daily horizontal accuracy was also recorded in December. Max_H-Accuracy (orange line) shows maximum values of 3.80833333 meters (October), 3.47916667 meters (November), and 4.06208333 meters (December), corresponding to a periodic increase in error. This problem is often associated with changes in signal propagation conditions and sensitivity to multiple reflections in portable GPS systems, as shown in the graph.

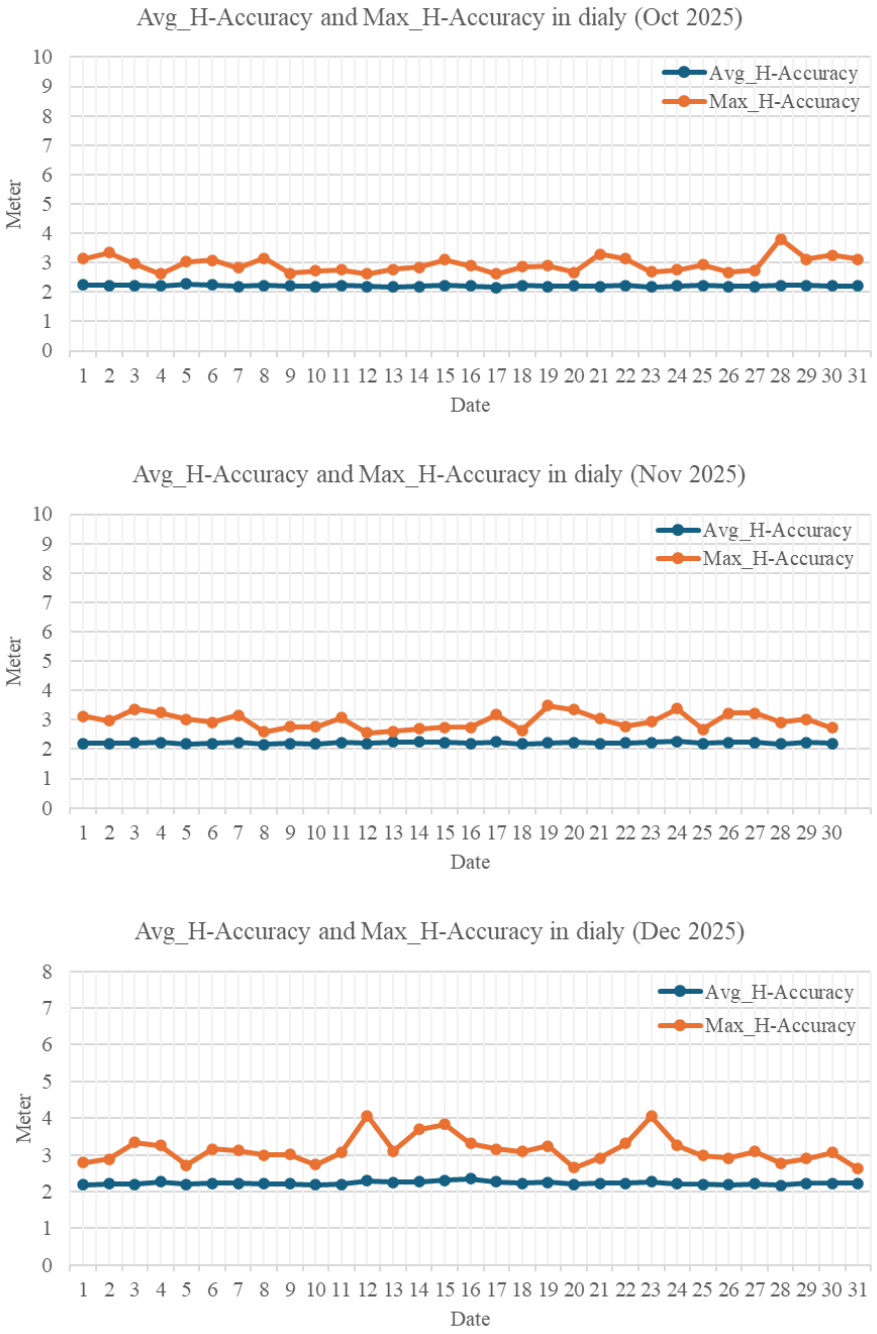

Figure 3 Average daily horizontal accuracy

Vertical accuracy remains significantly worse and more volatile than horizontal, with average daily vertical accuracy around 3.79285177-4.13100694 meters (October average 3.94491225 meters; November average 3.91736364 meters; December average 3.93984530 meters), and higher daily peaks of 6.84458333 meters (October), 6.97041667 meters (November), and 7.77666667 meters (December), reflecting the more pronounced influence of unsimulated atmospheric effects on altitude, as shown in the graph in Figure 4.

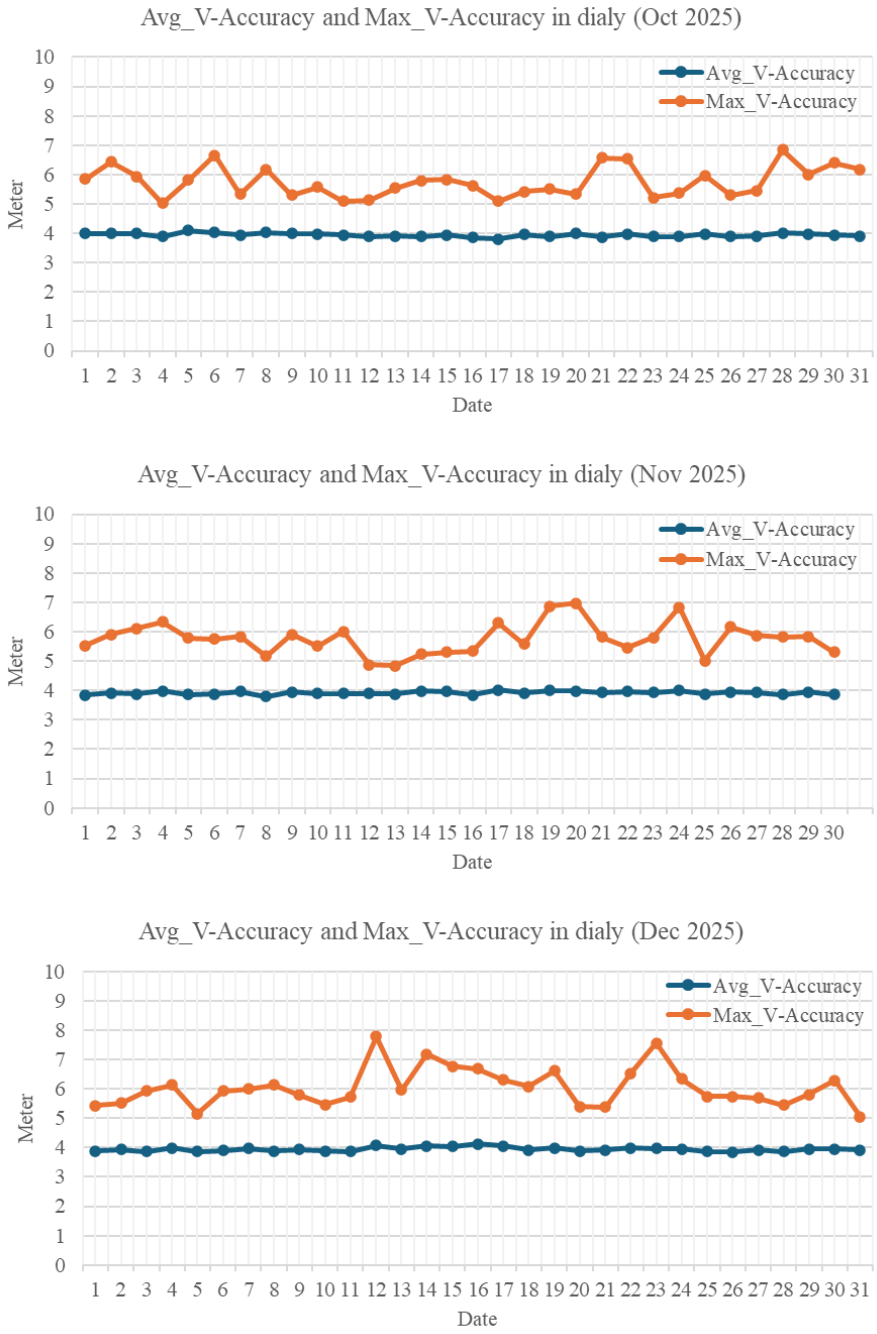

Figure 4 Average daily vertical accuracy

Analysis of the positioning errors at a single GPS station reveals significant monthly (hourly) variations in positioning errors over a three-month period (October-December 2025). Horizontal positioning accuracy (Avg_H-Accuracy) shows relatively small hourly variations, with minimum values of approximately 2.03135556-2.05518280 meters and maximum values of approximately 2.32912903-2.42572043 meters, depending on the month and time of day. For example, in October, the lowest horizontal error occurred at 7:00 PM (2.05518280 meters) and the highest at 10:00 AM (2.32912903 meters); in November, the lowest occurred at 6:00 PM (2.03135556 meters) and the highest at 7:00 AM (2.40340000 meters); and in December, the lowest occurred at 4:00 PM (2.04505376 meters) and the highest at 5:00 AM (2.42572043 meters), as shown in the graph in Figure 5.

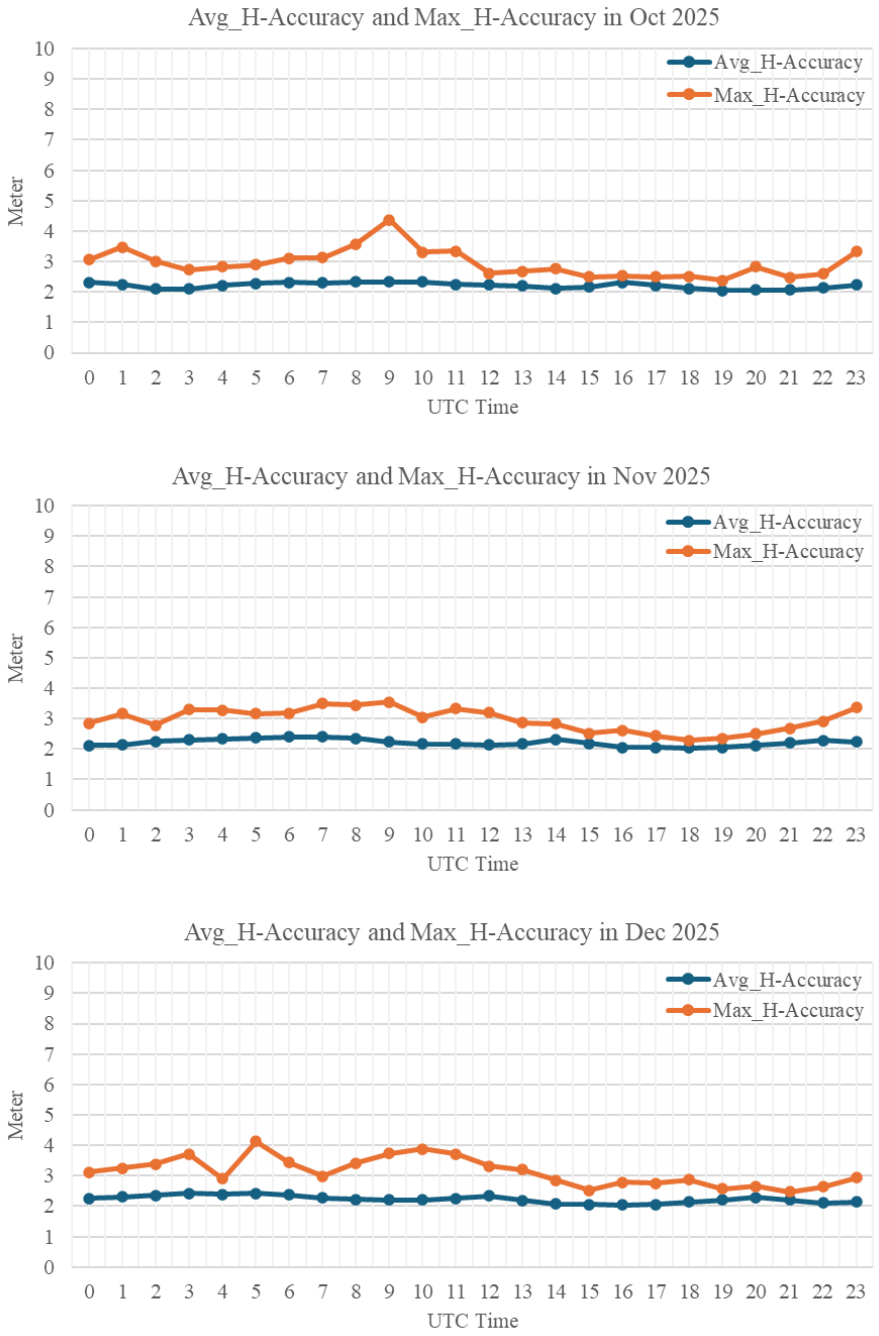

Figure 5 Average hourly horizontal accuracy

Conversely, vertical positioning accuracy, or average ionosphere accuracy (Avg_V-Accuracy), shows more pronounced hourly variation, ranging from approximately 3.34075000 to 4.44749462 meters, with peaks occurring at various times each month (October: 12:00 PM, November: 3:00 AM, December: midnight), and higher peaks of 7.89677419 meters (October), 7.66633333 meters (November), and 7.50000000 meters (December), reflecting the more pronounced influence of unsimulated atmospheric effects on altitude, as shown in the graph in as shown in the graph in Figure 6.

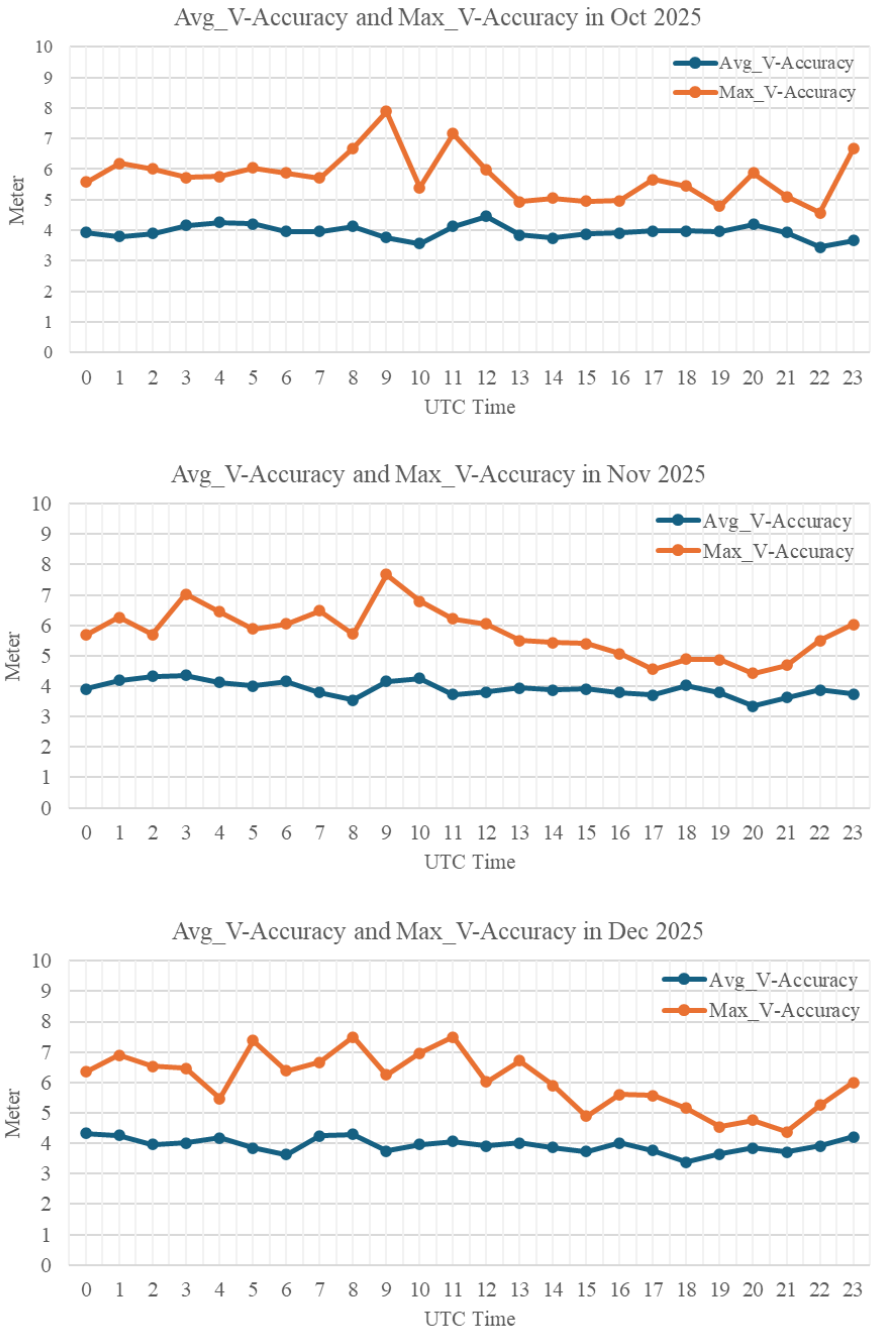

Figure 6 Average hourly horizontal accuracy

Single GPS station positioning error tracking in the GPS was conducted at multiple satellites for a continuous three-month period. Analysis of daily, monthly, and vertical-horizontal positioning data showed significant and low errors, with an average investigational error of 2.21676354 meters for patients. Significant vertical errors were seen, requiring more extensive research than usual. Low-latitude GPS server data was obtained from the normality of the ionosphere drive, the amount of directional control itself, and will be supported throughout the study.

6. Conclusion and Discussion

This study investigated single GPS station positioning error using continuous observations from a fixed station in Bangkok, Thailand, over a three-month period. The results prove that standalone GPS positioning provides stable horizontal performance with low variability, while vertical positioning accuracy stays poorer and more sensitive to environmental effects. Despite consistently good satellite availability and geometry, the observed positioning errors show that ionospheric delay plays a critical role in limiting accuracy, particularly in the vertical part. These findings confirm that single GPS stations can deliver reliable positioning performance for general applications in low latitude urban environments, but their accuracy is fundamentally constrained by ionospheric conditions characteristic of equatorial regions.

The results of this study support earlier research by Kenpankho (2014) and Sumniang et al. (2025), confirming that strong TEC variability at equatorial magnetic latitudes has a substantial impact on GPS signal propagation and positioning accuracy. Diurnal and monthly fluctuations in positioning error, particularly in the vertical direction, highlight the considerable influence of ionospheric delay in low-latitude environments, like findings in southern Thailand. Sumniang et al. (2025) emphasized that ionospheric delay is the primary limiting factor for standalone and low-cost GNSS applications, especially in dynamic or real-time settings. This study extends those findings by showing that ionospheric effects are still the main source of error even in static single-station scenarios. Although ample satellite availability enhances solution stability, it does not cut ionospheric interference, making ionospheric modeling or correction essential for improving GPS accuracy in low-latitude regions. The observed single GPS station error of approximately 2.22 m at the KMITL, Thailand station over three months is consistent with the expected influence of ionospheric conditions, as described by Kenpankho (2014) and Sumniang et al. (2025). While ionospheric variability is a dominant error source, the moderate impact during the study period allowed for practical single-station positioning. This aligns with Sumniang et al. (2025), who demonstrated that systems with limited correction capability can still achieve sub-meter accuracy under typical ionospheric conditions, indicating that the KMITL station experienced ionospheric behavior typical of equatorial regions and that single GPS station positioning is practical in Thailand when severe ionospheric disturbances are absent.

7. Acknowledgements

We express sincerity about the external appearance and academic aspects of the Department of Engineering Education at the Faculty of Industrial Education and Research, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand. This provides a perspective on the facilities for control and research, contributing to the success of this medical research and the resources available for data verification and reporting. Data analysis and the research conducted by this, we appreciated.

8. References

Bilgen, B., İnal, C., & Bülbül, S. (2022). Point positioning performance of Trimble-RTX in different satellite combinations. Konya Journal of Engineering Sciences, 10(4), 941-949. DOI: https://doi.org/10.36306/konjes.1165922.

Fabbro, V., Jacobsen, K. S., Andalsvik, Y. L., & Rougerie, S. (2021). GNSS positioning error forecasting in the Arctic: ROTI and Precise Point Positioning error forecasting from solar wind measurements. Journal of Space Weather and Space Climate, 11, 43. DOI: https://doi.org/10.1051/swsc/2021024.

Geng, J., Yang, S., & Guo, J. (2021). Assessing IGS GPS/Galileo/BDS-2/BDS-3 phase bias products with PRIDE PPP-AR. Satellite Navigation, 2(1), 17. DOI: https://doi.org/10.1186/s43020-021-00049-9.

Guo, Z., Yao, Y., Feng, Q., Xu, C., Zhang, L., & Hu, M. (2026). GNSS robust algorithm based on elevation-error statistical feature for deformation monitoring. Measurement, 259, 119671. DOI: https://doi.org/10.1016/j.measurement.2025.119671.

Harsha, P. B. S., Ratnam, D. V., Nagasri, M. L., Sridhar, M., & Raju, K. P. (2020). Kriging-based ionospheric TEC, ROTI and amplitude scintillation index (S_4) maps for India. IET Radar, Sonar & Navigation, 14(11), 1751-1763. DOI: https://doi.org/10.1049/iet-rsn.2020.0202.

Hernández-Pajares, M., Juan, J. M., Sanz, J., Orús, R., Garcia-Rigo, A., Feltens, J., Komjathy, A., Schaer, S., & Krankowski, A. (2009). The IGS VTEC maps: A reliability study. Journal of Geodesy, 83(3-4), 263-275. https://doi.org/10.1007/s00190-008-0266-1.

Hofmann-Wellenhof, B., Lichtenegger, H., & Wasle, E. (2008). GNSS - Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more. Springer-Verlag. DOI: https://doi.org/10.1007/978-3-211-73017-1.

Jamjareegulgarn, P., Supnithi, P., Kenpankho, P., Wichaipanich, N., & Nayak, C. (2020). Improving the modeling of bottomside thickness parameters over midlatitudes and high latitudes. Advances in Space Research, 65(3), pp. 909-932. doi: https://doi.org/10.1016/j.asr.2019.10.026.

Karaim, M., Elsheikh, M., & Noureldin, A. (2018). GNSS error sources. In R. B. Rustamov (Ed.), Multifunctional operation and application of GPS (pp. 79-96). IntechOpen. DOI: https://doi.org/10.5772/intechopen.75493.

Kenpankho, P. (2014). Study of total electron content from GPS frequency band satellite at the equatorial magnetic latitude station, Chumphon, Thailand [Doctoral dissertation, King Mongkut's Institute of Technology Ladkrabang].

Kenpankho, P., Chaichana, A., Trachu, K., Supnithi, P., & Hozumi, K. (2021). Real-time GPS receiver bias estimation. Advances in Space Research, 68(5), pp. 2152-2159. doi: https://doi.org/10.1016/j.asr.2021.01.032.

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), pp. 4245-4259. doi: https://doi.org/10.1016/j.asr.2024.08.019.

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75, 4245-4259. DOI: https://doi.org/10.1016/j.asr.2024.08.012.

Leick, A., Rapoport, L., & Tatarnikov, D. (2015). GPS Satellite Surveying (4th ed.). John Wiley & Sons. DOI: https://doi.org/10.1002/9781119066323.

Míguez, J., Perello Gisbert, J. V., Garcia-Molina, J. A., Zoccarato, P., Crosta, P., Ries, L., Pérez, R. O., Seco-Granados, G., & Crisci, M. (2017). Multi-GNSS dynamic high precision positioning in urban environment. In Proceedings of the 30th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2017) (pp. 408-413). DOI: https://doi.org/10.33012/2017.15197.

Misra, P., & Enge, P. (2011). Global Positioning System: Signals, Measurements, and Performance (2nd ed.). Ganga-Jamuna Press.

Nguyen, C. T., Oluwadare, S. T., Le, N. T., Alizadeh, M., Wickert, J., & Schuh, H. (2022). Spatial and temporal distributions of ionospheric irregularities derived from regional and global ROTI maps. Remote Sensing, 14(1), 10. DOI: https://doi.org/10.3390/rs14010010.

Ochałek, A., Niewiem, W., Puniach, E., & Ćwiąkała, P. (2018). Accuracy evaluation of real-time GNSS precision positioning with RTX Trimble technology. Civil and Environmental Engineering Reports, 28(4), 49-61. DOI: https://doi.org/10.2478/ceer-2018-0050.

Özbey, V., Mutlu, B., Erol, S., Selbesoğlu, M. O., Yavasoğlu, H. H., & Alkan, R. M. (2025). Performance analysis of multi-GNSS PPP for accurate ship-borne positioning in Antarctic region. International Journal of Engineering and Geosciences, 10(3), 428-439. DOI: https://doi.org/10.26833/ijeg.1574964.

Pansong, C., & Kenpankho, P. (2025). GPS TEC anomalies and earthquake events in Thailand. Earth Sciences Research Journal, 29(3), pp. 297-312. doi: https://doi.org/10.15446/esrj.v29n3.117195.

Pansong, C., Wongsak, P., Ruttanaburee, S., Pornsopin, P., & Kenpankho, P. (2025). Low latitude TEC disturbances during extreme geomagnetic storms. Advances in Space Research, 76(12), pp. 7521-7532. doi: https://doi.org/10.1016/j.asr.2025.03.071.

Rizos, C., Grejner-Brzezinska, D. A., Feng, Y., Wang, C., & Toth, C. K. (2012). CORS Networks: The Global Infrastructure for Precision Positioning. In G. Xu (Ed.), Sciences of Geodesy - II. Springer. https://doi.org/10.1007/978-3-642-28000-9_11.

Seeber, G. (2003). Satellite Geodesy: Foundations, Methods, and Applications (2nd ed.). Walter de Gruyter. https://doi.org/10.1515/9783110200089.

Su, K., Jin, S., & Hoque, M. M. (2019). Evaluation of ionospheric delay effects on multi-GNSS positioning performance. Remote Sensing, 11(2), 171. DOI: https://doi.org/10.3390/rs11020171.

Sukhenko, A., Meirambekuly, N., Syzdykov, A., Mukhamedgali, A., & Mellatova, Y. (2025). GNSS for high-precision and reliable positioning: A review of correction techniques and system architectures. Applied Sciences, 15(22), 12304. DOI: https://doi.org/10.3390/app152212304.

Sumniang, P., Sittichai, W., & Kenpankho, P. (2025). Ionospheric delay and low-cost robots. Advances in Space Research, 75(5), pp. 4386-4393. doi: https://doi.org/10.1016/j.asr.2024.12.011.

Teunissen, P. J., & Montenbruck, O. (Eds.). (2017). Springer Handbook of Global Navigation Satellite Systems. Springer International Publishing. DOI: https://doi.org/10.1007/978-3-319-42928-1.

Teunissen, P. J., & Montenbruck, O. (Eds.). (2017). Springer Handbook of Global Navigation Satellite Systems. Springer International Publishing. https://doi.org/10.1007/978-3-319-42928-1.

Uçarlı, A. C., Demir, F., Erol, S., & Alkan, R. M. (2021). Farklı GNSS uydu sistemlerinin hassas nokta konumlama (PPP) tekniğinin performansına etkisinin incelenmesi. Geomatik, 6(3), 247-258. DOI: https://doi.org/10.29128/geomatik.779420.

Van Sickle, J. (2015). GPS for Land Surveyors (4th ed.). CRC Press. https://doi.org/10.1201/b18366.

Yasyukevich, Y. V., Zhang, B., & Devanaboyina, V. R. (2024). Advances in GNSS positioning and GNSS remote sensing. Sensors, 24(4), 1200. DOI: https://doi.org/10.3390/s24041200.

Yiğit, C. Ö., Kızılarslan, M., & Çalışkan, E. (2016). GPS-PPP ve GPS/GLONASS-PPP yöntemlerinin konum belirleme performanslarının ölçü süresine bağlı olarak değerlendirilmesi. Harita Teknolojileri Elektronik Dergisi, 8(1), (22-39. DOI: https://doi.org/10.15659/hartek.16.03.289.

Zhao, X., Li, G., Xie, H., Hu, L., Sun, W., Li, Y., Dai, G., Liu, J., Li, Y., Ning, B., Nishioka, M., Perwitasari, S., & Kenpankho, P. (2025). Regional equatorial plasma bubble prediction. Space Weather, 23(2). doi: https://doi.org/10.1029/2024SW004224.

PARTICULATE MATTER BY USING GLONASS SATELLITE

Pattawut Wongsak*, Jedsada Puang-im, and Prasert Kenpankho

67036098@kmitl.ac.th, 68036015@kmitl.ac.th, and prasert.ke@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 67036098@kmitl.ac.th

ABSTRACT

This study investigates the estimation of total atmospheric particulate matter using observations from the GLONASS satellite system through the analysis of GNSS signal delays in the ionosphere and troposphere. The dataset was collected over a one-month period at the satellite receiving station of King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand. Slant Total Electron Content (STEC) was computed and converted to Vertical Total Electron Content (VTEC) using an appropriate mapping function. In the tropospheric analysis, signal delay was separated into Zenith Hydrostatic Delay (ZHD) and Zenith Wet Delay (ZWD) based on standard atmospheric models. These components were combined to obtain the Zenith Tropospheric Delay (ZTD = ZHD + ZWD), which represents the physical variability of the lower atmosphere. The derived atmospheric delay parameters were used as proxy variables to estimate total particulate matter (TPM) and were compared with ground-based PM2.5 measurements. The results show that during hours 5–19, GLONASS-derived TPM values range between approximately 100–140 AQI, while ground-based PM2.5 measurements range between 60–80 AQI. During nighttime periods (hours 1–4 and 20–24), GLONASS-TPM values decrease to below 60 AQI, whereas sensor PM2.5 values remain above 60 AQI. After bias correction, the two datasets show improved agreement, with GLONASS-TPM values ranging from 75–145 AQI and PM2.5 measurements ranging from 70–140 AQI. The comparison indicates that GLONASS-derived parameters capture the overall temporal variation of atmospheric particulate conditions. However, differences remain because GNSS-derived parameters represent vertically integrated atmospheric properties, whereas PM2.5 sensors measure particulate concentrations near the surface. These findings demonstrate the potential of GLONASS-based atmospheric sensing as a complementary and cost-effective approach for air quality monitoring in urban environments.

Keywords: GLONASS, GNSS, TEC, ZTD, ZHD, ZWD, PM2.5

1. Statement of the Problem

Airborne particulate matter (PM), particularly fine particles such as PM2.5, has become a critical environmental and public health issue worldwide. Long-term exposure to particulate matter significantly increases the risk of cardiovascular and respiratory diseases. Although conventional ground-based monitoring systems provide reliable and accurate measurements, their limited spatial distribution constrains comprehensive regional air quality assessment. In contrast, Global Navigation Satellite Systems (GNSS), including GLONASS, offer continuous atmospheric observations through signal propagation analysis. GNSS signals are affected by ionospheric and tropospheric conditions, enabling the retrieval of atmospheric parameters that can potentially be linked to particulate matter variability.

Previous research demonstrates that GNSS observations provide a comprehensive framework for investigating atmospheric processes, ionospheric Total Electron Content (TEC), tropospheric delay, and their potential application in environmental monitoring. Atmospheric studies have shown significant ionospheric variability, particularly at equatorial and low latitudes, under geomagnetic disturbances and extreme events (Kenpankho, 2014; Krypiak-Gregorczyk, 2019; Liu et al., 2020; Pansong et al., 2025), while tropospheric delay modeling has been enhanced through stochastic approaches and simplified zenith delay models for real-time applications (Hadas et al., 2017; Mao et al., 2021). The estimation of TEC from GNSS data has evolved from robust carrier-phase editing algorithms (Blewitt, 1990) to advanced geometry-free combinations, phase bias corrections, and multi-frequency multi-constellation precise point positioning (PPP) techniques (Krypiak-Gregorczyk & Wielgosz, 2018; Geng et al., 2019; An et al., 2020; Li et al., 2020; Liu et al., 2020; Zhang et al., 2020; Liu et al., 2021; Keokhumcheng & Kenpankho, 2025). The foundational relationship between ZWD and precipitable water vapor established GNSS meteorology as a reliable method for atmospheric parameter retrieval (Bevis et al., 1994), further supported by traceable time and frequency measurements via GNSS receivers (Bauch et al., 2021). Moreover, advancements in receiver technology, including calibrated low-cost dual-frequency systems and multi-constellation integration such as GLONASS (BCS Inside GNSS, 2015; Krietemeyer et al., 2022), together with cycle-slip correction and numerical modeling techniques (Li et al., 2019; Wang et al., 2019), enable high-precision atmospheric delay estimation. In parallel, studies on airborne particulate matter emphasize its atmospheric processes and measurement principles (Hester et al., 2016; Kremier et al., 2021; Kirešová & Guzan, 2022), supporting the emerging concept that GNSS-derived ionospheric and tropospheric parameters may serve as indirect indicators for estimating TPM in the atmosphere through integrated multi-GNSS processing and advanced modeling approaches.

This research adopts an integrated methodological framework focusing on ionospheric delay estimation and atmospheric water vapor retrieval using GNSS observations. Dual-frequency GLONASS pseudo range and carrier phase data are processed to compute Slant Total STEC, which is subsequently mapped to VTEC under the thin-shell ionospheric assumption. The estimation of TEC parameters follows approaches widely applied in low-latitude ionospheric studies, particularly those conducted in Thailand (Kenpankho, 2014; Keokhumcheng & Kenpankho, 2025; Pansong et al., 2025). Tropospheric delay is separated into ZHD and ZWD using standard atmospheric models based on surface meteorological parameters, and the combined Zenith Tropospheric Delay (ZTD) is used as a key atmospheric indicator. In addition, the ZWD component is converted into Precipitable Water (PW) following the approach proposed by Bevis et al. (1994), enabling the estimation of atmospheric water vapor content from GNSS-derived parameters. Finally, statistical correlation and regression analyses are conducted to investigate the relationships between VTEC, ZTD, ZWD, PW, and ground-based PM2.5 measurements collected during the same observation period.

This research develops and validates a model for estimating total atmospheric particulate matter using observations from the GLONASS satellite system. GNSS signal processing techniques are applied to derive TEC and analyze ionospheric delay parameters. These parameters are used to establish a quantitative relationship between GNSS-derived atmospheric delays and particulate matter concentrations. The estimated values are compared with measurements from ground-based monitoring stations to evaluate consistency and accuracy. The proposed approach extends GNSS meteorology toward environmental monitoring by integrating ionospheric delay estimation with air quality assessment. This methodology provides a systematic framework for

atmospheric particulate monitoring, particularly in regions where ground-based observation networks are limited.

2. Objectives

2.1 Apply GNSS signal processing techniques to derive TEC from GLONASS observations and compute ionospheric delay parameters.

2.2 Compute the estimated total particulate matter (TPM) obtained from GLONASS data.

3. Research Methodology

This section describes the data processing workflow and mathematical formulation used to estimate atmospheric parameters and TPM under the framework of Particulate Matter Using GLONASS based on GLONASS observations. The estimation of STEC from GLONASS satellite signals, following the approach proposed by Blewitt (1990), can be described as follows. Due to the dispersive nature of the ionosphere, the ionospheric delay is frequency dependent. By applying the geometry-free linear combination of dual-frequency carrier phase observations, the geometric distance and clock error terms can be eliminated, leaving only the ionospheric contribution.
The fundamental equation in Equation (1) is used for calculating STEC as

$$STEC = \frac{2(f_1^2 f_2^2)}{k(f_1^2 - f_2^2)}(L_1\lambda_1 - L_2\lambda_2) \quad (1)$$

For the GLONASS satellite system:

f_1 frequency is 1602 MHz,

f_2 frequency is 1248.6 MHz,

L_1 is carrier phase of G1,

L_5 is carrier phase of G2,

λ_1(G1 wavelength) is 0.1871 m,

λ_2(G2 wavelength) is 0.2401 m,

k is the ionospheric refractivity correction factor (80.62 m^2/s^2).

In this study, ionospheric delay estimation is performed using dual-frequency carrier phase observations from GLONASS. Due to the dispersive nature of the ionosphere, the ionospheric delay is frequency-dependent and inversely proportional to the square of the signal frequency. The study of signal delay in Global Navigation Satellite System (GNSS) signals, the analysis can begin by considering the general propagation delay of electromagnetic signals as they travel through a medium (Davies et al., 1975). The signal delay caused by transmission through a medium can be expressed by the following Equation (2):

$$\Delta t = \int_s \left(\frac{1}{v_g} - \frac{1}{c}\right) ds \quad (2)$$

where:

Δt is the signal propagation delay of the satellite signal, expressed in seconds (s),

c is the speed of light in vacuum, equal to 299,792,458 meters per second (m/s),

v_g is the group delay of the signal as it propagates through the medium, expressed in seconds (s),

s is the geometric distance between the receiver and the transmitter, expressed in meters (m).

The refractive index of the signal can be studied based on the relationship between the speed of light and the group velocity of the signal, as well as the relationship among electron density, the communication frequency, and the refractive coefficient of the medium (Allnutt, 1989). The relationship can be expressed as the following Equation (3)-(4):

$$\mu'=\frac{c}{v_g} \tag{3}$$

$$\mu'=1+A\frac{n}{f^2} \tag{4}$$

where:

μ' is refractive index of the signal.

c is the speed of light in vacuum, equal to 299,792,458 meters per second (m/s).

v_g is the group delay of the signal as it propagates through the medium, expressed in seconds (s).

A is the refractive index of the medium.

where:

$A=\frac{e^2}{8\pi^2 m\varepsilon_0}$,

where:

e^2 is the charge of an electron, equal to 1.6022×10^{-19}coulombs (C),

m is the mass of an electron, equal to 9.109×10^{-31}kilograms (kg),

ε_0 is the permittivity of free space, which is 8.8542×10^{-12}farads per meter (F/m).

The signal propagation delay of the GLONASS satellites can be determined when the communication frequencies used by the GLONASS system are known. These frequencies and corresponding signal parameters are defined as follows in Equation (5):

$$\Delta t = \frac{A}{cf^2}TEC \tag{5}$$

$$\Delta t = \frac{80.62}{299,792,458f^2}TEC$$

$$\Delta t = \frac{80.62}{299,792,458f^2}TEC$$

$$\Delta t = \frac{2.68919\times10^{-7}}{f^2}TEC$$

$$\frac{1}{f^2} = \frac{1602MHz^2 - 1248.6MHz^2}{1602MHz^2 \times 1248.6MHz^2} = \frac{0.1007\times10^{18}}{4.001\times10^{24}} = 2.5168\times10^{-7}$$

$$f^2 = \frac{1}{2.5168 \times 10^{-7}} = 4,511,006.856$$

$$\Delta t = \frac{80.62}{cf^2} TEC$$

$$\Delta t = \frac{2.68919 \times 10^{-7}}{4,511006.856}$$

$$\Delta t = 5.9614 \times 10^{-26} GLOTEC$$

Therefore, the vertical total delay represents the total signal delay in the zenith direction, which is considered as the propagation error introduced by the atmosphere. This total delay is approximated as the tropospheric delay component as Equation (6):

$$ZTD = ZHD + ZWD \tag{6}$$

The estimation of Total Particulate Matter Content (TPMC) in the atmosphere is based on the approximation that the total vertical delay is equivalent to the tropospheric delay. The ZTD, which consists of the ZHD caused by the dry component of the atmosphere and ZWD caused by atmospheric water vapor, can therefore be separated to quantify the physical properties of the troposphere. This separation enables atmospheric delay parameters to be applied in the estimation of TPM within the troposphere. Furthermore, the obtained delay values can be used to calculate total atmospheric precipitable water vapor according to the relationship proposed by Bevis et al. (1994) as in Equation (7).

$$ZWD = \frac{TPWV}{\Pi} \tag{7}$$

where:

$TPWV$ represents the total precipitable water vapor in the atmosphere, typically expressed in millimeters (mm).

Π represents coefficient used for estimating total precipitable water vapor can be approximated using the following Equation (8):

$$\Pi = \frac{10^6}{P_w \times R_v + \left(\frac{k_3}{T_m} + k_2' \right)} \tag{8}$$

where:

P_w is density of liquid water (999.97 kg/m³),

R_v is specific gas constant for water vapor (461.525 J/kg·K),

k_2' is refractivity constant for the troposphere (22.1 K/mbar),

k_3 is refractivity constant for the troposphere (3,739 K²/mbar),

T_m is refractivity constant for the troposphere (3,739 K²/mbar).

Based on the analysis of the atmospheric delay caused by moisture in the troposphere and the use of total precipitable water vapor values, the TPM in the atmosphere can be estimated by applying the following from Equation (7) to Equation (9).

$$\frac{TPWV}{\Pi} = ZTD - ZHD \tag{9}$$

When the zenith delay caused by the dry hydrostatic component of the atmosphere is reformulated through an appropriate coefficient transformation for estimation purposes, it can be approximated as being proportional to the TPM in the atmosphere. Consequently, the following Equation (10) can be derived.

$$\frac{TPWV}{\Pi} = ZTD - TPMC \tag{10}$$

Therefore, the vertical TPM content in the atmosphere is expressed as:

$$TPMC = ZTD - \frac{TPWV}{\Pi}$$

Therefore, Δt represents the total signal delay in the zenith direction, which is considered as the atmospheric propagation error. This total delay is approximated as the tropospheric delay component (ZTD): using $\Delta t = ZTD$, then, $\Delta t = 2.9785 \times 10^{-26} GLOTEC$ as shown the equation for the TPMC.

$$TPMC = 2.9785 \times 10^{-26} GLOTEC - \frac{TPWV}{\Pi}$$

From the above equation, TPMC can be estimated from the atmospheric delay parameters by subtracting the wet delay component from the total atmospheric delay. This approach utilizes the tropospheric delay derived from GNSS observations to approximate the TPM present in the atmosphere.

3.1 Data Collection

The data used in this study were collected at the GNSS receiving station located at King Mongkut's Institute of Technology Ladkrabang (KMITL) in Bangkok, Thailand. The observation data were obtained over a one-month period, from 1 February 2026 to 28 February 2026. During this period, GNSS signals received at the station were continuously recorded and processed to obtain atmospheric parameters related to signal propagation, which were subsequently used for further analysis of atmospheric conditions affecting the GNSS signals.

3.2 Data Analysis

The collected GNSS observation data were processed to derive atmospheric parameters related to signal propagation through the ionosphere and troposphere. The analysis focused on estimating Total Electron Content (TEC) and atmospheric signal delays derived from GNSS observations using established mathematical models commonly applied in GNSS atmospheric studies. The derived TEC values were analyzed to examine their temporal variability during the observation

period. To evaluate atmospheric conditions associated with particulate matter occurrence, the median value of TEC was used as the primary statistical measure. TEC values were analyzed on hourly and daily timescales and subsequently aggregated to represent monthly variations. In addition, the calculated atmospheric parameters were compared with PM2. measurements to investigate potential relationships between GNSS-derived atmospheric conditions and variations in particulate matter concentration in the lower atmosphere. The use of the median TEC helps reduce the influence of extreme values and provides a more reliable representation of TEC variability.

5. Results

This section presents the results obtained from the analysis of GNSS-derived atmospheric parameters and their comparison with ground-based PM2.5 measurements. The results are illustrated through graphical comparisons to examine the temporal variability of particulate matter during the observation period. The analysis is performed at hourly, daily, and monthly timescales to investigate the relationship between GNSS-derived atmospheric parameters and PM2.5 variability.

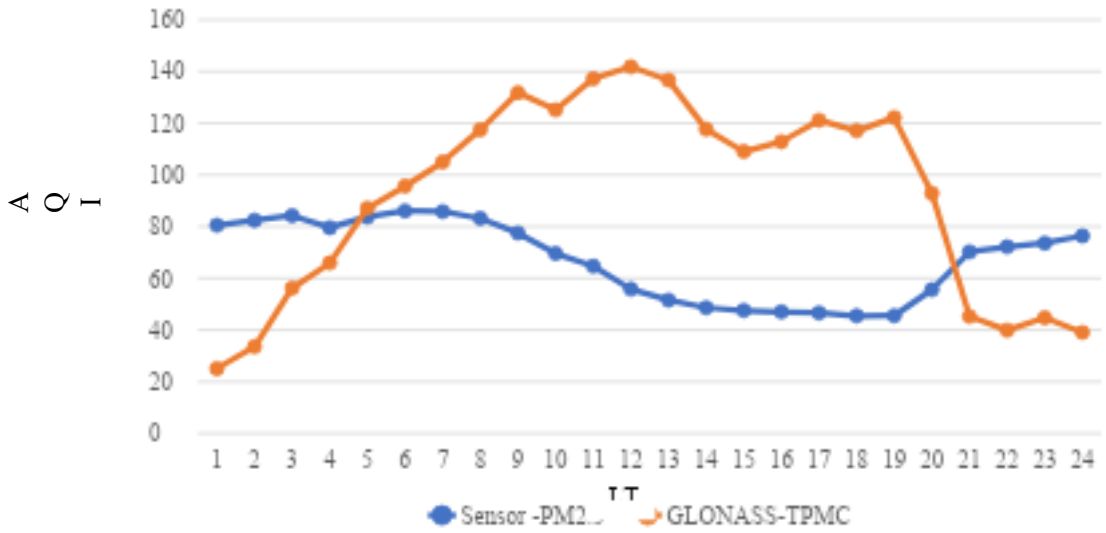

Figure 1 Sensor PM2.5 and GLONASS-TPMC

Figure 1 presents the hourly average values of TPM obtained over 24 hours per day during the 28-day observation period. The results show that during hours 1–4 and hours 20–24, the TPM values derived from GLONASS TPMC are generally below 60 AQI, whereas the particulate matter values obtained from the ground-based sensor are typically above 60 AQI. In contrast, during hours 5–19, the GLONASS-derived TPMC values increase significantly and range between approximately 100–140 AQI, while the particulate matter values measured by the sensor range between 60–80 AQI. These results indicate that the GNSS-derived parameter exhibits temporal variations that differ from the particulate measurements obtained from the ground-based sensor.

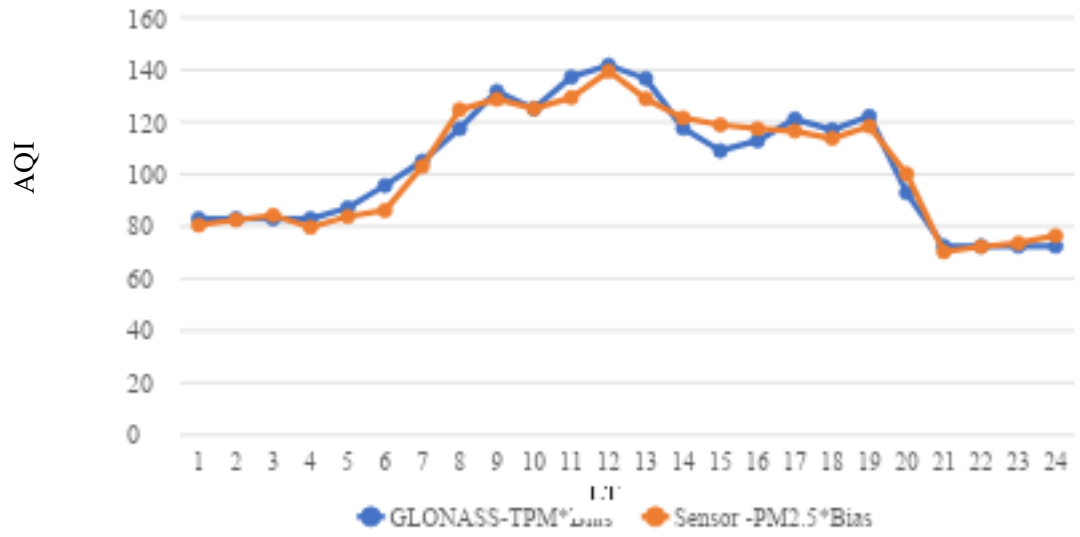

Figure 2 Sensor PM2.5 and GLONASS-TPMC after bias correction

Figure 2 shows bias correction method. To improve the comparability between GLONASS-derived Total Particulate Matter Content (GLONASS-TPMC) and the ground-based PM2.5 sensor measurements, a bias correction method was applied. The observation period was divided into two intervals: nighttime and daytime. The nighttime period was defined as 20:00 and 05:00. During this period, the average values of Sensor PM2.5 and GLONASS-TPMC were calculated. The difference between these averages was used as the bias value and subtracted from the Sensor PM2.5 measurements. For the daytime period (hours 06:00–19:00), the same procedure was applied. The average values of Sensor PM2.5 and GLONASS-TPMC were calculated, and the resulting difference between the two averages was used as the bias value. In this case, the bias value was subtracted from the GLONASS-TPMC data. This correction reduces the systematic difference between the two datasets and improves the comparability between satellite-derived atmospheric parameters and ground-based particulate measurements.

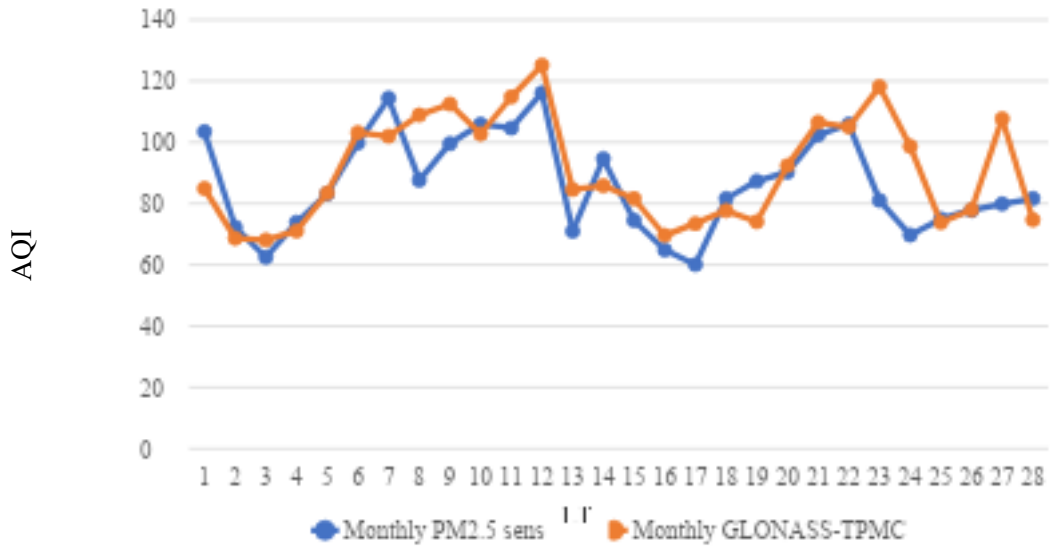

Figure 3 Daily PM2.5 sensor and daily GLONASS-TPMC

Figure 3 illustrates the daily variation of particulate matter during the 28-day observation period. The GLONASS TPMC values range from approximately 60 AQI to 125 AQI, while the PM2.5 values measured by the sensor range from approximately 65 AQI to 120 AQI. During the early observation period (approximately days 1–7), the particulate matter values show a gradual increase. The highest values are observed during the middle of the observation period (approximately days 8–15), where both datasets reach values between 110–125 AQI. After this period, the particulate values decrease during days 16–20 and increase again around days 21–23, followed by fluctuations between 70–110 AQI toward the end of the observation period. These results indicate that both datasets exhibit similar temporal patterns during several observation intervals.

The analysis results derived from GNSS observations and ground-based sensor measurements reveal the temporal variability of atmospheric particulate matter during the observation period. The hourly analysis shows that during hours 1–4 and 20–24, the GLONASS-derived TPMC values remain below 60 AQI, while the PM2.5 measurements obtained from the ground-based sensor are generally above 60 AQI. In contrast, during hours 5–19, the GLONASS TPMC values increase significantly and range between 100–140 AQI, whereas the sensor measurements range between 60–80 AQI. After applying bias correction, the temporal patterns between the two datasets become more consistent, with GLONASS TPMC values ranging from approximately 75–145 AQI and sensor measurements ranging from 70–140 AQI. In the daily analysis over the 28-day observation period, the GLONASS TPMC values vary between 60–125 AQI, while the sensor PM2.5 measurements range between 65–120 AQI. Both datasets show increasing particulate levels during the early and middle observation periods before decreasing toward the later intervals. Overall, the results indicate that GNSS-derived atmospheric parameters capture the general temporal behavior of particulate matter variability during the study period.

6. Conclusion and Discussion

This study investigated the relationship between GNSS-derived atmospheric parameters and ground-based PM2.5 measurements using GLONASS observations collected at the GNSS station of King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand. The methodological framework integrates ionospheric delay estimation and tropospheric delay analysis to derive key atmospheric parameters including VTEC, ZTD, ZWD, and PW. The results indicate that GNSS observations capture temporal atmospheric variations associated with particulate matter conditions. Comparisons between GNSS-derived parameters and PM2.5 measurements reveal similar temporal patterns during several observation intervals, particularly after bias correction. These findings suggest that GNSS atmospheric observations can serve as a complementary tool for studying atmospheric particulate variability and improving air quality monitoring, especially in low-latitude regions.

The comparison between GNSS-derived atmospheric parameters and ground-based PM2.5 measurements shows partial agreement in their temporal variations during the observation period. The GLONASS-derived parameters, including VTEC, ZTD, ZWD, and PW, represent integrated atmospheric conditions along the GNSS signal propagation path. The estimation of TEC parameters follows approaches widely applied in low-latitude ionospheric studies (Kenpankho, 2014; Keokhumcheng & Kenpankho, 2025; Pansong et al., 2025), while the conversion of ZWD to atmospheric water vapor content follows the methodology proposed by Bevis et al. (1994).The graphical comparison indicates that GNSS-derived parameters exhibit similar temporal trends to PM2.5 observations during several intervals, particularly after bias correction. However, differences remain because GNSS parameters represent vertically integrated atmospheric properties, whereas PM2.5 sensors measure particulate concentrations near the surface. Similar characteristics have been reported in previous GNSS atmospheric studies, where GNSS-derived parameters reflect large-scale atmospheric variability rather than localized surface conditions (Bevis et al., 1994; Kenpankho, 2014). Despite these differences, the statistical results suggest that GNSS atmospheric parameters can provide useful complementary information for monitoring atmospheric particulate conditions.

7. Acknowledgements

The authors would like to express their sincere gratitude to the Space, Satellite, and Study Laboratory (SSS Lab), Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand, for their continuous academic support and provision of research facilities. The laboratory's technical resources, research environment, and expert guidance have significantly contributed to the successful completion of this study. The authors also appreciate the institutional support and encouragement provided by the faculty members and staff of the Department of Engineering Education.

8. References

An, X., Meng, X., & Jiang, W. (2020). Multi-constellation GNSS precise point positioning with multi-frequency raw observations and dual-frequency observations of ionospheric-free linear combination. Satellite Navigation, 1, Article 7. https://doi.org/10.1186/s43020-020-00007-0.

Bauch, A., Piester, D., & Polewka, T. (2021). Correction to: On the possibility of getting traceable time and frequency measurements via GNSS receivers. GPS Solutions, 25, Article 114. https://doi.org/10.1007/s10291-021-01101-7.

BCS Inside GNSS. (2015). ComNav M300 Pro GNSS reference station receiver. Inside GNSS. https://insidegnss.com/comnav-wins-gnss-receivers-tender-in-china-national-cors-project.

Bevis, M., Businger, S., Herring, T. A., Rocken, C., Anthes, R. A., & Ware, R. H. (1994). GPS meteorology: Mapping zenith wet delays onto precipitable water. Journal of Applied Meteorology, 33(3), 379–386. https://doi.org/10.1175/1520-0450(1994)033.

Blewitt, G. (1990). An automatic editing algorithm for GPS data. Geophysical Research Letters, 17(3), 199–202. https://doi.org/10.1029/GL017i003p00199.

Geng, J., Guo, J., Chang, H., Li, X., Zhao, Q., & Liu, J. (2019). Toward global instantaneous decimeter-level positioning using tightly coupled multi-constellation and multi-f requency GNSS. Journal of Geodesy, 93, 977–991. https://doi.org/10.1007/s00190-018-1222-2.

Hadas, T., Teferle, F. N., Kazmierski, K., Hordyniec, P., Paziewski, J., & Bosy, J. (2017). Optimum stochastic modeling for GNSS tropospheric delay estimation in real-time. GPS Solutions, 21, 1069–1081. https://doi.org/10.1007/s10291-016-0596-5.

Hester, R. E., Harrison, R. M., & Querol, X. (Eds.). (2016). Airborne particulate matter: Sources, atmospheric processes and health (Issues in Environmental Science and Technology, Vol. 42). Royal Society of Chemistry. https://doi.org/10.1039/9781782626589.

Kenpankho, P. (2014). Study of total electron content from GPS satellite at the equatorial magnetic latitude station, Chumphon, Thailand (Doctoral dissertation). King Mongkut's Institute of Technology Ladkrabang.

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), 4245–4259. https://doi.org/10.1016/j.asr.2024.08.019.

Kirešová, S., & Guzan, M. (2022). Measurement of particulate matter: Principles and options of measurement at present. Acta Electrotechnica et Informatica, 22(2), 8–18. https://doi.org/10.2478/aei-2022-0007.

Kremier, M., et al. (2021, October). Report on air quality in Slovak Republic in 2020. Slovak Hydrometeorological Institute.https://www.shmu.sk/File/oko/rocenky/2020_Sprava_o_KO_v_SR_v2.pdf.

Krietemeyer, A., van der Marel, H., van de Giesen, N., & ten Veldhuis, M.-C. (2022). A field calibration solution to achieve high-grade-level performance for low-cost dual-frequency GNSS receiver and antennas. Sensors, 22(6), Article 2109. https://doi.org/10.3390/s22062109.

Krypiak-Gregorczyk, A. (2019). Ionosphere responses to three extreme events occurring near spring equinox in 2012, 2013 and 2015, observed by regional GNSS-TEC model. Journal of Geodesy, 93, 931–951. https://doi.org/10.1007/s00190-018-1221-3.

Krypiak-Gregorczyk, A., & Wielgosz, P. (2018). Carrier phase bias estimation of geometry-free linear combination of GNSS signals for ionospheric TEC modeling. GPS Solutions, 22, Article 45. https://doi.org/10.1007/s10291-018-0721-3.

Li, B., Qin, Y., & Liu, T. (2019). Geometry-based cycle slip and data gap repair for multi-GNSS and multi-frequency observations. Journal of Geodesy, 93, 399–417. https://doi.org/10.1007/s00190-018-1176-4.

Li, M., Yuan, Y., & Zhang, X. (2020). A multi-frequency and multi-GNSS method for the retrieval of the ionospheric TEC and intraday variability of receiver DCBs. Journal of Geodesy, 94, Article 102. https://doi.org/10.1007/s00190-020-01426-0.

Liu, J. Y., Lin, C. Y., & Chen, Y. I. (2020). The source detection of 28 September 2018 Sulawesi tsunami by using ionospheric GNSS total electron content disturbance. Geoscience Letters, 7, Article 11. https://doi.org/10.1186/s40562-020-00165-8.

Liu, T., Chen, H., & Chen, Q. (2021). Characteristics of phase bias from CNES and its application in multi-frequency and multi-GNSS precise point positioning with ambiguity resolution. GPS Solutions, 25, Article 58. https://doi.org/10.1007/s10291-021-01064-9.

Liu, T., Zhang, B., Yuan, Y., & Li, M. (2020). On the application of the raw-observation-based PPP to global ionosphere VTEC modeling: An advantage demonstration in the multi-frequency and multi-GNSS context. Journal of Geodesy, 94, Article 37. https://doi.org/10.1007/s00190-020-01369-6.

Mao, J., Wang, Q., Liang, Y., Zhang, B., & Yuan, Y. (2021). A new simplified zenith tropospheric delay model for real-time GNSS applications. GPS Solutions, 25, Article 43. https://doi.org/10.1007/s10291-020-01058-w.

Pansong, C., Wongsak, P., Ruttanaburee, S., Pornsopin, P., & Kenpankho, P. (2025). Low latitude TEC disturbances during extreme geomagnetic storms. Advances in Space Research, 76(12), 7521–7532. https://doi.org/10.1016/j.asr.2025.03.071.

Sumniang, P., Sittichai, W., & Kenpankho, P. (2025). Ionospheric delay and low-cost robots. Advances in Space Research, 75(5), 4386–4393. https://doi.org/10.1016/j.asr.2024.12.011.

Wang, H., Gu, Y., & Yu, Y. (2019). Numerical solution of fractional-order time-varying delayed differential systems using Lagrange interpolation. Nonlinear Dynamics, 95, 809–822. https://doi.org/10.1007/s11071-018-4602-0.

Zhang, B., Hou, P., & Liu, T. (2020). A single-receiver geometry-free approach to stochastic modeling of multi-frequency GNSS observables. Journal of Geodesy, 94, Article 37. https://doi.org/10.1007/s00190-020-01368-7.

ASSESSMENT OF IONOSPHERIC TEC USING A LOW-COST NEO-6M SINGLE-FREQUENCY GPS TEC MEASUREMENT

Thanapon Keokhumcheng[1]*, Pharinya Phothila[2], Samatchaya Maichuen[2]
Patiphan Sumniang[2], and Prasert Kenpankho[2]

kthanaponok@gmail.com*, 66036080@kmitl.ac.th, 67036099@kmitl.ac.th,
65036065@kmitl.ac.th, and prasert.ke@kmitl.ac.th

[1]Department of Electronics, Nongbualumphu Technical College,
Institute of Vocational Education Northeastern Region 1. Nongbualumphu 39000 Thailand
[2]Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: kthanaponok@gmail.com

ABSTRACT

This study investigates the capability of the low-cost GPS NEO-6M single-frequency module in measuring ionospheric Total Electron Content (TEC). TEC data were collected at the GNSS monitoring station in Nongbualumphu Province, Thailand, during October-December 2025 at hourly intervals (00:00-23:00). Measurements from NEO-6M were compared with three references: ionospheric TEC (iTEC), the International Reference Ionosphere (IRI) model, and the BG2s multi-frequency GPS receiver. Results show that NEO-6M provides TEC values consistent with iTEC, IRI, and BG2s, with strong positive correlations across all datasets ($r > 0.94$). The instrument evaluation also showed high reliability, with an average score of 4.58 (SD = 0.57), which is classified as 'very good'. These findings confirm the reliability of the NEO-6M for scientific applications, highlighting its cost-effectiveness and accessibility. The study suggests that single-frequency GPS modules can serve as practical alternatives for TEC monitoring in resource-limited regions.

Keywords: Ionosphere, TEC, Low-cost NEO-6M, Single-frequency, GPS

1. Statement of the Problem

The ionosphere plays a critical role in the propagation of Global Navigation Satellite System (GNSS) signals, and the TEC is one of the most important parameters for quantifying ionospheric delay. Accurate TEC measurement is essential for improving GNSS positioning, navigation, and timing applications. However, high-precision multi-frequency receivers are expensive and not always accessible in resource-limited regions. This limitation motivates the exploration of low-cost alternatives. The GPS NEO-6M module, a single-frequency receiver, offers an affordable solution for TEC monitoring. Investigating its performance can provide valuable insights into whether such low-cost devices can be effectively used for scientific research and practical applications.

Early foundational works established the basis for ionospheric TEC studies. Blewitt (1990, pp. 199-202) introduced an automatic editing algorithm for GPS data in 1990, which became a cornerstone for reliable GNSS data processing. Building on this, Ma and Maruyama (2003, pp. 2083-2093) derived TEC and estimated instrumental biases from GEONET in Japan, while Kenpankho et al. (2011, pp. 365-370) compared GPS TEC measurements with IRI predictions at

the equatorial latitude station in Chumphon, Thailand, highlighting discrepancies between empirical data and model outputs. Wang et al. (2016, pp. 1555-1569) later improved the Klobuchar model for single-frequency ionospheric delay corrections. Subsequent research focused on refining GPS receiver performance and bias estimation. Kenpankho et al. (2021, pp.2152-2159) proposed real-time GPS receiver bias estimation, while Mitrović et al. (2022, pp. 11-16) compared the performance of different GPS receivers in practical applications. Ashrafuzzaman et al. (2021, pp. 1-6) developed a low-cost smart stick for visually impaired people (2021), demonstrating the broader applicability of affordable GNSS technologies. More recent works emphasized regional ionospheric phenomena and low-cost applications. Nambut and Kenpankho (2024, pp. 1-7) analyzed water vapor from GNSS observations over Bangkok and Chumphon, while Pansong et al. (2024, pp. 8-15) investigated auroral electrojet signatures associated with earthquakes at low latitudes. Keokhumcheng and Kenpankho (2024, pp. 16-23) studied GPS delay times during geomagnetic days, and Sumniang and Kenpankho (2024, pp. 24-32) developed a low-cost robotic platform for GPS investigations under quiet and disturbed conditions. Huang and Kenpankho (2024, pp. 33-40) extended this approach using BeiDou satellites. These DRLE 2024 conference papers collectively demonstrated the integration of GNSS with innovative low-cost platforms. The most recent contributions (2025) advanced TEC monitoring and prediction. Keokhumcheng and Kenpankho (2025, pp. 4245-4259) studied TEC using single-frequency GPS receivers, while Phothila et al. (2025, pp. 1-6) evaluated the performance of such devices, confirming their feasibility. Maichuen et al. (2025, pp. 1-6) investigated TEC over Thailand using BeiDou satellites, and Buakao et al. (2025, pp. 1-6) examined the rate of TEC index variations. Pansong et al. (2025, pp. 7521-7532) analyzed low-latitude TEC disturbances during extreme geomagnetic storms, and Pansong and Kenpankho (2025, pp. 297-312) explored GPS TEC anomalies linked to earthquake events in Thailand. Sumniang et al. (2025, pp. 4386-4393) investigated ionospheric delay effects on low-cost robots, while Zhao et al. (2025) developed regional equatorial plasma bubble prediction models. Dhanaselvam et al. (2025, pp. 1-7) proposed a geospatial alert framework for maritime borders using low-power communication, further illustrating GNSS versatility. Collectively, these studies demonstrate a clear progression from foundational GPS data processing to advanced TEC modeling, regional applications, and the integration of low-cost GNSS technologies for ionospheric research.

Among the reviewed literature, three studies are particularly relevant to this work. Keokhumcheng and Kenpankho (2025, pp. 4245-4259) investigated the study of total electron content on the ionosphere using single-frequency GPS receivers, demonstrating that low-cost devices can provide meaningful TEC measurements. Phothila et al. (2025, pp. 1-6) evaluated the performance of single-frequency GPS devices, confirming their feasibility and reliability under specific conditions. Maichuen et al. (2025, pp. 1-6) extended TEC studies over Thailand using BeiDou satellites, highlighting the applicability of affordable GNSS technologies in regional ionospheric research. Building on these works, this study focuses on the GPS NEO-6M module, aiming to validate its performance in TEC measurement and compare its results with iTEC, BG2s, and the IRI model.

This research is significant because it addresses the need for cost-effective ionospheric monitoring tools in regions where high-cost multi-frequency receivers are not feasible. By evaluating the GPS NEO-6M module, the study contributes to the development of affordable GNSS-based solutions for TEC measurement. The findings will not only validate the potential of single-frequency receivers but also provide practical insights for expanding ionospheric

monitoring networks in Thailand and similar regions. Ultimately, this work supports the broader effort to enhance GNSS accuracy and reliability through accessible and innovative approaches.

2. Objectives

The objectives of this study are:

2.1 To evaluate the reliability and performance of the NEO-6M single-frequency GPS receiver through expert assessment, ensuring its suitability for scientific applications in terms of hardware, software, usability, safety, and maintenance.

2.2 To compare and validate TEC measurements obtained from the NEO-6M receiver with established reference sources (iTEC, the IRI model, and the BG2s multi-frequency GPS receiver), to confirm consistency in diurnal and seasonal ionospheric variations.

2.3 To analyze the correlation and deviation of NEO-6M TEC data relative to reference systems under quiet geomagnetic conditions, thereby determining the accuracy, limitations, and potential of the NEO-6M as a cost-effective instrument for ionospheric monitoring.

3. Research methodology

This study employed both expert evaluation and comparative analysis to assess the performance of the GPS NEO-6M module for ionospheric TEC measurement. The methodology consisted of two main components: expert assessment of the instrument and comparative analysis of TEC data against established reference values. The NEO-6M is shown in Figure 1.

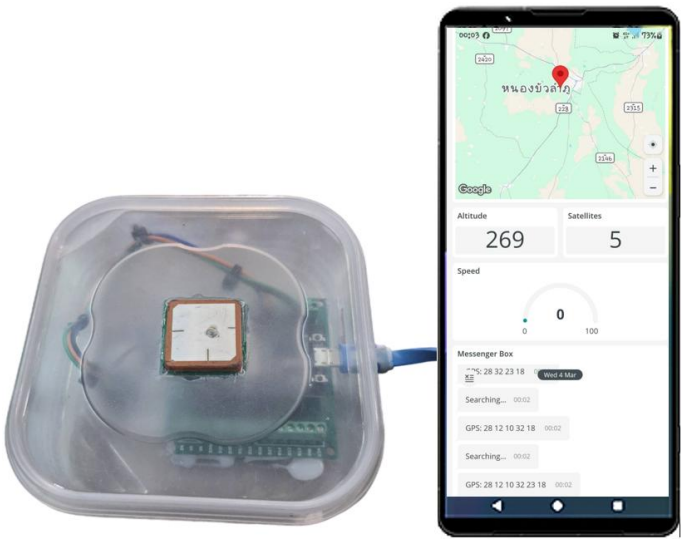

Figure 1 The NEO-6M single-frequency GPS TEC measurement

For the expert evaluation, a TEC measurement system was developed using the GPS NEO-6M single-frequency module. Five experts in GNSS and satellite communication were invited to assess the instrument through a structured 20-question survey. The evaluation was divided into five categories: hardware, software, usability, safety, and maintenance. The results indicated mean scores greater than 4.00 in all categories, corresponding to a “good” level of performance. This confirmed that the NEO-6M system is reliable and suitable for scientific applications.

For the comparative analysis, TEC data obtained from the NEO-6M module were collected at the GNSS monitoring station in Nongbualumphu Province, Thailand. Measurements were recorded at every hour intervals throughout the day (00:00-23:00) from October to December

2025. The NEO-6M data were compared with three reference sources: iTEC (a single-frequency GPS TEC monitoring system at the same station), the IRI model, and BG2s (a multi-frequency GPS receiver). The comparison focused on identifying trends, evaluating deviations, and calculating correlation coefficients between NEO-6M and each reference source.

The results demonstrated significant positive correlations between NEO-6M and iTEC, NEO-6M and IRI, and NEO-6M and BG2s. These findings confirm that the low-cost GPS NEO-6M module provides TEC measurements consistent with those of established systems and models under quiet geomagnetic conditions. Consequently, the NEO-6M receiver can be considered a practical alternative for TEC monitoring in regions with limited resources, while multi-frequency receivers remain essential for high-precision applications. The information about the research is as follows.

3.1 Ionosphere

The ionosphere is an ionized atmospheric layer that significantly affects GNSS signals through delays and disturbances. TEC measurements using GPS and BeiDou satellites are widely applied to study these effects, especially during geomagnetic storms and plasma bubble events, with implications for navigation accuracy (Kenpankho et al., 2011, pp. 365-370; Pansong et al., 2025, pp. 7521-7532; Sumniang et al., 2025, pp. 4386-4393).

3.2 TEC

The TEC quantifies the number of electrons along the satellite–receiver path and is a key factor influencing GNSS accuracy. In single-frequency GPS receivers, TEC variations cannot be corrected by dual-frequency methods, making ionospheric delay a major source of positioning error, particularly in equatorial regions (Keokhumcheng & Kenpankho, 2025, pp. 4245-4259; Phothila et al., 2025, pp. 1-6). The TEC equation is shown in Equation (1).

$$\text{GPS TEC} = \frac{\mathrm{I}_i \, cf_i^2}{\mathrm{A}} \tag{1}$$

whereas

I is the delay caused by the ionosphere,

i is each GPS satellite,

c is the vacuum, light speed,

f_i is the operating frequency of GPS,

A is the conductivity coefficient and mass of an electron (40.31).

3.3 Low-cost NEO-6M

For low-cost GPS single-frequency receivers, such as the NEO-6M module, these effects are especially significant. Unlike dual-frequency receivers, single-frequency devices cannot apply advanced correction techniques to mitigate ionospheric delay. As a result, TEC fluctuations have a stronger impact on their performance, particularly in equatorial regions where ionospheric disturbances are more intense. Despite these limitations, low-cost receivers remain valuable tools for monitoring TEC, conducting educational experiments, and enabling affordable ionospheric research, since they provide continuous data at minimal cost. The NEO-6M is shown in Figure 2.

Figure 2 NEO-6M module

3.4 Single-frequency

R544R555555555555555556Single-frequency GPS receivers operate using only one signal band, typically the L1 frequency. Unlike dual-frequency systems, they cannot apply advanced correction techniques to mitigate ionospheric delay, making them more susceptible to positioning errors in regions with strong ionospheric variability. Despite these limitations, single-frequency receivers remain valuable for low-cost monitoring and educational applications.

Recent studies have demonstrated their effectiveness in ionospheric research. Keokhumcheng and Kenpankho (2025, pp. 4245-4259) showed that single-frequency GPS receivers can be used to study ionospheric behavior, though they are more sensitive to delay errors compared to dual-frequency systems. Phothila et al. (2025, pp. 1-6) evaluated the performance of low-cost single-frequency GPS devices, confirming their potential for practical TEC monitoring despite inherent limitations. Additionally, Maichuen et al. (2025, pp. 1-6) extended this approach using BeiDou satellites, reinforcing the role of single-frequency receivers in equatorial ionospheric studies. The single frequency is shown in Equation (2).

$$f_{1GPS} = \sqrt{\frac{A \times TEC_{GPS}}{cI_n}} \quad (2)$$

whereas

f_{1GPS} : GPS satellites single frequency,
A : Scaling constant receiver bias the GPS signal measurements for TEC (40.31),
TEC_{GPS} : TEC value from each GPS satellite,
c : Vacuum light speed (2.998×10^8 m/s),
I_n : GPS Ionospheric delay time.

3.5 GPS

The Global Positioning System (GPS) is a satellite-based navigation system developed to provide precise positioning, navigation, and timing information anywhere on Earth. It operates through a constellation of satellites that transmit signals to receivers on the ground. By calculating the travel time of these signals, a GPS receiver can determine its location with high accuracy.

GPS receivers are generally categorized into dual-frequency and single-frequency devices. Single-frequency receivers (such as low-cost modules widely used in research and applications)

rely only on one band, typically L1. This makes them more affordable and accessible but also more vulnerable to ionospheric disturbances, which can introduce positioning errors.

Recent research has shown that single-frequency GPS receivers can still be effectively applied in scientific studies. For example, they have been used to monitor ionospheric behavior and evaluate performance under disturbed conditions, especially in equatorial regions where ionospheric variability is stronger (Keokhumcheng & Kenpankho, 2025, pp. 4245-4259; Phothila et al., 2025, pp. 1-6).

3.6 Research procedure

The research was designed to evaluate the performance of the low-cost GPS NEO-6M single-frequency receiver in measuring ionospheric TEC. The procedure combined two main components: expert evaluation of the developed instrument and comparative analysis of TEC data against established references. First, a TEC measurement system was constructed using the GPS NEO-6M module. The instrument was assessed to ensure its suitability for scientific applications. The evaluation focused on key aspects of hardware, software, usability, safety, and maintenance, with results indicating performance at a "good" level. Second, TEC data were collected from the NEO-6 M receiver installed at the GNSS monitoring station in Nongbualumphu Province, Thailand. Measurements were recorded at every hour intervals throughout the day (00:00-23:00) during October-December 2025 under quiet geomagnetic conditions. The collected data were then compared with three reference sources: iTEC (a single-frequency GPS TEC monitoring system), the IRI model, and the BG2s multi-frequency GPS receiver.

3.7 Instrument development and Expert evaluation

A TEC measurement system was developed using the GPS NEO-6M single-frequency module, selected for its low cost and accessibility. The system was designed to capture ionospheric TEC values and operate under quiet geomagnetic conditions. The development process focused on ensuring stable hardware integration, reliable software processing, and user-friendly operation suitable for scientific applications. To assess the instrument's performance, expert evaluation was conducted. Five specialists in GNSS and satellite communication were invited to review the system. The evaluation employed a structured framework consisting of 20 items, divided into five categories: hardware, software, usability, safety, and maintenance. Each item was rated using a five-point Likert scale to quantify performance. The results of the expert assessment indicated mean scores greater than 4.00 across all categories, corresponding to a "good" level of performance.

3.8 iTEC

The ionospheric Total Electron Content (iTEC) is a measure of the number of electrons along the path between a satellite and a ground receiver, and it is a critical parameter for understanding ionospheric effects on GNSS signals. Single-frequency GPS devices, while more cost-effective than dual-frequency systems, are particularly sensitive to ionospheric variability because they cannot apply dual-frequency corrections to mitigate delay errors.

Phothila et al. (2025) conducted a performance evaluation of single-frequency GPS devices for measuring iTEC and demonstrated that, despite their limitations, these devices can provide reliable data for monitoring ionospheric conditions. Their study highlights the potential of low-cost GPS receivers in practical applications and educational contexts, especially in equatorial regions where ionospheric disturbances are more pronounced. The iTEC is shown in Figure 3.

Figure 3 iTEC GPS satellite receiver

3.9 BG2s

The BG2s GNSS receiver is capable of tracking multi-frequency signals from GPS, BeiDou, GLONASS, and Galileo. The BG2s is shown in Figure 4.

Figure 4 The BG2s receiver

The BG2s has been employed in collaborative projects between the Institute of Geology and Geophysics, Chinese Academy of Sciences, the Earthquake Surveillance Division of the Thai Meteorological Department, and the Space, Satellite, and Study Laboratory (SSS Lab) at King Mongkut's Institute of Technology Ladkrabang (KMITL). It has been used to measure TEC variations over Thailand, supporting both scientific research and educational applications in equatorial ionospheric studies. In addition to TEC monitoring, BG2s contributes to long-term ionospheric modeling, space weather observation, GNSS signal quality assessment, and disaster-related studies, making it a versatile tool for both academic and applied geoscience research.

3.10 Data Collection

TEC data were collected from four sources: the GPS NEO-6M single-frequency module, ionospheric TEC (iTEC), the IRI model, and the BG2s multi-frequency GPS receiver. All instruments were installed at the GNSS monitoring station in Nongbualamphu Province, Thailand, ensuring that measurements were obtained under identical environmental and geomagnetic conditions. Data collection was conducted from October to December 2025. TEC values were recorded at every hour intervals throughout the day, spanning the time range from 00:00 to 23:00.

This schedule enabled systematic monitoring of diurnal variations in ionospheric TEC. The NEO-6M receiver provided continuous measurements, which were then synchronized with the outputs from iTEC, IRI, and BG2s to facilitate direct comparison. The collected dataset served as the foundation for subsequent comparative and correlation analyses, enabling the evaluation of the consistency and reliability of the NEO-6 M module against established TEC measurement systems and models.

3.11 Comparative Analysis

A comparative analysis was conducted to evaluate the consistency and reliability of TEC measurements obtained from the GPS NEO-6M module against established references. Three sources were selected for comparison: iTEC, the IRI model, and the BG2s multi-frequency GPS receiver. The iTEC system, operating as a single-frequency GPS TEC monitoring tool at the same station, provided a baseline for assessing whether the low-cost NEO-6M receiver could replicate conventional single-frequency measurements. The IRI model offered a theoretical benchmark, enabling comparison between observed TEC values and climatological predictions of ionospheric behavior. The BG2s receiver, with its multi-frequency capability, served as a high-precision reference to determine the extent to which NEO-6M approximated advanced GNSS systems. Data collected from all sources were synchronized to identical time intervals (00:00-23:00, every hour) during October-December 2025. Comparative evaluation focused on three aspects: (1) identifying similarities in diurnal and seasonal TEC trends, (2) assessing deviations under quiet geomagnetic conditions, and (3) calculating correlation coefficients between NEO-6M and each reference source. This approach enabled the study to determine whether the NEO-6M module, despite its single-frequency limitation and low cost, could provide TEC measurements consistent with both empirical models and high-precision receivers, thereby validating its potential for scientific applications in resource-limited environments.

3.12 Data Analysis

The data analysis focused on evaluating the consistency and reliability of TEC measurements obtained from the GPS NEO-6M module in comparison with established reference values. Statistical methods were employed to examine both the temporal trends and the quantitative relationships among datasets. First, diurnal and seasonal variations in TEC were analyzed to determine whether the NEO-6M receiver captured patterns similar to those observed in iTEC, the IRI model, and the BG2s multi-frequency receiver. This step ensured that the low-cost module could reflect realistic ionospheric behavior. Second, a correlation analysis was performed to quantify the degree of agreement between the NEO-6M and each reference source. Correlation coefficients were calculated for NEO-6M versus iTEC, NEO-6M versus IRI, and NEO-6M versus BG2s. Significant positive correlations were observed in all cases, indicating that the NEO-6M module produced TEC measurements consistent with both empirical models and high-precision receivers. Finally, deviations were assessed under quiet geomagnetic conditions to evaluate measurement accuracy. The results demonstrated that the NEO-6M receiver maintained acceptable levels of deviation, confirming its reliability for scientific applications. Overall, the analysis validated the potential of the NEO-6M module as a cost-effective alternative for TEC monitoring, particularly in regions with limited resources.

4. Result

The results of this study demonstrate the capability of the NEO-6M single-frequency GPS TEC to measure ionospheric TEC and its consistency with established references.

4.1 Expert Evaluation Results

In Table 1, the expert evaluation confirmed the reliability of the developed instrument. The assessment yielded mean scores greater than 4.00 across all categories, there are hardware, software, usability, safety, and maintenance, indicating that the NEO-6M system achieved a "good" level of performance and was suitable for scientific applications.

Table 1 NEO-6M instrument evaluation form: TEC measurement system, single-frequency GPS navigation system

No.	Assessment	$\bar{x}$	SD	Results
Hardware				
1	Is the physical design of the NEO-6M module durable for long-term use?	4.80	0.42	Very good
2	Does the receiver provide stable signal acquisition under normal conditions?	4.60	0.49	Very good
3	Is the hardware integration with peripheral components (antenna, power supply) reliable?	4.60	0.49	Very good
4	Does the system maintain consistent performance without frequent hardware failures?	4.40	0.56	good
Software				
5	Is the software interface intuitive and easy to operate?	4.60	0.49	Very good
6	Does the system process TEC data accurately and efficiently?	4.20	0.88	good
7	Are the software functions (data logging, synchronization) reliable?	4.20	0.88	good
8	Is the software compatible with standard GNSS data formats and analysis tools?	4.60	0.49	Very good
Usability				
9	Is the system easy to set up and configure for TEC measurement?	4.40	0.84	good
10	Does the user interface support clear visualization of TEC data?	4.80	0.42	Very good
11	Is the system convenient for field operation and data collection?	4.40	0.84	good
12	Does the system provide sufficient documentation or user guidance?	4.20	0.88	good
Safety				
13	Is the system safe to operate under standard laboratory and field conditions?	4.80	0.42	Very good

Table 1 (continued)

No.	Assessment	$\bar{x}$	SD	Results
14	Are electrical connections and power supply adequately protected?	4.60	0.49	Very good
15	Does the system comply with basic safety standards for electronic devices?	4.80	0.42	Very good
16	Is the risk of malfunction or hazard during operation minimal?	4.60	0.49	Very good
Maintenance				
17	Is the system easy to maintain and troubleshoot when issues arise?	4.80	0.42	Very good
18	Are spare parts or replacement components readily available?	4.60	0.49	Very good
19	Does the system require minimal maintenance for reliable operation?	4.80	0.42	Very good
20	Is technical support or guidance accessible for long-term use?	4.80	0.42	Very good
Total		4.58	0.57	Very good

The expert evaluation of the NEO-6M single-frequency GPS TEC for TEC measurement revealed consistently high performance across all categories. The overall mean score was 4.58 with a standard deviation of 0.57, corresponding to a "Very Good" level of performance. This indicates that the instrument is reliable and suitable for scientific applications.

Hardware received strong ratings, with mean scores ranging from 4.40 to 4.80. The physical durability, stable signal acquisition, and reliable integration with peripheral components were rated as "Very Good," while long-term consistency was slightly lower, rated as "Good". Software performance was generally positive, with scores ranging from 4.20 to 4.60. The interface and compatibility with GNSS formats were rated "Very Good," whereas data processing accuracy and reliability of functions such as logging and synchronization were rated "Good". Usability results ranged from 4.20 to 4.80 rated "Very Good". Safety was consistently rated "Very Good" (4.60-4.80), confirming that the system meets safety standards and poses minimal operational risks. Maintenance achieved the highest consistency, with scores ranging from 4.60 to 4.80 rated "Very Good".

4.2 TEC Trend Comparison with Reference Systems

The comparative analysis revealed that the NEO-6M measurements followed similar diurnal and seasonal trends to those observed in the reference systems, as shown in Figure 5.

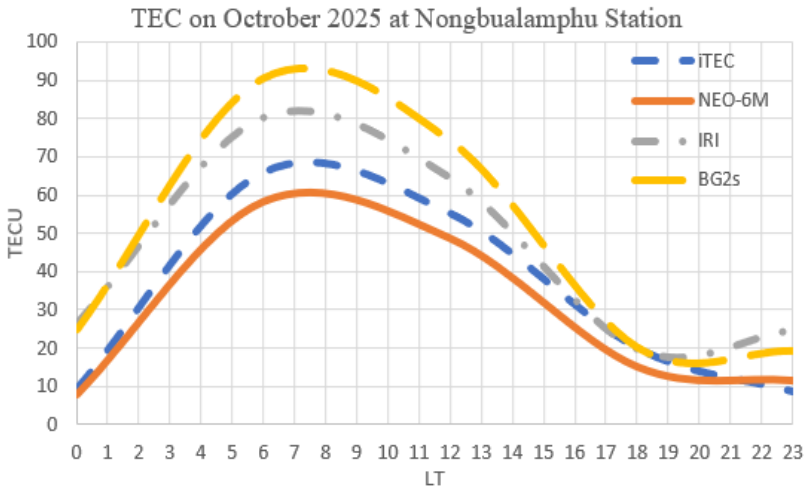

Figure 5 Comparison of TEC at Nongbualamphu station in October 2025

Figure 5 shows the diurnal variation of TEC at Nongbualamphu Station in October 2025. All datasets iTEC, NEO-6 M, IRI, and BG2 s follow the same overall trend: TEC values rise from midnight to reach a peak around 7-9 local time, then gradually decrease through the afternoon and evening.

4.3 Correlation coefficient Analysis of TEC Datasets

To further clarify the discrepancies in absolute TEC values, a correlation coefficient analysis was performed among iTEC, NEO-6M, IRI, and BG2s. Table 2 presents the correlation coefficients calculated using Keokhumcheng and Kenpankho (2025, p. 4249). The results indicate strong positive correlations ($r > 0.94$) across all datasets, confirming that although absolute values differ due to model assumptions and receiver biases, the trends in diurnal variation remain consistent.

Table 2 Correlation coefficient of TEC datasets at Nongbualamphu station (October 2025)

TEC	iTEC	NEO-6M	IRI	BG2s
iTEC	1.00	0.99	0.95	0.96
NEO-6M	0.99	1.00	0.94	0.95
IRI	0.95	0.94	1.00	0.99
BG2s	0.96	0.95	0.99	1.00

Table 2 shows the correlation coefficients among iTEC, NEO-6M, IRI, and BG2s. All datasets exhibit strong positive correlations ($r > 0.94$), indicating that despite discrepancies in absolute TEC values, the diurnal variation trends are highly consistent. For example, the correlation is $r = 0.99$ between iTEC and NEO-6M, $r = 0.95$ between iTEC and IRI, and $r = 0.99$ between IRI and BG2s. These high values confirm that the observed differences are mainly due to systematic biases such as receiver differential code biases and model assumptions, rather than random measurement errors.

5. Conclusion

In conclusion, the result highlights the reliability of the developed instrument and its suitability for scientific applications. Comparative analysis of TEC data collected from the NEO-6M receiver at the Nongbualumphu GNSS monitoring station during October–December 2025 revealed that

the measurements followed similar diurnal and seasonal trends to those observed in iTEC, the IRI model, and the BG2s multi-frequency GPS receiver. Although absolute TEC values from NEO-6M were generally lower than those from IRI and BG2s, the overall patterns remained consistent.

To further improve accuracy, calibration is recommended. The correlation analysis confirmed strong consistency in diurnal variation ($r > 0.94$), but systematic offsets of $15–25$ TECU during daytime remain. These discrepancies are attributed to receiver differential code biases (DCB) and model assumptions. Therefore, calibration using DCB correction and GPS-TEC reference is essential for enhancing the reliability of absolute TEC estimation.

6. Discussion

The results of this study align with and extend previous research on the use of single-frequency GPS receivers for ionospheric TEC monitoring. Keokhumcheng and Kenpankho (2025, pp. 4245-4259) demonstrated that single-frequency GPS receivers can effectively capture diurnal and seasonal variations in TEC, despite limitations in absolute accuracy. The present study supports this conclusion, showing that the NEO-6M single-frequency GPS TEC receiver consistently reflects ionospheric behavior in agreement with both empirical models and multi-frequency receivers. Similarly, Phothila et al. (2025, pp. 1-6) evaluated the performance of single-frequency GPS devices. They found that they provide reliable TEC measurements when compared with high-precision receivers, though calibration and correction methods are necessary to reduce discrepancies. Incorporating correction algorithms or calibration techniques, as recommended by earlier studies (Keokhumcheng & Kenpankho, 2025, pp. 4245-4259; Phothila et al., 2025, pp. 1-6), would enhance measurement accuracy and broaden the applicability of NEO-6M.

7. Acknowledgements

The authors would like to express their sincere gratitude to the Space, Satellite, and Study Laboratory (SSS Lab), Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand, for their invaluable support throughout the course of this research.

8. References

Ashrafuzzaman, M., Saha, S., Uddin, N., Saha, P. K., Hossen, S., & Nur, K. (2021). Design and development of a low-cost smart stick for visually impaired people. In 2021 International Conference on Smart Computing and Communication Technologies (ICSCT) (pp. 1-6). IEEE. https://doi.org/10.1109/ICSCT53883.2021.9642500

Blewitt, G. (1990). An automatic editing algorithm for GPS data. Geophysical Research Letters, 17(3), 199-202. https://doi.org/10.1029/GL017i003p00199

Buakao, N., Phothila, P., & Kenpankho, P. (2025, July). The study of the rate of TEC index over Thailand. In 2025 International Conference on Power, Energy and Innovations (ICPEI) (pp. 1-6). IEEE. https://doi.org/10.1109/ICPEI66116.2025.11282520

Dhanaselvam, H. P., Kumar, P. S., Kavitha, G. P., R., K., & V., G. (2025). Geospatial alert framework for maritime borders using low-power wide area communication. In 2025 International Conference on Information Technology, Communication, and Security (iTech SECOM) (pp. 1-7). IEEE. https://doi.org/10.1109/iTechSECOM64750.2025.11307562

Garcia-Huerta, R. A., Villalon-Turrubiates, I. E., GonzcHez-Jiménez, L. E., & Allende-Alba, G. (2019). Accuracy estimation of a low-cost GPS receiver using landmarks on aerial images. In IGARSS 2019 - IEEE International Geoscience and Remote Sensing Symposium (pp. 9244-9247). IEEE. https://doi.org/10.1109/IGARSS.2019.8899767

Huang, C., & Kenpankho, P. (2024). Low-cost robotic platform with BeiDou satellites. In DRLE 2024 International Conference (pp. 33-40).

Keokhumcheng, T., & Kenpankho, P. (2024). Delay time on GPS at low latitude station on geomagnetic day. In DRLE 2024 International Conference (pp. 16-23).

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), 4245-4259. https://doi.org/10.1016/j.asr.2024.08.019

Kenpankho, P., Chaichana, A., Trachu, K., Supnithi, P., & Hozumi, K. (2021). Real-time GPS receiver bias estimation. Advances in Space Research, 68(5), 2152-2159. https://doi.org/10.1016/j.asr.2021.01.032

Kenpankho, P., Watthanasangmechai, K., Supnithi, P., Tsugawa, T., & Maruyama, T. (2011). Comparison of GPS TEC measurements with IRI TEC prediction at the equatorial latitude station, Chumphon, Thailand. Earth, Planets and Space, 63, 365-370. https://doi.org/10.5047/eps.2011.01.010

Ma, G., & Maruyama, T. (2003). Derivation of TEC and estimation of instrumental biases from GEONET in Japan. Annales Geophysicae, 21, 2083-2093. https://doi.org/10.5194/angeo-21-2083-2003

Maichuen, S., Keokhumcheng, T., & Kenpankho, P. (2025, July). Study of ionospheric total electron content over Thailand using BeiDou satellites. In 2025 International Conference on Power, Energy and Innovations (ICPEI) (pp. 1-6). IEEE. https://doi.org/10.1109/ICPEI66116.2025.11282796

Mitrović, N., Veljković, S., Prijić, Z., & Danković, D. (2022, May). Comparison of the performance of the different GPS receivers in practical applications. In 2022 International Conference on ZINC (pp. 11-16). IEEE. https://doi.org/10.1109/ZINC55034.2022.9840698

Nambut, P., & Kenpankho, P. (2024). Water vapor analysis from GNSS observation over Bangkok and Chumphon, Thailand. In DRLE 2024 International Conference (pp. 1-7).

Pansong, C., Sittichai, W., & Kenpankho, P. (2024). Signatures of the auroral electrojet (AE) index associated with earthquakes and GNSS at low latitude. In DRLE 2024 International Conference (pp. 8-15).

Pansong, C., Wongsak, P., Ruttanaburee, S., Pornsopin, P., & Kenpankho, P. (2025). Low latitude TEC disturbances during extreme geomagnetic storms. Advances in Space Research, 76(12), 7521-7532. https://doi.org/10.1016/j.asr.2025.03.071

Pansong, C., & Kenpankho, P. (2025). GPS TEC anomalies and earthquake events in Thailand. Earth Sciences Research Journal, 29(3), 297-312. https://doi.org/10.15446/esrj.v29n3.117195

Phothila, P., Keokhumcheng, T., Kraisi, P., Pansong, C., Buakao, N., & Kenpankho, P. (2025, July). Performance evaluation of a single frequency GPS device for measuring ionospheric total electron content. In 2025 International STEM Education Conference (iSTEM-Ed) (pp. 1-6). IEEE. https://doi.org/10.1109/iSTEM-Ed65612.2025.11129348

Sumniang, P., & Kenpankho, P. (2024). Low-cost robotic platform using GPS investigation on quiet and geomagnetic days. In DRLE 2024 International Conference (pp. 24–32).

Sumniang, P., Sittichai, W., & Kenpankho, P. (2025). Ionospheric delay and low-cost robots. Advances in Space Research, 75(5), 4386-4393. https://doi.org/10.1016/j.asr.2024.12.011

Wang, N., Yuan, Y., Li, Z., & Huo, X. (2016). Improvement of Klobuchar model for GNSS single-frequency ionospheric delay corrections. Advances in Space Research, 57(7), 1555-1569. https://doi.org/10.1016/j.asr.2016.01.010

Zhao, X., Li, G., Xie, H., Hu, L., Sun, W., Li, Y., Dai, G., Liu, J., Li, Y., Ning, B., Nishioka, M., Perwitasari, S., & Kenpankho, P. (2025). Regional equatorial plasma bubble prediction. Space Weather, 23(2). https://doi.org/10.1029/2024SW004224

GPS SIGNAL DELAY CAUSED BY THE IONOSPHERE MEASUREMENT BY USING SINGLE GPS SATELLITE RECEIVER

Burin Phutthong*, Uthai Kaiphalang, Patiphan Sumniang, and Prasert Kenpankho

67036097@kmitl.ac.th, 68036069@kmitl.ac.th, patiphan.su@kmitl.ac.th,
and prasert.ke@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 67036097@kmitl.ac.th

ABSTRACT

This study investigates GPS signal delay caused by the ionosphere and its impact on positioning accuracy in low-latitude regions. A single-frequency GPS receiver mounted on a low-cost robotic platform was used to collect positioning data at KMITL Chumphon Campus, Thailand, during February to March 2026. Solar activity was classified using the F10.7 cm solar radio flux index, with values below 150 sfu considered low activity and values equal to or above 150 sfu considered high activity. Observations were conducted at four local times (00:00, 06:00, 12:00, and 18:00 UTC+7), and the parameters measured included Total Electron Content (TEC), ionospheric delay time, and positioning error at target distances of 50 m and 100 m. Data were obtained from three sources: the iTEC Chumphon station, the BG2s dual-frequency GNSS receiver, and field measurements from the GPS robot. Results indicate that positioning errors increased under high solar activity, with mean errors rising from 1.96 m to 3.04 m at 50 m and from 1.72 m to 3.51 m at 100 m, while the larger error at 100 m reflects cumulative ionospheric effects over longer navigation distances. These findings confirm that solar activity and electron density variations significantly affect single-frequency GPS performance, and the experiment demonstrates that a low-cost robotic platform can serve as a practical tool for monitoring ionospheric variations and evaluating GNSS positioning behavior in low-latitude regions such as Thailand.

Keywords: GPS, Ionosphere, TEC, Delay time, Low-cost GPS robot, GNSS

1. Statement of the Problem

Global Positioning System (GPS) satellites, one of Global Navigation Satellite Systems (GNSS), are widely used for navigation, surveying, and robotic control. However, signal delay caused by the ionosphere remains one of the main sources of positioning error, especially in low-latitude regions such as Thailand where ionospheric activity is strong and changes rapidly. Variations in Total Electron Content (TEC) and solar activity can increase signal delay and reduce positioning accuracy (Jamjareegulgarn et al., 2020, pp. 909–932; Zhao et al., 2025). For low-cost GPS robots used in teaching and field experiments, understanding ionospheric delay is important for improving positioning accuracy, motion stability, and system reliability.

Many studies investigated ionospheric modeling and TEC estimation using GPS satellites from GNSS observations. Jamjareegulgarn et al. (2020, pp. 909–932) improved the modeling of bottom-side ionospheric thickness parameters over mid- and high-latitude regions, while Kenpankho et al. (2021, pp. 2152–2159) developed a real-time GPS receiver bias estimation

method to improve TEC calculation from GNSS observations. Research using single-frequency Global Positioning System receivers has shown that TEC can be estimated with acceptable accuracy in low-cost systems (Keokhumcheng & Kenpankho, 2024, pp. 16–23; Keokhumcheng & Kenpankho, 2025, pp. 4245–4259). In addition, several studies have examined ionospheric disturbances and their influence on GNSS signals in low-latitude regions. TEC disturbances during geomagnetic storms and other ionospheric events have been reported to significantly affect GNSS signal propagation and positioning accuracy (Pansong et al., 2025a, pp. 7521–7532; Pansong et al., 2025b, pp. 167–178). In Thailand, TEC anomalies and ionospheric variations related to natural phenomena have also been investigated using GNSS observations (Pansong & Kenpankho, 2025, pp. 297–312; Phansori et al., 2021, pp. 69–72; Phansori et al., 2022, pp. 153–156). Regional GPS signals for GNSS observation have been used to analyze atmospheric and ionospheric parameters specifically over the country (Nambut & Kenpankho, 2024, pp. 1–7). Complementary to these ionospheric studies, research on GPS receiver in GNSS design and frequency filter development has been conducted to enhance signal processing and reduce interference, including some satellites in GNSS frequency such as Galileo-E6, Galileo-E5a, and QZSS L1 bandwidth filter designs (Chinnapark et al., 2021, pp. 57–62; Mekpradab et al., 2021, pp. 133–138; Onanong et al., 2021, pp. 27–32). These engineering contributions provide a technical foundation that supports ionospheric monitoring and positioning accuracy improvements in both academic and applied contexts.

Recent studies have also explored low-cost GPS in GNSS experimental platforms for positioning and ionospheric investigations, including robotic GPS systems and multi-constellation positioning experiments (Huang & Kenpankho, 2024, pp. 33–40; Sumniang & Kenpankho, 2024, pp. 24–32; Sumniang et al., 2025, pp. 4386–4393). Other research has focused on ionospheric delay behavior and irregularities such as equatorial plasma bubbles that influence GNSS signal propagation in low-latitude regions (Pansong et al., 2025a, pp. 7521–7532; Zhao et al., 2025). In parallel, GNSS receiver hardware and filter design innovations have been introduced to strengthen the robustness of low-cost platforms against ionospheric disturbances, ensuring that robotic navigation experiments can be conducted with improved reliability (Chinnapark et al., 2021, pp. 57–62; Mekpradab et al., 2021, pp. 133–138; Onanong et al., 2021, pp. 27–32). Together, these studies highlight the synergy between ionospheric science and GNSS engineering, demonstrating how integrated approaches can advance both theoretical understanding and practical applications in navigation and robotic control.

The purpose of this study is to measure GPS satellite signal delay caused by the ionosphere using a single-frequency GPS receiver together with a low-cost GNSS navigation robot during a two-month experiment at KMITL Chumphon, Thailand. Data are collected at 00:00, 06:00, 12:00, and 18:00 local time under solar activity conditions defined by Solar Radio Flux F10.7 < 150 sfu and F10.7 ≥ 150 sfu. The study records TEC, ionospheric delay time, positioning error, and robot motion stability to explain how ionospheric variations affect low-cost GNSS robots, especially for GPS satellite signal, in low-latitude regions and to provide practical data for improving navigation accuracy and ionospheric monitoring in Thailand.

2. Objectives

2.1 Analyzing GPS signal delay under different solar radio flux conditions and variations in TEC influence the positioning accuracy, motion stability, and reliability of a low-cost GPS robot in KMITL Chumphon, low-latitude region.

2.2 Comparing field measurements of GPS signal delay from a low-cost GPS robot with ionospheric data from monitoring stations.

3. Research Methodology

3.1 Research methodology

This study employed an experimental approach to investigate the influence of ionospheric delay on GPS positioning accuracy using a single-frequency GPS receiver mounted on a low-cost GPS robot. The robot was used as a mobile measurement platform to collect GPS positioning data under open-sky conditions at KMITL Chumphon during February to March 2026. The experimental design aimed to evaluate the relationship between solar activity, ionospheric delay, and positioning accuracy in a low-latitude region.

3.2 Research procedure

The experiment was conducted at KMITL Chumphon, Thailand. The starting reference point was located at 10.72356° N, 99.37561° E. Two additional test points were set along a straight path from the starting point to evaluate positioning accuracy at different distances. The first point was about 50 m from the starting point at 10.72399° N, 99.37575° E, and the second point was about 100 m from the starting point at 10.72442° N, 99.37588° E. The locations of the starting point and the test points can be seen on the map in Figure 1.

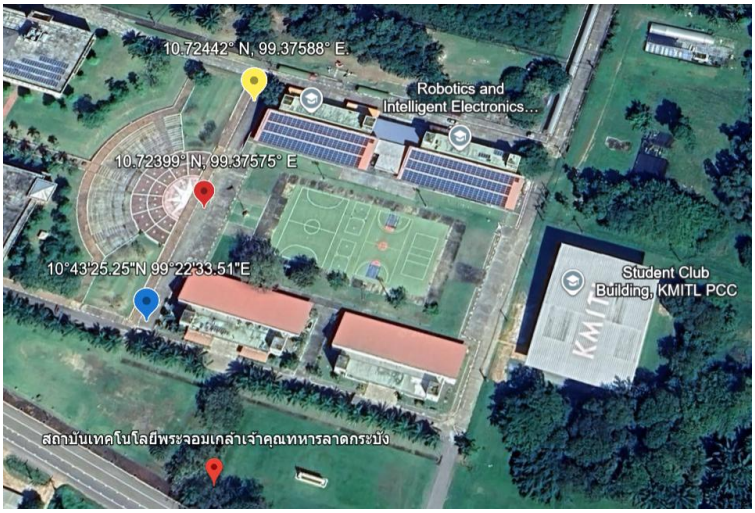

Figure 1 Map of the experimental area at KMITL Chumphon

Figure 1 shows the starting reference point and two test points located at distances of approximately 50 m and 100 m from the starting point. GPS measurements were recorded while the mobile platform moved slowly along the predefined path to minimize motion-related errors. During the experiment, a low-cost robot was used as a simple mobile platform to carry the GPS receiver along the experimental path. The robot itself was not the main focus of this study; any low-cost robot capable of moving toward a target point could be used. Its main role was to provide stable movement while collecting positioning data.

A Quescan G10A-F30 receiver module was installed on the robot to record GPS signals as the robot moved toward the target locations. The installation of the receiver module on the robot platform is shown in Figure 2.

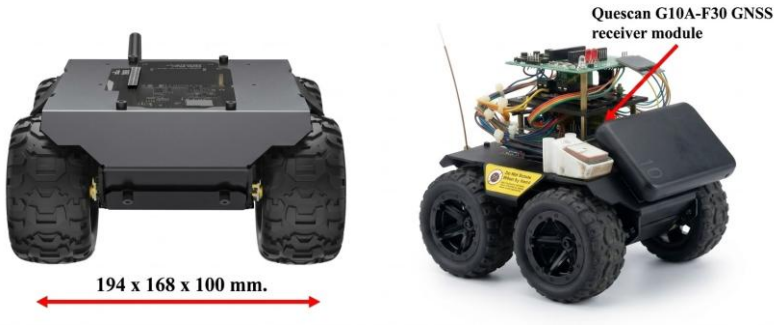

Figure 2 Quescan G10A-F30 GPS receiver module on the low-cost robot platform used in the experiment

Figure 2 shows the installation of the Quescan G10A-F30 GPS receiver module on the low-cost robot used in the experiment with the dimension of 194x168x100 mm. The receiver module was mounted on the robot platform to record GPS positioning data while the robot moved toward the target points during the field test.

The ionospheric data in this study were obtained from two measurement systems installed at KMITL Chumphon, as shown in Figure 3 and Figure 4. Ionospheric Total Electron Content (iTEC) data from the iTEC Chumphon station were obtained using a GPS antenna to collect single-frequency observations, from which TEC is estimated and then used to calculate ionospheric delay. The station is permanently installed on-site, allowing continuous monitoring of ionospheric conditions over the study area. In contrast, the BG2s receiver shown in Figure 4 is connected to a GNSS antenna and operates as a dual-frequency system, enabling ionospheric delay to be derived more directly from signal behavior at different frequencies. Since both systems are located in the same environment, the measurements reflect ionospheric conditions over KMITL Chumphon under similar atmospheric conditions.

Figure 3 Ionospheric Total Electron Content (iTEC)

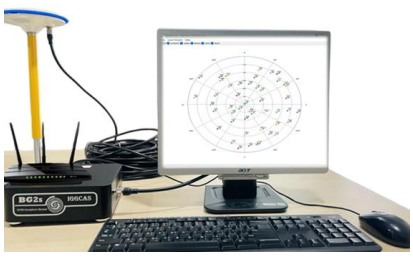

Figure 4 BG2s dual-frequency GNSS receiver

Due to these differences in measurement approaches, the ionospheric delay obtained from the BG2s receiver generally shows higher precision than the values derived from the iTEC station. However, the iTEC data still provide a consistent representation of ionospheric variation over time. Although the absolute values differ between the two systems, the overall trends remain similar across the observation periods. These differences are mainly attributed to the use of single-frequency and dual-frequency techniques, as well as the different calculation methods applied in each system. Therefore, the comparison between these datasets supports the analysis of ionospheric effects on GNSS positioning accuracy in this study.

3.3 Data Collection

For the ionospheric delay time analysis, Total Electron Content (TEC) and ionospheric delay data were collected from three sources during February to March 2026. These sources included the iTEC Chumphon Station regional ionospheric model, the BG2s receiver at KMITL Chumphon, and field measurements obtained from a single-frequency GNSS receiver installed on the low-cost GPS robot.

Solar activity conditions were classified using the F10.7 cm solar radio flux index, which is commonly used as an indicator of ionospheric activity. The observation days from February to March 2026 were grouped into two categories: low solar activity (F10.7 < 150 sfu) and high solar activity (F10.7 ≥ 150 sfu).

In this study, the observation days were expressed in Day of Year (DOY), where the count starts from January 1 as DOY 1. For example, February 1 corresponds to DOY 32 and February 28 corresponds to DOY 59, while March 1 corresponds to DOY 60.

For February, the selected DOY values were classified as low solar activity (DOY 33, 34, 35, and 36) and high solar activity (DOY 49, 50, 51, and 52).

For March, additional observation days were included to provide a broader representation of ionospheric conditions. The selected DOY values for high solar activity were DOY 60, 61, 62, 63, 64, and 65, while the selected DOY values for low solar activity were DOY 69, 70, 71, 74, 76, 77, 78, 81, 83, 84, 85, and 88.

Table 1 Selected solar activity days during February to March 2026

Month	Numbers of solar activity (Days)		Purposive selected experiment DOY	
	Low	High	Selected DOY (Low)	Selected DOY (High)
February	20	8	49,50,51,52	33,34,35,36
March	24	7	69, 70, 71, 74, 76, 77, 78, 81, 83, 84, 85, 88.	61,62,63,64,65

Table 1 presents the selected DOY values during February to March 2026 used in this study. DOY is counted sequentially from January 1 as DOY 1. The selected DOY values were categorized according to solar activity conditions using the F10.7 cm radio flux index, where F10.7 < 150 sfu indicates low solar activity and F10.7 ≥ 150 sfu indicates high solar activity.

In addition, the variation of solar activity during the observation period was examined using daily F10.7 radio flux values. The distribution of F10.7 values in February 2026 is shown in Figure 5, while the corresponding distribution for March 2026 is presented in Figure 6, showing how solar activity changes over time, including the transition between low and high activity levels. The selected DOY values listed in Table 1 were chosen to represent both quiet and disturbed ionospheric conditions within these periods.

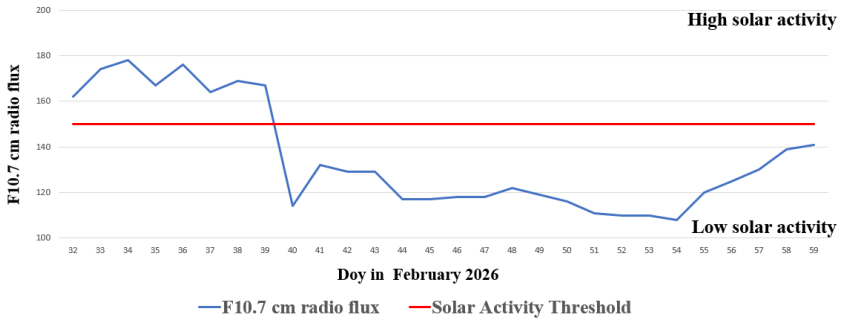

Figure 5 Solar activity by F10.7 index in February 2026

Figure 5 shows the daily F10.7 radio flux values in February 2026 (DOY 32–59), showing the classification of low and high solar activity conditions. The selected DOY values used in this study, as presented in Table 1, correspond to specific periods within this distribution.

Figure 6 Solar activity by F10.7 index in March 2026

Figure 6 shows the daily F10.7 radio flux values in March 2026 (DOY 60–88), illustrating the variation of solar activity during the extended observation period. Similar to February, both low and high solar activity conditions can be observed. The additional data from March help support the analysis and provide a clearer view of solar activity patterns over time.

3.4 Data Analysis

In our study for the ionospheric delay and TEC analysis, we looked at how TEC levels directly lead to ionospheric delay for the GPS L1 signals. Since GPS signals have to pass through the ionosphere, the density of free electrons measured as TEC slows them down. To get a clear picture of this, we calculated the actual delay time (Δt) by using the standard physical relationship where the delay depends on both the TEC value and the signal frequency as shown in Equation (1)-(2).

$$\Delta t = \frac{40.31}{f^2} TEC \tag{1}$$

$$\text{where } \frac{1}{f^2} = 4.0291 \times 10^{-19}$$

$$\Delta t = 1.6237 \times 10^{-17} TEC \tag{2}$$

whereas

Δt = Ionospheric delay time (ns),
TEC = Total Electron Content (1 TECU = 10^{16} electrons/m²),
f = GPS L1 signal frequency (1575.42 MHz).

By tracking these TEC levels during our field tests at the KMITL Chumphon, we were able to estimate how much this specific delay contributed to the positioning errors we saw with the GPS robot.

To consistently interpret the collected data, the arithmetic mean was applied to calculate average values of TEC, ionospheric delay time, and positioning errors, thereby providing a reliable basis to compare results across different DOY and observation times. The arithmetic mean was computed as follows in Equation (3).

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3}$$

whereas

$\bar{x}$ = Average value of the observations,
x_i = Value of each observation,
n = Total number of observations.

Using these averages allowed us to clearly see the difference between low and high solar activity based on the F10.7 cm solar radio flux index. By looking at the mean values, we could better understand how changing TEC levels directly influence the ionospheric delay time, which in turn impacts the robot's navigation accuracy. This approach made it much easier to track how higher solar activity leads to longer signal delays and larger positioning errors during our tests at the KMITL Chumphon.

4. Results

4.1 Ionospheric delay over KMITL Chumphon

To examine ionospheric effects on GNSS signals, delay values were obtained from three different sources: the low-cost GPS robot receiver, the iTEC Chumphon model, and direct measurements at the KMITL Chumphon station. These datasets provide complementary perspectives, ranging from simplified low-cost instrumentation to standardized regional modeling and full-scale station observations.

TEC values from each source were extracted for the period from February to March 2026 and used in Equation (2) to compute the corresponding ionospheric delay at the GPS L1 frequency. The resulting delay values were then compared between daytime and nighttime periods to examine variations under different solar activity conditions.

To further analyze ionospheric effects on GNSS signals, delay values were obtained from three different sources: the low-cost GPS robot receiver, the iTEC Chumphon model, and direct measurements from the KMITL Chumphon station. These datasets provide complementary perspectives, ranging from low-cost instrumentation to regional modeling and full-scale station observations.

Table 2 Ionospheric delay over Chumphon station

Month	Ionospheric delay (ns)								
	The low-cost GPS robot			iTEC Chumphon			KMITL Chumphon		
	Day	Night	Average	Day	Night	Average	Day	Night	Average
February	13.70	3.52	8.78	21.03	8.63	14.83	68.47	27.07	47.77
March	12.23	3.46	7.84	30.49	8.79	19.64	73.41	31.42	52.41

As shown in Table 2, the KMITL Chumphon station consistently produced the highest ionospheric delay values in both months, with average delays of 47.77 ns in February and 52.41 ns in March. The iTEC Chumphon model showed intermediate delay levels, with average values of 14.83 ns in February and 19.64 ns in March. In contrast, the low-cost GPS robot yielded the lowest delay values, with average delays of 8.78 ns in February and 7.84 ns in March.

The differences in ionospheric delay values among the three data sources can be attributed to variations in measurement techniques and data processing approaches. The low-cost GPS robot utilizes raw observations without applying bias correction, which may lead to an underestimation of ionospheric delay. In contrast, the iTEC Chumphon model is derived from single-frequency observations, where ionospheric delay is estimated using simplified assumptions and empirical models. Although this approach provides reasonable estimates, its accuracy is limited compared to dual-frequency methods.

The BG2s receiver installed at KMITL Chumphon operates using dual-frequency measurements, enabling direct estimation of ionospheric delay based on frequency-dependent signal dispersion. This method reduces ionospheric-related errors and provides more reliable delay values. Consequently, the delay values obtained from the KMITL Chumphon station show better agreement with expected ionospheric behavior and are generally higher than those derived from the other two sources.

4.2 GPS positioning error of the low-cost GPS robot under low and high solar activity conditions

The positioning performance of the low-cost GPS robot was evaluated under both low and high solar activity conditions during February to March 2026. The experiments were conducted at distances of 50 m and 100 m. Solar activity levels were classified using the F10.7 index, where values ≥ 150 sfu indicate high solar activity and values < 150 sfu indicate low solar activity.

Table 3 summarizes the average positioning errors observed during high solar activity days in February 2026.

Table 3 Average position error of the low-cost GPS robot under high solar activity days

DOY 2026	Position error at 50 m	Position error at 100 m
33	3.19	3.37
34	3.24	3.47
35	3.22	3.75
36	2.91	3.45

Table 3 shows that under high solar activity conditions in February 2026, the positioning error remained relatively high at both distances and was generally larger at 100 m, indicating the influence of ionospheric delay. These results are presented as observational values rather than statistical analysis, reflecting the variation of positioning error under changing ionospheric conditions.

Table 4 presents the positioning errors observed during low solar activity days in February 2026.

Table 4 Average position error of the low-cost GPS robot under low solar activity days

DOY 2026	Position error at 50 m	Position error at 100 m
49	1.18	1.32
50	1.88	2.08
51	1.88	2.08
52	1.53	1.93

Table 4 shows that under low solar activity conditions in February 2026, the positioning error was reduced and more stable compared to high solar activity, with generally lower values at both distances. These results are presented as observational values rather than statistical analysis, reflecting the variation of positioning error under changing ionospheric conditions. Further validate these observations, additional experiments were conducted in March 2026 using the same experimental setup.

Table 5 summarizes the average positioning errors observed during high solar activity days in March 2026.

Table 5 Average positioning error of the low-cost GPS robot under high solar activity days

DOY 2026	Position error at 50 m	Position error at 100 m
61	3.35	3.54
62	3.04	3.65
63	3.38	3.94
64	3.05	3.70
65	3.55	3.70

Table 5 shows that under high solar activity conditions in March 2026, the positioning error remained relatively high at both distances and was consistently larger at 100 m, indicating the influence of ionospheric delay. It should be noted that these results are presented as observational values rather than statistical analysis, reflecting the variation of positioning error under changing ionospheric conditions.

Table 6 Average positioning error of The low-cost GPS robot under low solar activity days

DOY 2026	Position error at 50 m	Position error at 100 m
69	1.22	1.35
70	1.93	2.14
71	1.93	2.14
74	1.60	1.99
76	1.22	1.35
77	1.93	2.14
78	1.93	2.14
81	1.60	1.99
83	1.62	1.35
84	1.93	2.14
85	1.93	2.14
88	1.60	1.99

Table 6 shows that under low solar activity conditions in March 2026, the positioning error was reduced and more stable at both distances, with generally lower values compared to high solar activity. These results are presented as observational values rather than statistical analysis, reflecting the variation of positioning error under changing ionospheric conditions.

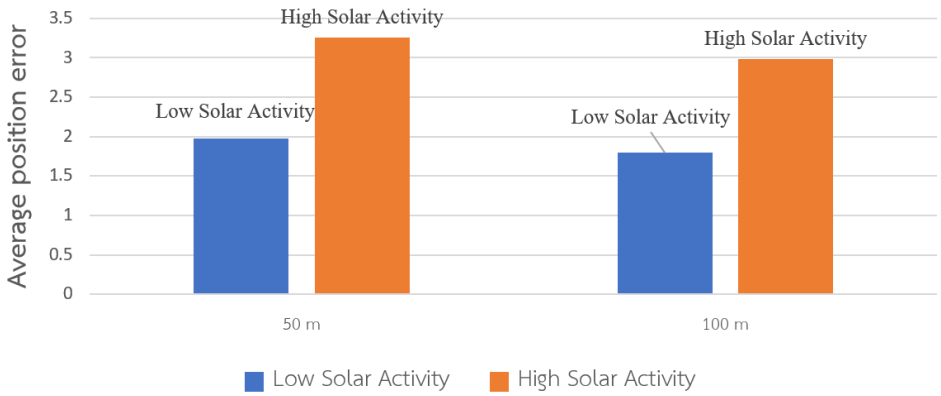

Figure 7 Positioning error of the low-cost GPS robot

Figure 7 confirms that increased ionospheric electron density and the resulting signal delay under elevated solar radio flux conditions made the error on positioning performance of single-frequency GNSS systems in low-latitude regions such as KMITL Chumphon. The low solar radio flux gives low average position error. However, the high solar radio flux gives more average position error. The graphical comparison highlights the vulnerability of low-cost GNSS receivers to solar activity, especially at longer distances, where ionospheric disturbances exert a stronger influence on navigation accuracy.

5. Conclusion and Discussion

The results demonstrate a clear relationship between solar activity and the positioning accuracy of the low-cost GPS robot at KMITL Chumphon Campus. During periods of high solar activity (F10.7 ≥ 150 sfu), the ionospheric delay time increased significantly, leading to larger positioning errors. In contrast, under low solar activity conditions (F10.7 < 150 sfu), the delay time was smaller and more stable, resulting in improved positioning accuracy. The difference became more pronounced at the 100 m distance compared with 50 m, indicating that positioning deviations accumulate as navigation distance increases. Because the system relies on a single-frequency GPS receiver, the ionospheric delay time cannot be effectively corrected or eliminated, and variations in TEC directly influence the signal delay and consequently affect positioning accuracy. These observations are consistent with previous studies on low-cost GPS robotic platforms, which reported that ionospheric conditions and geomagnetic disturbances can significantly affect positioning performance in single-frequency GNSS systems (Huang & Kenpankho, 2024, pp. 33–40; Sumniang & Kenpankho, 2024, pp. 24–32).

This study examined the influence of solar activity on ionospheric delay time and positioning accuracy using a single-frequency GPS receiver mounted on a low-cost GNSS robot at KMITL Chumphon during February–March 2026. The results clearly indicate that positioning errors increased under high solar activity conditions (F10.7 ≥ 150 sfu) compared with low solar activity conditions (F10.7 < 150 sfu). The mean positioning error rose from 1.96 m to 3.04 m at 50 m and from 1.72 m to 3.51 m at 100 m in February, while in March the error increased further, with average values exceeding 3.5 m at 100 m under high solar activity compared with less than 2.1 m under low solar activity. These results correspond to longer ionospheric delay times caused by higher TEC levels; the greater impact observed at the 100 m distance suggests that ionospheric-induced delay effects accumulate as navigation distance increases. Because the system relies on a single-frequency GPS receiver, the ionospheric delay cannot be effectively removed, resulting in larger positioning deviations during periods of enhanced solar activity. These findings are consistent with previous studies on low-cost GNSS

robotic platforms and ionospheric effects on positioning performance (Huang & Kenpankho, 2024, pp. 33–40; Sumniang & Kenpankho, 2024, pp. 24–32; Keokhumcheng & Kenpankho, 2025, pp. 4245–4259). Overall, they confirm that variations in solar activity and ionospheric delay significantly influence single-frequency GNSS positioning performance in low-latitude regions, while providing practical insight for improving low-cost GNSS robot navigation and supporting ionospheric monitoring research in Thailand.

6. Acknowledgements

The authors would like to express their sincere gratitude to the Space, Satellite, and Study Laboratory (SSS Lab) for providing technical support, research facilities, and valuable guidance throughout this study. The authors also acknowledge the support from King Mongkut's Institute of Technology Ladkrabang, Chumphon, where field experiments and GNSS measurements were conducted. Their support greatly contributed to the successful completion of this research.

7. References

Chinnapark, S., Onanong, N., Pattameak, J., Mekpradab, T., & Kenpankho, P. (2021). Galileo-E6 bandwidth frequency filter design for Galileo receiver. ASEAN Journal of Science and Engineering, 1(2), 57-62. https://doi.org/10.17509/ajse.v1i2.34224.

Huang, C., & Kenpankho, P. (2024). Low-cost robotic platform with BeiDou satellites. In Proceedings of the DRLE 2024 International Conference (pp. 33-40).

Jamjareegulgarn, P., Supnithi, P., Kenpankho, P., Wichaipanich, N., & Nayak, C. (2020). Improving the modeling of bottomside thickness parameters over midlatitudes and high latitudes. Advances in Space Research, 65(3), 909-932. https://doi.org/10.1016/j.asr.2019.10.026.

Kenpankho, P., Chaichana, A., Trachu, K., Supnithi, P., & Hozumi, K. (2021). Real-time GPS receiver bias estimation. Advances in Space Research, 68(5), 2152-2159. https://doi.org/10.1016/j.asr.2021.01.032.

Keokhumcheng, T., & Kenpankho, P. (2024). Delay time on GPS at low latitude station on geomagnetic day. In Proceedings of the DRLE 2024 International Conference (pp. 16-23).

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), 4245-4259. https://doi.org/10.1016/j.asr.2024.08.019.

Mekpradab, T., Onanong, N., Chinnapark, S., Pattameak, J., & Kenpankho, P. (2021). Galileo-E5a bandwidth frequency filter design for Galileo-E5a receiver. ASEAN Journal of Science and Engineering, 2(2), 133-138. https://doi.org/10.17509/ajse.v2i2.37798.

Nambut, S., & Kenpankho, P. (2024). Water vapor analysis from GNSS observation over Bangkok and Chumphon, Thailand. In Proceedings of the DRLE 2024 International Conference (pp. 1-7).

Onanong, N., Pattameak, J., Mekpradab, T., Chinnapark, S., & Kenpankho, P. (2021). QZSS L1 bandwidth frequency filter design for QZSS receiver. ASEAN Journal of Science and Engineering, 1(1), 27-32. https://doi.org/10.17509/ajse.v1i1.33764.

Pansong, C., & Kenpankho, P. (2025). GPS TEC anomalies and earthquake events in Thailand. Earth Sciences Research Journal, 29(3), 297-312. https://doi.org/10.15446/esrj.v29n3.117195.

Pansong, C., Kraisi, P., Nambut, S., & Kenpankho, P. (2025). Estimation of geostationary BeiDou satellite total electron content during the extreme geomagnetic storm. In Proceedings of the DRLE 2025 International Conference (pp. 167-178).

Pansong, C., Ruttanaburee, S., Sunthonkanokpong, W., & Kenpankho, P. (2025). Pre-seismic ionospheric total electron content anomalies associated with the June 28, 2023 earthquake in Thailand. International Journal of Industrial Education and Technology, 7(2). https://doi.org/10.55003/ijiet.7206.

Pansong, C., Wongsak, P., Ruttanaburee, S., Pornsopin, P., & Kenpankho, P. (2025). Low latitude TEC disturbances during extreme geomagnetic storms. Advances in Space Research, 76(12), 7521-7532. https://doi.org/10.1016/j.asr.2025.03.071.

Phansori, N., Boatong, P., Phukrongta, S., Kriamthaisong, O., & Kenpankho, P. (2021). Analysis of the relationship between earthquake events and the disturbance of Ionosphere by using IGS TEC. ASEAN Journal of Science and Engineering Education, 1(1), 6972. https://doi.org/10.17509/ajsee.v1i1.32446.

Phansori, N., Phukrongta, S., Kriamthaisong, O., & Kenpankho, P. (2022). Study the relationship of earthquake and ionosphere using IRI TEC for education. ASEAN Journal of Science and Engineering Education, 2(2), 153-156. https://doi.org/10.17509/ajsee.v2i2.32447.

Sumniang, P., & Kenpankho, P. (2024). Low-cost robotic platform using GPS investigation on quiet and geomagnetic days. In Proceedings of the DRLE 2024 International Conference (pp. 24-32).

Sumniang, P., Sittichai, W., & Kenpankho, P. (2025). Ionospheric delay and low-cost robots. Advances in Space Research, 75(5), 4386–4393. https://doi.org/10.1016/j.asr.2024.12.011.

Zhao, X., Li, G., Xie, H., Hu, L., Sun, W., Li, Y., Dai, G., Liu, J., Li, Y., Ning, B., Nishioka, M., Perwitasari, S., & Kenpankho, P. (2025). Regional equatorial plasma bubble prediction. Space Weather, 23(2). https://doi.org/10.1029/2024SW004224.

TOTAL ELECTRON CONTENT MEASUREMENT BY USING BEIDOU SATELLITE

Jianfeng Zhang[1]*, Pattawut Wongsak[1], Thanapon Keokhumcheng[1,2], and Prasert Kenpankho[1]

68036001@kmitl.ac.th, 67036098@kmitl.ac.th,
kpongthanaponok@gmail.com, and prasert.ke@kmitl.ac.th

[1]Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand
[2]Department of Electronics, Nongbualumphu Technical College,
Institute of Vocational Education Northeastern Region 1, Nongbualumphu 39000 Thailand

*Corresponding Author Email: 68036001@kmitl.ac.th

ABSTRACT

Ionospheric Total Electron Content (TEC) plays a fundamental role in determining the accuracy of Global Navigation Satellite System (GNSS) positioning, navigation, and timing performance, as ionospheric delays constitute one of the largest error sources for single-frequency and even multi-frequency GNSS users. Accurate TEC estimation is therefore essential for improving ionospheric modeling, enhancing space weather monitoring, and ensuring high-precision applications. While the Global Positioning System (GPS) has been widely utilized and validated for TEC retrieval over many years, the capability and reliability of the BeiDou Navigation Satellite System (BDS) particularly when evaluated in direct comparison with GPS under identical geophysical and observational conditions-remain less thoroughly documented. This lack of comparatives studies is especially notable in low-latitude regions, where ionospheric variations are strong and dynamic. To address this research gap, the present study conducts a comprehensive assessment of TEC measurements derived from both BDS and GPS signals during December 2025 at the monitoring station of the School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand (13.73°N, 100.78°E). Comparative analysis reveals strong consistency between the two GNSS systems. BDS-derived TEC demonstrates a Root Mean Square Error (RMSE) of 18.14 and a correlation coefficient of 0.81 relative to GPS, indicating robust agreement in capturing diurnal TEC variations and peak electron density patterns. These results confirm that BDS possesses the capability to produce reliable TEC observations comparable to those of GPS.

Keywords: TEC, BDS TEC, GPS TEC

1. Statement of the Problem

The ionosphere is a dynamic region of the Earth's upper atmosphere that significantly influences the propagation of radio signals. Variations in ionospheric electron density can introduce delays and errors in Global Navigation Satellite System (GNSS) signals, thereby affecting the accuracy of positioning, navigation, and communication applications. Among the parameters used to characterize ionospheric conditions, the Total Electron Content (TEC) is particularly important, as it represents the integrated number of electrons along the path between a satellite and a ground receiver. Accurate TEC measurements are therefore essential for both scientific studies of ionospheric behavior and practical improvements in GNSS

performance. Over the past decades, GPS has been the primary system employed for TEC monitoring, providing extensive datasets and insights into diurnal, seasonal and geomagnetic variations. However, with the rapid development of the BeiDou Navigation Satellite System (BDS), there is growing interest in evaluating its capability for ionospheric research, especially in regions where BDS coverage is strong.

In recent decades, the development of TEC modeling has significantly benefited from the integration of multi-GNSS observations. Early studies based on ground-based GPS data introduced new approaches for global ionospheric determination, laying the theoretical foundation for high-resolution TEC mapping (Hernandez-Pajares et al., 1999). Subsequent work further clarified the effects of the ionosphere on space geodetic techniques and emphasized the importance of accurate ionospheric modeling for mitigating positioning errors (Hernández-Pajares et al., 2011). With the inclusion of BDS, Galileo, and GLONASS, multi-GNSS integration has become a dominant trend in global ionospheric modeling. Ren et al. (2016) demonstrated that combining multiple GNSS constellations significantly improves global ionospheric representation, while Wang et al. (2022) compared the performance of BDS and Galileo in global ionospheric modeling. At the regional scale, the integration of GPS and BDS observations has been shown to enhance regional ionospheric model accuracy (Abdelazeem et al., 2017), and long-term GNSS-TEC mapping over East Asia has confirmed the robustness of ground-based multi-GNSS modeling (Wang et al., 2025). Regarding broadcast and single-frequency ionospheric models, Song and Liu (2019) and Xu et al. (2020) evaluated the adaptability of BDS ionospheric models under varying solar activity conditions, whereas Wang et al. (2018) assessed multi-system ionospheric correction models in both range delay and positioning domains. The potential of advanced signal structures, such as Galileo and BDS AltBOC signals, for TEC retrieval has also been investigated (Chen et al., 2024). in addition, ionospheric disturbances during geomagnetic storms have been extensively studied, including the global response to the 2015 St. Patrick's Day storm (Astafyeva et al., 2015) and three-dimensional ionospheric anomaly monitoring using multi-GNSS and COSMIC data (Cheng et al., 2021). Long-term analyses of the equatorial ionization anomaly (EIA) region have revealed the complex variability of low-latitude ionospheric structures (Oluwadare et al., 2019), and comparisons between observed TEC and IRI predictions over equatorial Thailand further highlight regional modeling challenges (Kenpankho et al., 2013). More recently, improved algorithms have demonstrated that reliable TEC estimates can also be obtained from single-frequency GPS receivers (Keokhumcheng & Kenpankho2025). Moreover, multi-GNSS integration has enhanced precise point positioning (PPP) performance by improving ionospheric delay mitigation (Cai & Gao, 2013). 0verall, existing studies have systematically advanced ionospheric modeling from global to regional scales, from multi-frequency to single-frequency observations, and from quiet to disturbed conditions; however, further refinement remains necessary, particularly for long-term stability and multi-system optimization in low-latitude regions.

The data and methodology of this study build upon established approaches in GNSS-based ionospheric research. Ren et al. (2016) demonstrated the effectiveness of integrating GPS, BDS, Galileo, and GLONASS observations for global ionospheric modeling, emphasizing that multi-system datasets reduce uncertainties and improve TEC estimation. At the regional scale. Kenpankho et al. (2013) compared observed TEC values with IRl-2007 predictions in equatorial Thailand, showing the importance of ground-based GNSS receivers in validating ionospheric models under local conditions. More recently, Keokhumcheng and Kenpankho (2025) investigated TEC using single-frequency GPS receivers, highlighting practical approaches for monitoring ionospheric variability with limited instrumentation. Guided by these frameworks, the present study utilizes ground-based GNSS receivers to collect TEC data from both GPS and BDS during December 2025, applying statistical metrics such as Root

Mean Square Error (RMSE) and correlation coefficients to assess the reliability of BDS relative to GPS. This methodological design ensures comparability with prior studies while addressing the research gap in event-specific TEC monitoring in Southeast Asia.

2. Objectives

2.1 Evaluating the accuracy and stability of BDS relative to GPS using statistic metrics such as RMSE and correlation coefficients.

3. Research and Methodology

3.1 Study Area

In the Figure 1 the study area is located at the KMITL, School of industrial Education and Technology monitoring station in Bangkok, Thailand, with geographic coordinates 13.73°N, 100.78°E (THBK).

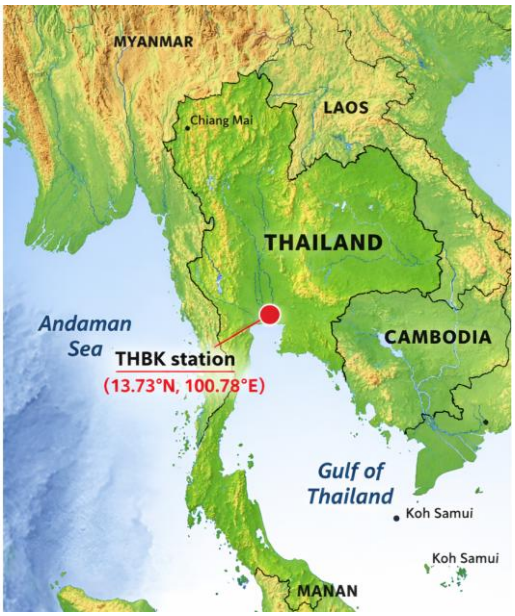

Figure 1 THBK station

This study in the low-latitude region of Thailand, where ionospheric activity is highly dynamic and influenced by solar activity, geomagnetic storms, and equatorial ionization anomalies. Being situated near the equatorial anomaly zone, TEC variations in this region exhibit pronounced diurnal and seasonal patterns and are particularly sensitive to space weather disturbances. Consequently, the KMITL monitoring station provides an ideal environment for comparative studies of GPS and BDS TEC measurements, enabling the assessment of system consistency and differences in low-latitude ionospheric monitoring. The findings from this study area contribute to regional ionospheric modeling and space weather forecasting in Thailand.

3.2 TEC Computation

TEC data were collected using a multi-frequency GNSS receiver, and the computation the BDS TEC and GPS TEC followed the methodology proposed by Keokhumcheng and Kenpankho (2025). Slant TEC (STEC) was calculated using the equation (1):

$$STEC = \frac{2\left(f_1^2 \cdot f_2^2\right)}{k\left(f_1^2 - f_2^2\right)} \cdot \left(L_1\lambda_1 - L_2\lambda_2\right) \quad (1)$$

where:
f_1, f_2: multi-frequency carrier frequencies,
L_1, L_2: the carrier phase measurements (in cycles),
λ_1, λ_2: the corresponding wavelengths of the two carrier signals,
$k = 80.62\ m^3/s^2$ is the ionospheric refractivity constant.

The constant k is derived from fundamental physical constants (electron charge, vacuum permittivity, and electron mass) and corresponds to twice the classical coefficient 40.31 used in the ionospheric delay equation. This formulation ensures dimensional consistency between the ionospheric delay (meters) and TECU (electrons/m^2). Frequencies are for BDS TEC: f_1 = 1561.098 MHz and f_2 = 1207.14 MHz Frequencies are for GPS TEC: f_1 = 1575.48 MHz and f_2 = 1227.60 MHz.

Since the slant TEC (STEC) varies with the satellite elevation angle, it dependent on the geometry of the ionospheric signal path. To correct for this effect and achieve a consistent parameter, STEC is transformed into vertical TEC (VTEC) by applying a mapping function at the ionospheric pierce point (IPP), according to equation (2).

$$VTEC = STEC \times \cos\chi \tag{2}$$

Where χ is the zenith angle of the satellite signal at the IPP. The zenith angle is determined from the satellite elevation angle as:

$$\chi = arc\sin\left(\frac{R_E \cos\alpha}{R_E + h}\right) \tag{3}$$

Where R_E is the mean Earth radius, α is denotes the satellite elevation angle at the receiver is the assumed ionospheric shell height, which is assumed to be 400 kilometers (Kenpankho et al., 2013; Keokhumcheng & Kenpankho, 2025).

3.3 Data Collection and Tools

Data collection was conducted at the KMITL School of Industrial Education and Technology monitoring station in Bangkok, Thailand (13.73°N,100.78°E). The GNSS observation data were obtained using the BG2s multi-frequency GNSS receiver developed by the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), as show in Figure 2. The BG2s receiver is capable of tracking multiple Global Navigation Satellite Systems, including BDS, GPS, GLONASS, and Galileo, providing high precision pseudorange and carrier phase measurements suitable for ionospheric TEC analysis. The system setup consisted of a GNSS antenna, receiver unit, and data acquisition computer. The antenna was installed in an open-sky environment at Bangkok site to ensure stable satellite signal reception and minimize multipath interference.

Figure 2 BG2s GNSS observation system and receiver used for TEC data collection.

The study data collection period was in December 2025, covering a month for ionospheric conditions. During this period, multi-frequency GNSS signals were continuously recorded at a 30 second sampling rate, and the raw data were converted into RINEX format for subsequent processing and TEC computation. All TEC results presented in this study refer to VTEC which allows direct comparison between GPS and BDS observations. The dataset provides a representative view of ionospheric dynamics over Bangkok, enabling a detailed assessment of GPS and BDS performance in low-latitude TEC estimation.

4. Results

This study analyzed BDS and GPS TEC data collected at the KMITL monitoring station in Bangkok during December 2025. Both systems exhibited typical low-latitude ionospheric behavior: TEC values remained low at midnight, increased rapidly after sunrise, peaked around local noon, and gradually declined in the evening. This pattern reflects ionospheric dynamics driven by solar EUV radiation and EIA.

4.1 BDS TEC

The diurnal variation of BDS TEC shows a distinct low-latitude pattern, is show in Figure 3 Midnight (00:00-5:00 LT) values remained low (31-76 TECU), reflecting reduced ionization dominated by electron-ion recombination. Morning (06:00-11:00 LT) values rose sharply, reaching a peak of about 114 TECU around 10:00 LT, corresponding to enhanced ionization from solar EUV radiation and upward ExB drift. In the afternoon (12:00-18:00 LT), a secondary peak (99 TECU) was observed, indicating continued ionospheric disturbance possibly linked to re-intensification of the equatorial ionization anomaly. At nighttime (19:00-23:00 LT), TEC values declined to about 12 TECU, reflecting reduced ionization. Overall, BDS TEC exhibited higher peak amplitudes and additional afternoon enhancement, highlighting its sensitivity to ionospheric disturbances.

4.2 GPS TEC

GPS TEC followed a similar trend but with slightly lower magnitudes, is show in Figure 3 Midnight (00:00-05:00 LT) values remained low (18-64 TECU), close for BDS. Morning (06:00-14:00 LT) values rose rapidly, peaking at 105 TECU around 10:00-11:00 LT, about 18 TECU higher than BDS. Afternoon (12:00-18:00 LT) values declined smoothly without a pronounced secondary peak, suggesting reduced sensitivity to ionospheric disturbances. Nighttime (19:00-03:00 LT) values (16 TECU) converged with BDS. GPS TEC curves were smoother, indicating stable response but potentially underestimating short-term enhancements.

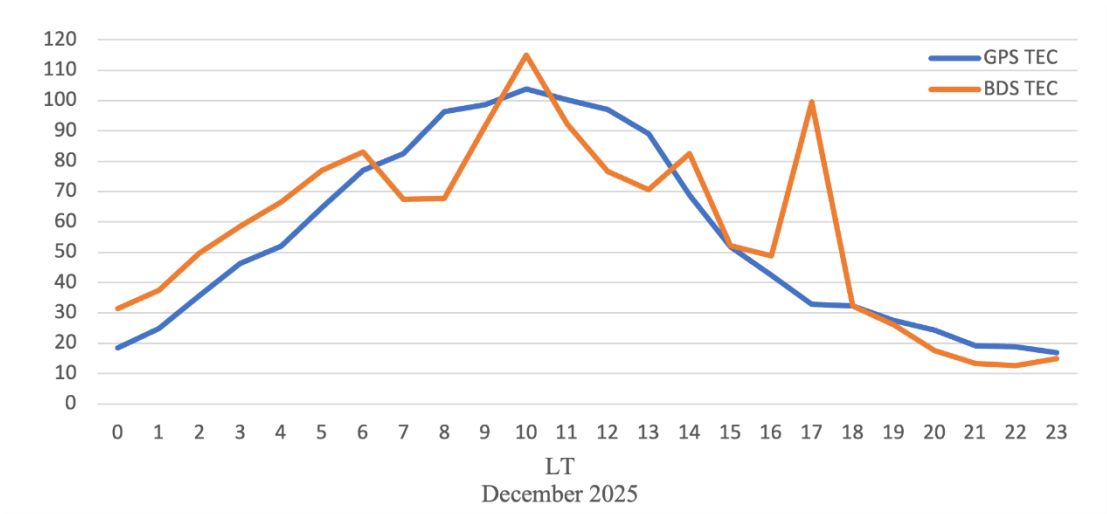

Figure 3 BDS and GPS TEC.

4.3 TEC Comparison

Based on the BDS and GPS TEC variations observed in December 2025, both systems exhibit similar diurnal behavior and consistent ionospheric patterns over Bangkok. TEC values remain low during the early morning hours, increase rapidly after sunrise, and reach their maximum around local noon, reflecting the typical dynamics of the low-latitude ionosphere driven by solar EUV radiation and equatorial electrodynamics. However, noticeable differences remain in the magnitude of the daily peaks, the sharpness of afternoon gradients, and the overall smoothness of the TEC curves derived from the two constellations. BDS generally shows higher peak values and occasional secondary enhancements in the afternoon, while GPS curves tend to be smoother and more stable. To further quantify the degree of agreement and identify systematic differences between BDS and GPS observations, the following subsections evaluate their statistical consistency using two key metrics. Root Mean Square Error (RMSE) and the Pearson correlation coefficient is show in Table 1 and Table 2. These indicators provide an objective assessment of how closely BDS TEC matches GPS TEC during December and reveal the strengths and limitations of each system in capturing ionospheric variability.

Table 1 RMSE (TECU) between BDS TEC and GPS TEC observed at THBK (Bangkok) station from December 2025.

Month	BDS and GPS
December	18.14

Table 1 summarizes, the Root Mean Square Error (RMSE) between BDS and GPS TEC observed at the THBK station in Bangkok during December 2025 was 18.14 TECU. This value indicates that while both systems maintain strong overall consistency, certain deviations exist, particularly during peak periods BDS TEC peaks are typically ~20 TECU higher than GPS, with the largest differences occurring in the morning hours when ionization increases rapidly, despite these discrepancies, the RMSE level remains within a reasonable range, demonstrating that BDS can reliably reproduce the variation patterns of GPS TEC. In summary, the RMSE results highlight systematic differences in magnitude between the two systems, but the relatively low error confirms that BDS serves as a reliable complement to GPS for ionospheric monitoring and modeling in low-latitude regions.

While the RMSE results highlight the magnitude differences between BDS TEC and GPS TEC, error metrics alone are not sufficient to fully capture the consistency of their temporal variation patterns. Therefore, to provide a more comprehensive evaluation of the reliability of both systems in monitoring ionospheric diurnal behavior, the Pearson correlation coefficient was also calculated. This metric assesses the linear relationship between the two datasets, offering insights into their agreement in peak timing, diurnal variation patterns, and overall dynamics.

Table 2 The correlation coefficient between BDS TEC and GPS TEC observed at THBK (Bangkok) station from December 2025.

Month	BDS and GPS
December	0.81

Table 2 summarizes, the Pearson correlation coefficient between BDS and GPS TEC observed at the THBK station in Bangkok during December 2025 was 0.81. This value indicates a strong agreement between the two systems in terms of overall diurnal variation trends. Peak times are nearly coincident. And nighttime values show minimal differences, confirming their reliability in capturing daily ionospheric behavior. Although BDS exhibits a secondary afternoon peak while GPS declines more smoothly, this difference does not significantly affect the overall correlation. In summary, the correlation coefficient results validate the consistency of BDS and GPS in capturing ionospheric trends, showing that BDS not only reflects the general variation but also provides enhanced sensitivity during certain periods, making it a valuable complement for ionospheric monitoring and space weather studies.

Overall, the correlation analysis demonstrates that BDS TEC can reliably reproduce GPS TEC variations during December 2025 in Bangkok's low-latitude ionosphere. Despite minor differences in peak magnitudes and the presence of a secondary afternoon enhancement in BDS data, both systems captured highly consistent diurnal patterns, with nearly coincident peak times and similar nighttime behavior. The RMSE value of 18.14 TECU indicates that numerical deviations remain within a reasonable range, as previous studies have reported RMSE values between 15-25 TECU as typical for low-latitude ionospheric TEC analyses. Similarly, the correlation coefficient of 0.81 confirms strong agreement, since values above 0.80 are generally interpreted as strong correlation in geophysical research, while coefficients greater than 0.70 are considered marginally acceptable. Together, these findings provide robust evidence that BDS TEC serves as a dependable complement to GPS TEC, supporting GNSS-based ionospheric modeling and enhancing monitoring capabilities in equatorial regions.

5. Conclusion and Discussion

This study investigated the diurnal variation of ionospheric TEC using BDS and GPS observations collected at the THBK station in Bangkok during December 2025. Both systems exhibited highly consistent diurnal patterns, with low values at night, rapid enhancement after sunrise, and a pronounced midday peak, despite this overall agreement, BDS TEC consistently showed higher peak magnitudes and a secondary afternoon enhancement, while GPS curves were smoother and more stable. Statistical evaluation confirmed these findings: the RMSE of 18.14 TECU indicated that deviations between the two systems remained within a reasonable range, and the correlation coefficient of 0.81 demonstrated strong agreement in overall variation trends. Together, these results provide robust evidence that BDS TEC can serve as a reliable complement to GPS TEC, enhancing GNSS ionospheric modeling and monitoring capabilities in equatorial regions. Furthermore, the observed differences highlight the potential of BDS to capture short-term ionospheric disturbances more sensitively, offering valuable insights for space weather research and multi GNSS applications.

The comparative analysis of BDS and GPS TEC during December 2025 over Bangkok demonstrates that both systems successfully captured the fundamental diurnal ionospheric variation, characterized by low values at night, rapid enhancement after sunrise, and a midday peak driven by solar EUV radiation and equatorial electrodynamics. These findings are consistent with global multi-GNSS modeling studies, which have shown that integrating GPS, BDS, Galileo, and GLONASS observations enhances the reliability of ionospheric monitoring and reduces uncertainties in TEC estimation (Ren et al., 2016). At the regional scale, this study confirmed Kenpankho et al. (2013) that compared observed TEC values with lRl-2007 predictions in equatorial Thailand, confirming the importance of ground-based GNSS receivers for validating ionospheric models under local conditions. More recently, this study agreed with Keokhumcheng and Kenpankho (2025) who investigated TEC using single-frequency GPS receivers, demonstrating practical approaches for monitoring ionospheric variability with limited instrumentation. Statistical evaluation in the present study further supports these observations: the RMSE of 18.14 TECU indicates that deviations between BDS and GPS remain within a reasonable range, while the correlation coefficient of 0.81 confirms strong agreement in overall variation trends. Taken together, these results provide robust evidence that BDS TEC can serve as a reliable complement to GPS TEC, reinforcing the importance of multi-constellation GNSS observations for ionospheric monitoring and modeling in equatorial regions.

6. Acknowledgment

We would like to express their sincere gratitude to the Space, Satellite, and Study Laboratory (SSS Lab), Department of Engineering Education, School of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand for their invaluable support throughout this research. The laboratory provided essential resources, technical guidance, and an inspiring academic environment that greatly contributed to the successful completion of this study. The encouragement and assistance from faculty members and colleagues at SSS Lab have been instrumental in refining the methodology, enhancing the analysis, and ensuring the overall quality of this work.

7. References

Abdelazeem, M., Çelik, R. N., & El-Rabbany, A. (2017). An efficient regional ionospheric model using combined GPS/BeiDou observations. Journal of Spatial Science, 62(2), 323–335. https://doi.org/10.1080/14498596.2016.1253512.

Astafyeva, E., Zakharenkova, I., & Förster, M. (2015). Ionospheric response to the 2015 St. Patrick's Day storm: A global multi-instrumental overview. Journal of Geophysical Research: Space Physics, 120(10), 9023–9037. https://doi.org/10.1002/2015JA021629.

Cai, C., & Gao, Y. (2013). Modeling and assessment of combined GPS/GLONASS precise point positioning. GPS Solutions, 17(2), 223–236. https://doi.org/10.1007/s10291-012-0273-9.

Chen, C., Pavlov, I., Padokhin, A., Yasyukevich, Y., Demyanov, V., Danilchuk, E., & Vesnin, A. (2024). Galileo and BeiDou AltBOC signals and their perspectives for ionospheric TEC studies. Sensors, 24(19), 6472. https://doi.org/10.3390/s24196472.

Cheng, N., Song, S., Jiao, G. Q., Jin, X., & Li, W. (2021). Global monitoring of geomagnetic storm-induced ionosphere anomalies using 3-D ionospheric modeling with multi-GNSS and COSMIC measurements. Radio Science, 56(2), e2020RS007074. https://doi.org/10.1029/2020RS007074.

Hernández-Pajares, M., Juan, J. M., & Sanz, J. (1999). New approaches in global ionospheric determination using ground GPS data. Journal of Atmospheric and Solar-Terrestrial Physics, 61(16), 1237–1247. https://doi.org/10.1016/S1364-6826(99)00054-1.

Hernández-Pajares, M., Juan, J. M., Sanz, J., Aragón-Àngel, À., García-Rigo, A., Salazar, D., & Escudero, M. (2011). The ionosphere: Effects, GPS modeling and the benefits for space geodetic techniques. Journal of Geodesy, 85(12), 887–907. https://doi.org/10.1007/s00190-011-0508-5.

Keokhumcheng, T., & Kenpankho, P. (2025). The study of total electron content on ionosphere by using single frequency GPS receiver. Advances in Space Research, 75(5), 4245–4259. https://doi.org/10.1016/j.asr.2024.08.019.

Kenpankho, P., Supnithi, P., Nagatsuma, T., Tsugawa, T., & Maruyama, T. (2013). Comparison of observed TEC values with IRI-2007 TEC and IRI-2007 TEC with optional foF2 measurements predictions at an equatorial region, Chumphon, Thailand. Advances in Space Research, 52(10), 1820–1826. https://doi.org/10.1016/j.asr.2013.08.012.

Oluwadare, T. S., Nguyen Thai, C., Akala, A. O. O., Heise, S., Alizadeh, M., & Schuh, H. (2019). Characterization of GPS-TEC over African equatorial ionization anomaly (EIA) region during 2009–2016. Advances in Space Research, 63(1), 282–301. https://doi.org/10.1016/j.asr.2018.08.044.

Ren, X., Zhang, X., Xie, W., Zhang, K., Yuan, Y., & Li, X. (2016). Global ionospheric modelling using multi-GNSS: BeiDou, Galileo, GLONASS and GPS. Scientific Reports, 6, 33499. https://doi.org/10.1038/srep33499.

Song, S., & Liu, X. (2019). Adaptability of GPS/BDS broadcast ionospheric models to solar activities. Advances in Space Research, 63(9), 2867–2876. https://doi.org/10.1016/j.asr.2019.01.049.

Wang, N., Wang, Y., & Xiong, J. (2018). GPS, BDS and Galileo ionospheric correction models: An evaluation in range delay and position domain. Journal of Atmospheric and Solar-Terrestrial Physics, 170, 83–91. https://doi.org/10.1016/j.jastp.2018.02.014.

Wang, Y., Le, H., Liu, L., Chen, Y., Xiong, B., Zhang, R., Liu, B., Li, W., Sun, W., & Li, Y. (2025). Mapping the ionosphere over East Asia based on ground-based GNSS TEC data (2010–2023). Space Weather, 23(2), e2025SW004343. https://doi.org/10.1029/2025SW004343.

Wang, Y., Wang, H., Dang, Y., Ma, H., Xu, C., Yang, Q., Ren, Y., & Fang, S. (2022). BDS and Galileo: Global ionosphere modeling and the comparison to GPS and GLONASS. Remote Sensing, 14(21), 5479. https://doi.org/10.3390/rs14215479.

Xu, L., Li, X., & He, L. (2020). Performance analysis of BDS single frequency ionosphere model. Chinese Journal of Space Science, 40(3), 341–348. https://doi.org/10.11728/cjss2020.03.341.

THE DEVELOPMENT OF INSTRUCTIONAL MATERIALS BASED ON HOLISTIC LEARNING PRINCIPLES FOR THE DESIGN AND ANALYSIS OF AUDIO FREQUENCY AMPLIFIER CIRCUITS

Kitipong Mano* and Pitsini Mano

kitipong.ma@kmitl.ac.th and pitsini.ma@kmitl.ac.th

Department of Engineering Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author Email: kitipong.ma@kmitl.ac.th

ABSTRACT

This research aimed to develop instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits and to investigate their quality, efficiency, and students' opinions toward the developed instructional materials. The sample group consisted of 10 first-year undergraduate students enrolled in the Bachelor of Technology Program in Electronics Technology at King Mongkut's Institute of Technology Ladkrabang, selected by simple random sampling. The research instruments consisted of instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits, including content documents, worksheets, performance assessment rubrics, and a student opinion questionnaire. The instruments were evaluated by three experts who possessed at least a master's degree and had no less than five years of teaching experience in electronics. The statistics used for data analysis were mean and standard deviation. The research results revealed that the developed instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits achieved a very high level of quality ($\overline{X}$ = 4.77, S.D. = 0.35). In addition, the efficiency of the instructional materials showed an E1/E2 value of 81.97/82.38, which met the established criterion of 80/80. Furthermore, students' opinions toward the use of the instructional materials were at the highest level ($\overline{X}$ = 4.68, S.D. = 0.24). The findings indicate that students were able to better understand the content and improve their learning outcomes after completing the learning process, both in terms of conceptual understanding and practical skills in electronic circuit design. Moreover, students expressed positive opinions toward the developed instructional materials, indicating that the materials were consistent with holistic learning principles. As a result, students were able to effectively integrate theoretical knowledge with practical applications.

Keywords: Amplifier circuit design, Holistic learning, Instructional media

1. Background of the Problem

The Thirteenth National Economic and Social Development Plan (2023–2027) (Office of the National Economic and Social Development Council [NESDC], 2022) emphasizes the promotion of interactive and practice-oriented teaching approaches by supporting Active Learning, which enables learners to develop knowledge and skills through hands-on experiences. In contemporary engineering education, learners are expected not only to acquire theoretical knowledge but also to develop analytical thinking, design capabilities, practical skills, as well as social and emotional competencies, all of which are essential competencies for engineers in the 21st century. Consequently, the concept of Holistic Learning has gained

widespread attention because it aims to promote balanced learner development across multiple dimensions, including intellectual, creative, physical, social, and emotional aspects (Miller, 2007)

Previous studies have primarily focused on isolated problem-solving processes or the development of specific technical skills, while lacking instructional designs that enable learners to perceive the overall system and systematically connect knowledge toward deeper analysis and design (Avvento & Sudano, 2020; Freeman et al., 2014). In the context of electronics engineering education, particularly in electronic circuit analysis and design, most studies continue to emphasize theoretical analysis or circuit behavior simulation through mathematical models and software applications. Although such approaches help learners understand abstract circuit principles and facilitate circuit testing through development boards and simulation tools, they remain insufficient in supporting learners' ability to connect theoretical understanding to real-world circuit design practices (Taher, 2015).

The course on Electronic Circuit Analysis and Design covers both analog and digital circuit analysis and design, which are highly complex fields characterized by rapidly evolving technologies. Analog electronics topics include electronic devices, small-signal amplifiers, feedback circuits, power amplifiers, filter circuits, power supply circuits, and various functional circuits. Instruction is generally delivered through theoretical lectures, mathematical analysis, and computer-based simulations. Most learning activities focus on symbolic representations, mathematical equations, and circuit models, with limited opportunities for students to construct and implement actual circuits and systems (Tokatlidis et al., 2024). Effective learning in this field requires students to understand electronic devices, circuit operations, compatibility among circuit stages, and the ability to analyze, design, and integrate circuits into functional systems. Such learning processes can enhance students' circuit design skills, system integration capabilities, component selection, circuit optimization, communication within teams, self-directed learning, professional responsibility, and pride in their accomplishments.

However, classroom observations in the Electronic Circuit Analysis and Design course revealed that students still lack the ability to connect theoretical knowledge to practical applications, particularly in the topic of Audio Amplifier Design (Cordell, 2011). This topic involves several complex subsystems, including the Input Stage (IPS), Voltage Amplifier Stage (VAS), Output Stage (OPS), Tone Control circuits, Power Supply circuits, and integration with Bluetooth modules, which are widely used in modern electronic products. To support holistic engineering learning, the instructional approach in this study integrated Problem-Based Learning (PBL) (Savery, 2006), Project-Based Learning (PBL) (Thomas, 2000), and the Engineering Design Process (EDP). These approaches provide learners with opportunities to engage in authentic practices, including circuit analysis, design, PSPICE simulation, prototype construction, testing, and real-world implementation.

Based on the significance of these issues, the researcher aimed to develop instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits. The instructional materials were designed to support learners in developing analytical thinking, circuit design, circuit implementation, and system integration skills through authentic engineering practices. In addition, the instructional approach aimed to enhance communication skills, teamwork, self-confidence, and pride in learners' achievements. Ultimately, this study sought to improve the effectiveness of teaching and learning in the Electronic Circuit Design course, particularly in the topic of audio frequency amplifier circuit analysis and design, in alignment with the expected learning outcomes specified in the Bachelor

of Technology Program in Electronics Technology, Department of Engineering Education, Faculty of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang (Revised Curriculum, 2024).

2. Objectives

2.1 To develop and evaluate the efficiency of instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits.

2.2 To investigate students' opinions toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits.

3. Conceptual Framework and Hypothesis

The development of instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits was developed through the integration of the following conceptual frameworks:

3.1 Conceptual Framework

3.1.1 Holistic Learning

Holistic Learning emphasizes learner development through the integration of multiple dimensions of learning, including intellectual, creative, physical, social, and emotional aspects (Miller, 2005, 2007).

3.1.2 Project-Based Learning (PBL) and Problem-Based Learning (PBL)

Project-Based Learning and Problem-Based Learning are instructional approaches that emphasize learning through hands-on activities while promoting analytical thinking and problem-solving skills (Savery, 2006; Hmelo-Silver, 2004).

3.1.3 Engineering Design Process (EDP)

The Engineering Design Process is a systematic approach used to solve engineering problems. The process consists of several important stages, including problem analysis, design, prototype development, and testing (Dym et al., 2005).

3.1.4 Efficiency Evaluation of the Instructional Materials

The efficiency evaluation of the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits was conducted according to the framework proposed by Chaiyong Promwong (Phromwong, 2013). The efficiency of the instructional materials was determined using the E1/E2 criterion, where E1 (Efficiency of Process) refers to the efficiency of the learning process as measured through learners' performance during instruction, and E2 (Efficiency of Product) refers to the efficiency of the learning outcomes achieved after instruction.

3.2 Research Hypotheses

3.2.1 The instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits would achieve a quality level of "good" or higher.

3.2.2 The instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits would achieve an efficiency value (E1/E2) not lower than the established criterion of 80/80.

3.2.3 Students' opinions toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits would be at a high level or higher.

4. Research Methodology

4.1 Population and Sample

The population of this study consisted of 30 first-year undergraduate students enrolled in the Bachelor of Technology Program in Electronics Technology, Faculty of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang.

The sample group consisted of 10 first-year undergraduate students enrolled in the Bachelor of Technology Program in Electronics Technology, Faculty of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang. The participants were selected using a simple random sampling method.

4.2 Research Instruments

4.2.1 The instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits, as illustrated in Figure 1, consisted of PowerPoint instructional media for the Electronic Circuit Analysis and Design course on the topic of audio frequency amplifier circuit design and analysis, electronic components and equipment for circuit construction, and worksheets. Each worksheet consisted of the worksheet title, learning objectives, required tools and equipment, operational procedures, sections for recording significant results, and 12 post-activity questions accompanied by a four-level scoring rubric. The instructional materials were designed in accordance with the proposed conceptual framework and comprised a total of eight worksheets.

4.2.2 Quality Assessment Forms for Worksheets, Equipment, and PowerPoint Media

The quality assessment forms for the PowerPoint instructional media, worksheets, and laboratory equipment were designed to comprehensively evaluate six major aspects: content and academic accuracy, PowerPoint media and content presentation, worksheets and learning activities, equipment and laboratory practice, holistic learning, and measurement and valuation. The assessment employed a five-level Likert rating scale to evaluate the quality and appropriateness of the developed instructional materials.

4.2.3 Performance Assessment Rubric and Test Worksheets

The performance assessment rubric was developed in the form of an Analytic Rubric to evaluate students' performance in the design and analysis of audio frequency amplifier circuits. The rubric employed four performance levels: excellent (4 points), good (3 points), fair (2 points), and improvement needed (1 point) (Chan, 2015). Behavioral indicators were clearly defined for each level to systematically assess students' competencies.

The assessment criteria included planning, circuit analysis and design, correctness of circuit implementation, neatness of circuit assembly, operational efficiency, circuit testing, troubleshooting, teamwork, communication, information searching, and self-directed learning. These competencies were considered essential for engineering practice and aligned with the principles of holistic learning and authentic learning experiences.

The test worksheets were designed by integrating knowledge and practical skills related to the design and analysis of audio frequency amplifier circuits. In addition, 16 post-activity questions from the original worksheets that were aligned with the learning objectives were selected and adapted for use in the assessment activities.

4.2.4 Student Opinion Questionnaire

The student opinion questionnaire toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits consisted of eight major dimensions:

1. knowledge and understanding (3 items),
2. analysis and design skills (3 items),
3. project-based learning (3 items),
4. problem-solving skills (2 items),
5. real-world application and integration (2 items),

6. presentation and reflection (2 items),
7. five-dimensional holistic learning (5 items), and
8. satisfaction and overall learning experience (3 items).

The questionnaire contained a total of 22 items and employed a five-level Likert rating scale to evaluate students' opinions and satisfaction toward the developed instructional materials. The questionnaire was designed to comprehensively assess all dimensions of holistic learning in a systematic manner.

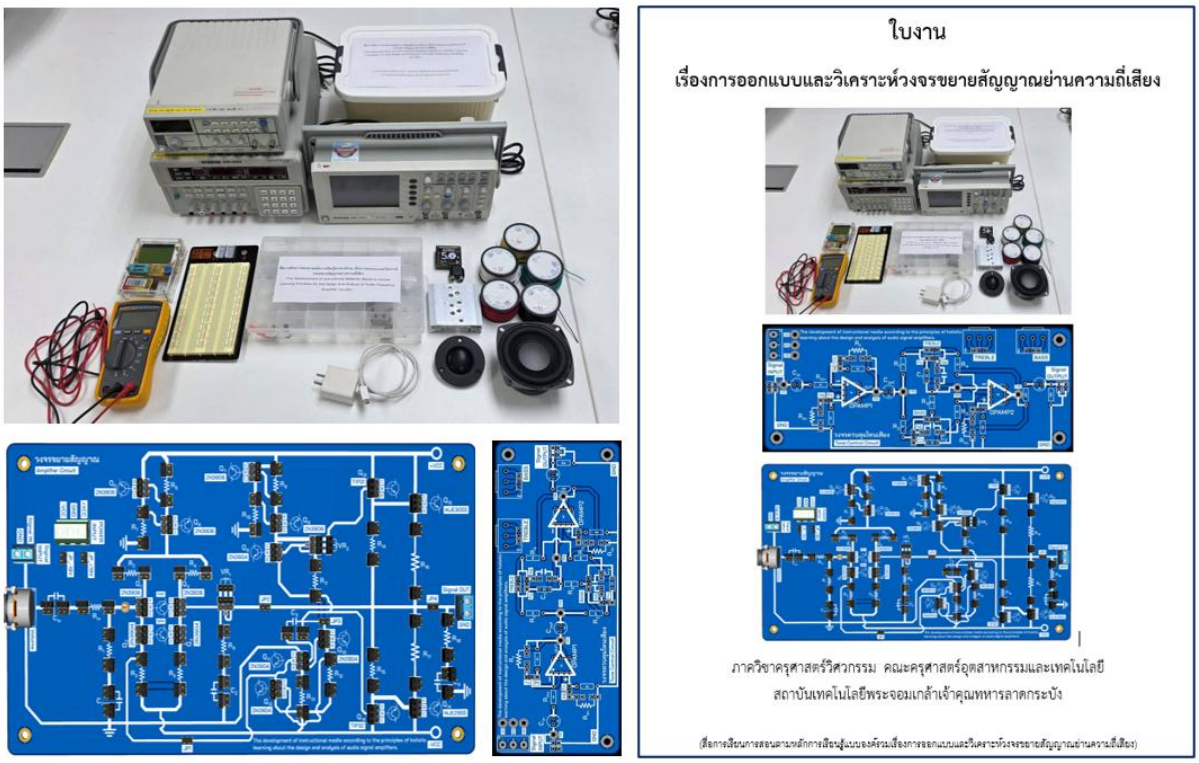

Figure 1 Instructional Materials Based on Holistic Learning Principles for the Design and Analysis of Audio Frequency Amplifier Circuits

The quality evaluation of the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits, as well as the verification of the congruence between the assessment questions and the learning objectives, was conducted by three experts who possessed at least a master's degree and had a minimum of five years of teaching experience in electronics.

The evaluation results revealed that the overall quality of the instructional materials across all six dimensions was at a very high level ($\bar{X}$ = 4.77, S.D. = 0.35). When considering each aspect individually, the findings showed that:

1. content and academic accuracy were rated at a very high level ($\bar{X}$ = 4.87, S.D. = 0.31);
2. PowerPoint media and content presentation were rated at a very high level ($\bar{X}$ = 4.93, S.D. = 0.25);
3. worksheets and learning activities were rated at a very high level ($\bar{X}$ = 4.83, S.D. = 0.29);
4. equipment and laboratory practice were rated at a very high level ($\bar{X}$ = 4.87, S.D. = 0.25);
5. holistic learning components were rated at a high level ($\bar{X}$ = 4.73, S.D. = 0.25); and
6. measurement and evaluation were rated at a high level ($\bar{X}$ = 4.25, S.D. = 0.00).

In addition, the results of the congruence analysis between the questions and the learning objectives revealed that the post-activity questions had Index of Item-Objective Congruence (IOC) values ranging from 0.67 to 1.00. This indicates that the questions were consistent with the learning objectives and were appropriate for implementation. A total of 96 questions met the established criteria.

4.3 Learning Activities

4.3.1 Knowledge Acquisition

This activity focused on providing learners with integrated foundational knowledge necessary for audio amplifier circuit design. The instructional content included small-signal amplifier circuits, differential amplifier circuits, current mirror circuits, constant current source circuits, class-AB power amplifiers, operational amplifier circuits, feedback circuits, filter circuits, tone control circuits, power supply circuits, circuit simulation using PSPICE software, Bluetooth modules, and audio systems. These topics were integrated to establish the foundational knowledge required for circuit design and implementation.

4.3.2 Circuit Analysis, Design, and Simulation

This learning activity emphasized the analysis and design of circuits required for audio amplifier systems. Students analyzed and designed electronic circuits and simulated their operation using PSPICE software. Students recorded experimental results and answered post-activity questions based on Worksheets 1–5.

4.3.3 Project-Based Learning

Students were divided into groups of two members. Each group was assigned a project involving the design of an audio power amplifier circuit and a tone control circuit. The project activities included planning, calculation, circuit design, circuit assembly on a prototyping board, and circuit testing.

Testing instruments included a multimeter, function generator, and oscilloscope. Students measured and recorded experimental results and completed post-activity questions based on Worksheet 6.

4.3.4 Problem-Based Learning

In this activity, students learned through solving practical problems commonly encountered in audio amplifier circuit design. The problems included signal distortion, insufficient output power, thermal issues, energy consumption control, and circuit tuning for efficiency and safety before operation with actual audio input signals.

Students analyzed the problems, adjusted and optimized circuit performance, recorded experimental results, and answered post-activity questions based on Worksheet 7.

4.3.5 Contextual Learning

This activity connected the designed and optimized audio amplifier circuits to real-world applications. Students connected a Bluetooth module to the amplifier input and connected the output to speakers. They then used their personal mobile devices to connect to the Bluetooth module and selected music from YouTube for testing purposes.

Students measured input and output signals, evaluated circuit performance, recorded the results, and answered post-activity questions based on Worksheet 8.

4.3.6 Presentation and Reflection

In this activity, students presented their projects for 10 minutes, with each team member responsible for approximately 5 minutes of presentation time. After the presentations, students participated in reflection activities through both guided and open-ended questions. Reflection topics included newly acquired knowledge, problem-solving approaches, design processes, simulation using PSPICE, differences between simulation and actual implementation, team member roles, team strengths, collaborative challenges, strategies for improving teamwork, and the aspects of the activity of which they were most proud.

Examples of students' activities and project outcomes are illustrated in Figure 2.

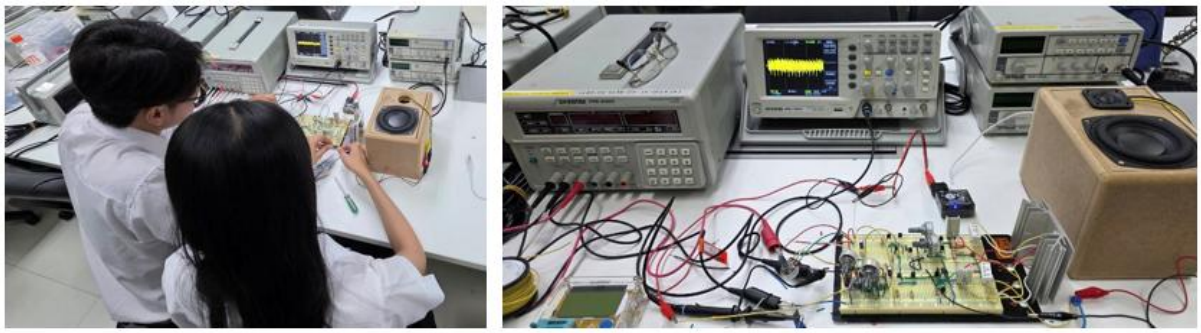

Figure 2 Examples of Learning Activities and Student Projects

4.4 Data Collection and Data Analysis

The data collection process consisted of two major parts. The first part involved collecting data to determine the efficiency of the instructional materials using the E1/E2 efficiency criterion. The process efficiency (E1) was calculated using the average percentage scores of the sample group obtained from the performance assessment rubrics and the post-activity worksheet questions from Worksheets 1–8.

The performance assessment rubric employed a four-level evaluation criterion. The scores for each worksheet were multiplied by a difficulty weighting factor; therefore, the total scores differed across worksheets according to the complexity of the practical activities. In contrast, the post-activity worksheet questions were evaluated using a four-level scoring rubric with equal total scores across all worksheets. The scores from both sections were combined to calculate the average scores and percentage values for determining the process efficiency (E1). The product efficiency (E2) was determined using the average percentage scores of the sample group obtained from the performance assessment rubric for the test worksheet and the post-test worksheet questions. Both assessment components employed four-level scoring criteria. The scores from these two sections were combined to calculate the average scores and percentage values for determining the product efficiency (E2).

The second part of the data collection involved gathering students' opinions toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits after the completion of all learning activities. Data were collected using a student opinion questionnaire consisting of eight dimensions and a total of 22 items. The collected data were analyzed using descriptive statistics, including mean and standard deviation, through Microsoft Excel software.

5. Research Results

The research results of the development of instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits are presented as follows.

5.1 Efficiency of the Instructional Materials Based on Holistic Learning Principles for the Design and Analysis of Audio Frequency Amplifier Circuits

The results of the efficiency evaluation of instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits are presented in Table 1.

Table 1 Efficiency of the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits

Experimental Results	Number of Students	Score		Percentage (Efficiency)
		Full Score	Mean Score	
Process Efficiency (E1)	10	175	143.45	81.97
Product Efficiency (E2)	10	80	65.90	82.38

According to Table 1, the process efficiency (E1) was 81.97, while the product efficiency (E2) was 82.38. These results indicate that the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits achieved an efficiency value (E1/E2) of 81.97/82.38.

5.2 Students' Opinions Toward the Instructional Materials Based on Holistic Learning Principles for the Design and Analysis of Audio Frequency Amplifier Circuits

The analysis of the sample group's opinions toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits was conducted across eight major dimensions. The results revealed that:

1. the knowledge and understanding dimension was rated at the highest level ($\bar{X}$ = 4.60, S.D. = 0.25);
2. the analysis and design dimension was rated at a high level ($\bar{X}$ = 4.43, S.D. = 0.03);
3. the project-based learning dimension was rated at the highest level ($\bar{X}$ = 4.48, S.D. = 0.30);
4. the problem-solving dimension was rated at a high level ($\bar{X}$ = 4.40, S.D. = 0.00);
5. the real-world application dimension was rated at the highest level ($\bar{X}$ = 4.75, S.D. = 0.37);
6. the presentation and reflection dimension was rated at the highest level ($\bar{X}$ = 4.55, S.D. = 0.22);
7. the five-dimensional holistic learning dimension was rated at the highest level ($\bar{X}$ = 4.82, S.D. = 0.21); and
8. the satisfaction and overall learning experience dimension was rated at the highest level ($\bar{X}$ = 5.00, S.D. = 0.00).

The detailed results for each questionnaire item are presented in Table 2.

Table 2 Students' opinions toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits

Questionnaire Items	N = 10		Opinion level
	$\bar{X}$	S.D.	
1. The instructional content enhances your understanding of the operating principles of audio amplifier circuits.	4.10	0.32	High
2. The integration of content (e.g., amplifiers, operational amplifiers, filters, and power supply circuits) enables you to understand the overall system.	5.00	0.00	Very high
3. The use of PSPICE enhances your understanding of circuit operation.	4.70	0.48	Very high

Table 2 (continued)

Questionnaire Items	N = 10		Opinion level
	$\overline{X}$	S.D.	
4. You are able to analyze and design amplifier circuits.	4.50	0.53	High
5. Circuit simulation enhances your confidence before performing real-world implementation.	4.30	0.48	High
6. The worksheets enhance your systematic analytical thinking skills.	4.50	0.53	High
7. Project-based activities enhance your ability to design real-world circuits.	5.00	0.00	Very high
8. Teamwork enhances the effectiveness of your learning.	4.40	0.52	High
9. The use of laboratory equipment enhances your practical skills.	5.00	0.00	Very high
10. You are able to analyze and solve circuit-related problems (e.g., distortion, thermal issues, and output power limitations).	4.40	0.52	High
11. Solving real-world problems enhances your engineering skills.	4.40	0.52	High
12. Integrating a Bluetooth module with the circuit enhances your understanding of practical applications.	5.00	0.00	Very high
13. Experimenting with real signals (e.g., YouTube) enables you to connect theoretical knowledge to real-world applications and recognize the value of what you have learned.	4.50	0.53	High
14. Presenting your work enhances your communication skills.	4.10	0.32	High
15. Reflection activities help you better understand your own learning process.	5.00	0.00	Very high
16. This activity enhances your intellectual development.	4.90	0.32	Very high
17. This activity enhances your creativity.	5.00	0.00	Very high
18. This activity enhances your practical (hands-on) skills.	5.00	0.00	Very high
19. This activity enhances your teamwork skills.	4.30	0.48	High
20. This activity enhances your confidence and sense of achievement (emotional development).	4.90	0.32	Very high
21. You would like this holistic learning approach to be used in future instruction.	5.00	0.00	Very high
22. All activities contribute to the development of your engineering skills.	5.00	0.00	Very high
Overall mean	4.68	0.24	Very high

According to Table 5.2, students' opinions toward the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits were at the highest level of satisfaction ($\overline{X}$ = 4.68, S.D. = 0.24), which was consistent with the research hypothesis.

6. Discussion and Conclusion

The findings of this study revealed that the instructional materials based on holistic learning principles for the design and analysis of audio frequency amplifier circuits achieved the established efficiency criterion of 80/80, with an E1/E2 value of 81.97/82.38. This indicates that the developed instructional materials were effective in enhancing students' learning both during the learning process and in terms of post-learning outcomes.

The process efficiency (E1) value of 81.97 reflects that the designed learning activities, including worksheets, circuit simulation using PSPICE software, and hands-on practical activities, were appropriate and supportive of student learning. As a result, students were able to understand the content and perform the activities effectively. These findings are consistent with the concept of Holistic Learning, which emphasizes the integration of knowledge, skills, and experiences to develop learners across multiple dimensions (Forbes, 2003).

Regarding the product efficiency (E2), the value of 82.38 indicates that students achieved higher learning outcomes after instruction and were able to apply their knowledge in practical contexts, particularly in the analysis and design of amplifier circuits, which are essential competencies in electronics engineering. Furthermore, the slightly higher E2 value compared with E1 also reflects the process of learning consolidation that occurred after the instructional activities.

The results of students' opinions revealed that the overall evaluation was at the highest level ($\overline{X}$ = 4.68, S.D. = 0.24), further supporting that the developed instructional materials and learning activities could create meaningful learning experiences for students. Learners were able to connect theoretical knowledge with real-world applications, such as experimenting with real audio signals and integrating actual devices, including Bluetooth modules.

In addition, Project-Based Learning (PBL) played a significant role in enhancing students' engineering competencies by promoting analytical thinking, problem-solving skills, and teamwork. These findings are consistent with the study by Prince and Felder (Prince & Felder, 2006), which reported that Project-Based Learning effectively enhances problem-solving abilities and deep learning among engineering students.

In terms of holistic learning outcomes, the findings demonstrated that the developed instructional approach successfully promoted all five dimensions of learner development: intellectual, creative, physical, social, and emotional aspects. This indicates that the proposed instructional model not only enhanced academic knowledge but also fostered essential 21st-century learner characteristics in a comprehensive manner. However, it was found that the dimensions related to content comprehension, presentation activities for communication skill development, and social skill development through teamwork were rated at a high level rather than the highest level. This may be attributed to the complexity and extensive nature of the content, particularly in topics involving circuit calculations and analysis. In addition, the participants were undergraduate students in the Bachelor of Technology program, whose curriculum does not specifically emphasize pedagogical or presentation skills. Consequently, some students may have perceived their presentation performance as insufficient. Furthermore, the teamwork activities may have been affected by the random grouping process, requiring students to spend additional time adapting to group collaboration and improving communication within their teams.

Therefore, it can be concluded that the instructional materials developed based on holistic learning principles, integrated with Project-Based Learning, Problem-Based Learning, and the

Engineering Design Process, were effective and appropriate for implementation in electronics engineering education. The developed instructional approach significantly enhanced students' academic achievement and essential engineering skills.

7. Acknowledgements

The authors would like to express their sincere gratitude to the Faculty of Industrial Education and Technology, King Mongkut's Institute of Technology Ladkrabang, for providing financial support for this research through institutional funding.

8. References

Avvento, R., & Sudano, E. (2020). Systems thinking and STEM/technical training: How to use a holistic view to prevent end-to-end system problems. In Proceedings of the 2020 IEEE Integrated STEM Education Conference (ISEC). IEEE.

Chan, C. K. Y. (2015). Rubrics for engineering education. Engineering Education Enhancement and Research Asia (E3R Asia).

Cordell, B. (2011). Designing audio power amplifiers. McGraw-Hill.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. Journal of Engineering Education, 94(1), 103–120.

Forbes, S. H. (2003). Holistic education: An analysis of its ideas and nature. Foundation for Educational Renewal.

Freeman, S., et al. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 111(23),8410–8415.

Hands-on and virtual laboratories in electronic circuits learning: Knowledge and skills acquisition.Information, 15(11), 672.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16(3), 235–266.

Miller, J. P. (2005). Holistic learning and spirituality in education. State University of New York Press.

Miller, R. (2007). What is holistic education? Holistic Education Review, 1(1), 1–10.

Office of the National Economic and Social Development Council (NESDC). (2022). The Thirteenth National Economic and Social Development Plan (2023–2027). Bangkok, Thailand: NESDC.

Phromwong, C. (2013). The efficiency testing of instructional media or instructional packages. Silpakorn Educational Research Journal, 5(1), 7–19.

Prince, M., & Felder, R. (2006). Journal of Engineering Education. Miller, J. (2007). Holistic curriculum.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. Journal of Engineering Education, 95(2), 123–138.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. Interdisciplinary Journal of Problem-Based Learning, 1(1), 9–20.

Taher, M. T. (2015). Effectiveness of simulation versus hands-on labs: A case study for teaching an electronics course. ASEE Conference Proceedings.

Thomas, J. W. (2000). A review of research on project-based learning. Autodesk Foundation.

SMART DECISION-MAKING ECOSYSTEM FOR ORGANIC RICE ADOPTION: INTEGRATING SOCIO-ECONOMIC FACTORS AND DIGITAL AGRICULTURAL EXTENSION

Kunlada Timkhaoprasert* and Pakkapong Poungsuk

68036007@kmitl.ac.th and pakkapong.po@kmitl.ac.th

Department of Agricultural Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 68036007@kmitl.ac.th

ABSTRACT

This study examines the key determinants influencing farmers' decision-making in participating in organic rice farming programs and develops an integrated conceptual framework within a smart agricultural ecosystem. A quantitative cross-sectional survey was conducted with 116 farmers in Wiang Chai District, Chiang Rai Province, Thailand, using a structured questionnaire. Descriptive statistics and inferential methods, including t-test and ANOVA, were applied. The results indicate that the overall influence on farmers' decision-making is high ($\bar{x}$ = 3.98, SD = 0.52). Socio-economic factors are the most influential ($\bar{x}$ = 4.38, SD = 0.45), followed by technological factors ($\bar{x}$ = 4.00, SD = 0.49), while environmental factors ($\bar{x}$ = 3.83, SD = 0.56) and institutional and market factors ($\bar{x}$ = 3.73, SD = 0.58) show moderate influence. Key determinants include the price of organic rice ($\bar{x}$ = 4.66, SD = 0.41), international market demand ($\bar{x}$ = 4.53, SD = 0.43), and farm size ($\bar{x}$ = 4.44, SD = 0.44). Group comparisons reveal that younger, more educated farmers and those with larger farm sizes are more likely to participate in organic rice farming programs. The study proposes a "Smart Decision-Making Ecosystem" integrating socio-economic, technological, environmental, and institutional and market factors with digital agricultural extension and innovation-driven approaches. The findings highlight the importance of market mechanisms, digital agricultural extension, and technological support in promoting sustainable agricultural adoption. These results provide practical implications for policymakers and agricultural extension services. Future research should apply advanced analytical methods and explore the long-term integration of digital agricultural technologies in sustainable farming systems.

Keywords: Organic rice farming, Farmers' decision-making, Smart agriculture

1. Statement of the Problem

Rice production plays a fundamental role in Thailand's economic, social, and food security systems, serving as both a staple food and a major export commodity. Despite Thailand's long-standing position as a leading rice exporter, productivity growth remains constrained, with increases largely driven by expansion in cultivated areas rather than improvements in efficiency (Panpluem et al., 2019). In recent years, global demand has shifted toward sustainable and organic agricultural products, prompting policy efforts to promote organic rice farming as a pathway to environmental sustainability, health safety, and value-added agricultural development. However, the transition from conventional to organic rice farming remains a complex and multidimensional process. Farmers' decisions to adopt organic practices are influenced by a combination of socio-

economic, environmental, and institutional factors. Previous studies have identified key determinants such as household income, farm size, access to markets, labor availability, and water resources as critical factors affecting production efficiency and adoption behavior (Panpluem et al., 2019). Similarly, economic incentives—particularly premium pricing and guaranteed markets—have been shown to significantly motivate farmers to shift toward organic agriculture (Thapa & Rattanasuteerakul, 2011; Pornpratansombat et al., 2011). In addition to economic drivers, social and knowledge-based factors also play an essential role. Farmers with higher levels of education, greater farming experience, and stronger participation in agricultural networks tend to exhibit more positive attitudes toward organic farming adoption (Anousack et al., 2024). Access to extension services, training, and information dissemination further enhances farmers' understanding and reduces perceived risks associated with organic production systems. Nevertheless, challenges such as limited technical knowledge, insufficient extension support, and market uncertainties continue to hinder wider adoption.

In the Thai context, structural constraints within the organic rice value chain further complicate adoption decisions. Studies have revealed that many farmers lack access to processing facilities, branding capabilities, and direct market channels, resulting in dependence on intermediaries and reduced economic returns (Pakdeenarong & Hengsadeekul, 2020; Kerdsriseam & Suwanmaneepong, 2015). Additionally, inadequate technological integration and limited use of digital tools in agricultural extension systems restrict farmers' ability to make informed and data-driven decisions.

Given these challenges, there is a critical need to better understand the underlying factors influencing farmers' decision-making in adopting organic rice farming within an integrated framework. While previous studies have examined individual determinants, there remains a gap in synthesizing these factors into a comprehensive "decision-making ecosystem" that incorporates economic, social, technological, and institutional dimensions. Furthermore, the role of digital agricultural extension and smart technologies in enhancing decision-making processes has not been sufficiently explored. Therefore, this study aims to investigate the key factors influencing farmers' participation in organic rice farming programs and to develop an integrated conceptual framework that supports smart decision-making in sustainable agricultural systems. The findings are expected to contribute to policy development, agricultural extension strategies, and the design of innovative learning ecosystems that promote sustainable and technology-driven agricultural transformation.

2. Objectives

The objectives of this study are to advance the understanding of farmers' decision-making processes in adopting organic rice farming within a sustainable and technology-driven agricultural context. Specifically, the study aims to:

2.1 To examine the key determinants influencing farmers' decision-making in participating in organic rice farming programs, focusing on socio-economic, technological, environmental, and institutional and market factors.

2.2 To develop an integrated smart decision-making framework for organic rice farming adoption by incorporating sustainable agricultural practices, digital extension systems, and innovation-driven approaches.

3. Conceptual Framework of the Study

The conceptual framework of this study is developed to explain farmers' decision-making processes in adopting organic rice farming within a sustainable and technology-driven agricultural

context. The framework integrates key theoretical perspectives, including decision-making theory, diffusion of innovation theory, and sustainable agriculture concepts, to provide a multidimensional understanding of farmers' participation in organic rice farming programs.

Decision-making theory suggests that individuals evaluate alternatives based on perceived benefits, risks, and available resources, which directly influence their behavioral choices (Simon, 1997). In agricultural contexts, farmers' decisions are shaped by both objective conditions and subjective perceptions, reflecting a complex interaction between economic, social, and environmental considerations.

In addition, the diffusion of innovation theory (Rogers, 2003) explains how new agricultural practices, such as organic farming, are adopted through processes influenced by perceived advantages, compatibility, and accessibility of innovations. This perspective is particularly relevant in understanding how farmers respond to organic farming practices and related technologies.

Furthermore, the concept of sustainable agriculture emphasizes the integration of economic viability, environmental sustainability, and social well-being (FAO, 2017). In this study, these dimensions are extended to include digital agricultural extension and innovation-driven approaches, which play an increasingly important role in enhancing farmers' decision-making capabilities.

Based on these theoretical foundations, the conceptual framework identifies four key dimensions influencing farmers' participation in organic rice farming:

- Socio-economic factors, including income, education, and farm characteristics
- Technological factors, such as access to agricultural innovations and digital extension services
- Environmental factors, including land suitability and natural resource conditions
- Institutional and market factors, such as price incentives, contract farming, and policy support

These dimensions interact within a "Smart Decision-Making Ecosystem," where traditional agricultural practices are integrated with digital technologies and innovation systems. This ecosystem perspective highlights the dynamic relationships among farmers, extension services, markets, and technological platforms in supporting sustainable agricultural transformation.

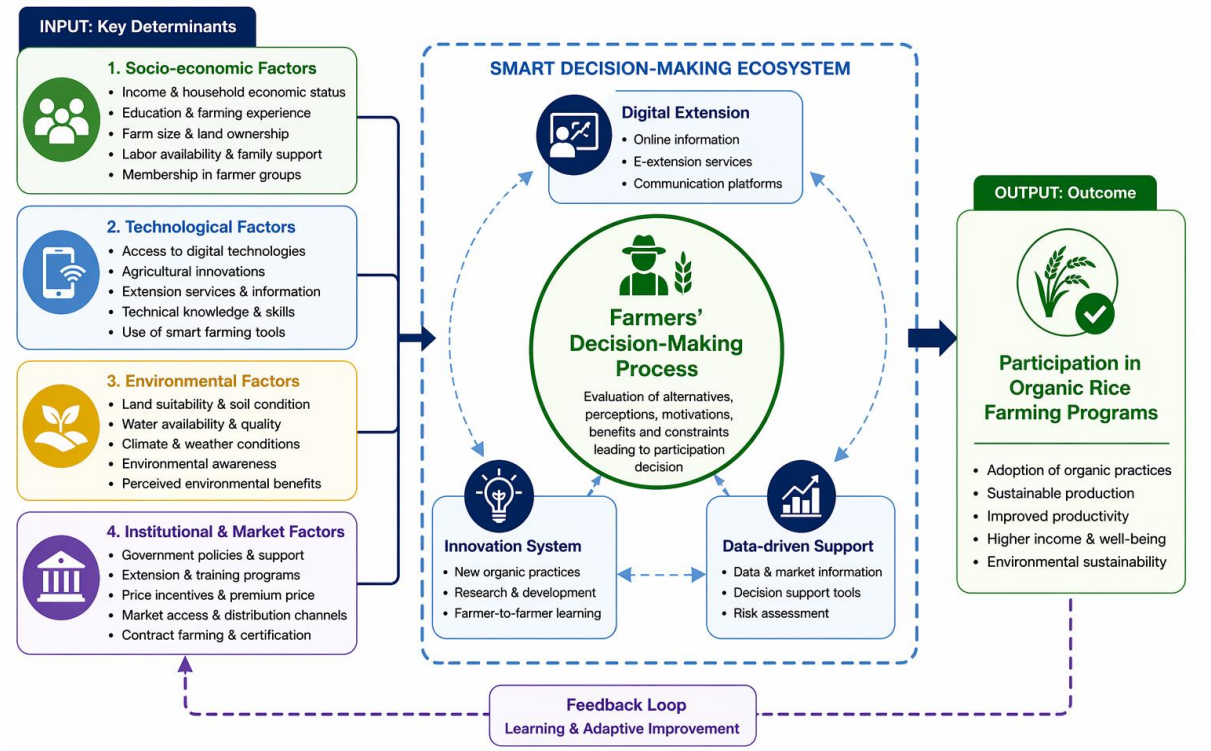

Figure 1 Conceptual framework of the study

4. Research Methodology

This study employs a quantitative research approach to investigate the key determinants influencing farmers' decision-making in participating in organic rice farming programs. The methodology is designed to ensure the validity and reliability of the findings while aligning with the research objectives and conceptual framework.

4.1 Research Methodology

This research adopts a descriptive and analytical research design to examine the factors influencing farmers' participation in organic rice farming programs. The study focuses on identifying multidimensional determinants, including socio-economic, technological, environmental, and institutional and market factors, and analyzing their influence on farmers' decision-making processes.

The research framework is grounded in a cross-sectional survey design, which allows data to be collected from a specific group of farmers at a single point in time. This approach is appropriate for capturing farmers' perceptions, attitudes, and decision-making behavior under real-world conditions.

4.2 Research Procedure

The research procedure consists of the following steps:

1. Literature Review: Relevant theories and empirical studies on decision-making, organic agriculture, and innovation adoption were reviewed to develop the conceptual framework.

2. Research Instrument Development: A structured questionnaire was designed based on the conceptual framework, covering key variables such as socio-economic characteristics, technological access, environmental conditions, and institutional support.

3. Instrument Validation: The questionnaire was reviewed by experts in agricultural education and agricultural extension to ensure content validity The Index of Item-Objective Congruence (IOC) scores ranged from 0.67 to 1.00, confirming the instrument is valid for the

study objectives. Data Collection: Data were collected from farmers participating in an organic rice farming program.

4. Data Processing and Analysis: Collected data were coded, verified, and analyzed using appropriate statistical techniques.

4.3 Data Collection

The population of this study consisted of approximately 250 farmers participating in an organic rice farming program in Wiang Chai District, Chiang Rai Province, Thailand. A total of 116 farmers were selected as the study sample using a purposive sampling method, focusing on newly participating farmers in the organic rice farming program. Data were collected using a structured questionnaire, which included the following sections:

- Socio-economic characteristics (e.g., age, education, income, farm size)
- Factors influencing decision-making (economic, social, technological, environmental, and institutional factors)
- Farmers' perceptions toward organic rice farming

The data collection was conducted over a defined period through field surveys and direct interaction with farmers to ensure data accuracy and completeness.

4.4 Data Analysis

The collected data were analyzed using both descriptive and inferential statistical methods to ensure a comprehensive interpretation of the research findings. Descriptive statistics, including frequency, percentage, mean, and standard deviation, were employed to summarize the socio-economic characteristics of farmers and to evaluate the level of influence of each factor on farmers' decision-making. In addition, inferential statistical techniques were applied to examine differences among farmer groups. An independent samples t-test was used to compare decision-making between two groups (e.g., younger and older farmers), while a one-way analysis of variance (ANOVA) was conducted to assess differences across multiple groups (e.g., education levels and farm sizes). Statistical significance was determined at the 0.05 level.

The analysis results were interpreted in relation to the conceptual framework to explain how socio-economic, technological, environmental, and institutional factors contribute to farmers' participation in organic rice farming programs. This combined analytical approach provides both a general overview and deeper insights into the determinants influencing farmers' decision-making.

5. Results

This section presents the findings of the study based on the analysis of data collected from 116 farmers participating in the organic rice farming program. The results are organized into two main parts: (1) socio-economic characteristics of the respondents and (2) factors influencing farmers' decision-making in participating in organic rice farming programs.

5.1 Socio-economic Characteristics of Farmers

The results indicate that farmers participating in the organic rice farming program exhibit diverse socio-economic characteristics. Most farmers have practical farming experience and are engaged in rice production as their primary occupation. The findings suggest that farm size, labor availability, and farming experience are important contextual variables that influence farmers' readiness to adopt organic rice farming practices.

In addition, access to agricultural information and participation in extension activities were found to support farmers' understanding of organic farming systems. These characteristics form a foundational context that shapes farmers' perceptions and decision-making behavior.

Table 1 Socio-economic characteristics of farmers (n = 116)

Variable	Frequency (n)	Percentage (%)
Gender		
Male	68	58.62
Female	48	41.38
Age (years)		
Below 40	21	18.10
40–49	34	29.31
50–59	38	32.76
60 and above	23	19.83
Education Level		
Primary education	52	44.83
Secondary education	41	35.34
Higher education	23	19.83
Farming Experience (years)		
Less than 10 years	28	24.14
10–20 years	47	40.52
More than 20 years	41	35.34
Farm Size		
Small (<10 rai)	33	28.45
Medium (10–20 rai)	49	42.24
Large (>20 rai)	34	29.31
Labor Availability		
Family labor only	61	52.59
Family and hired labor	55	47.41
Access to Information		
Limited	29	25.00
Moderate	53	45.69
High	34	29.31

Table 1 presents the socio-economic characteristics of the farmers participating in the organic rice farming program. The results indicate that the majority of farmers are male and fall within the middle to older age groups, reflecting the demographic structure of agricultural communities. Most farmers have primary or secondary education and possess substantial farming experience. In terms of farm size, medium-scale farms are predominant, and more than half of the farmers rely primarily on family labor. Additionally, access to agricultural information is generally at a moderate level, which plays a crucial role in supporting farmers' decision-making processes.

5.2 Factors Influencing Farmers' Decision-Making

This section presents the analysis of key factors influencing farmers' decision-making in participating in organic rice farming programs. The factors are categorized into four main dimensions: socio-economic, technological, environmental, and institutional and market factors. The results provide insights into the relative importance of each dimension and highlight the primary drivers shaping farmers' adoption behavior.

Table 2 Factors influencing farmers' decision-making in organic rice farming participation

Factor Dimension	Mean Score ($\bar{x}$)	Level	Rank
Social -Economic factors	4.38	High	1
Technological factors	4.00	High	2
Environmental factors	3.83	Moderate	3
Institutional and service factors	3.73	Moderate	
Overall	**3.98**	**High**	-

Table 2 summarizes the key factors influencing farmers' decision-making in participating in organic rice farming programs. The overall level of influence is high (mean = 3.98), indicating that farmers are strongly affected by multiple dimensions when making adoption decisions. Among these, socio-economic factors rank as the most influential (mean = 4.38), followed by technological factors, which also demonstrate a high level of influence. In contrast, environmental factors and institutional and market factors show comparatively moderate levels of influence. These findings highlight the dominant role of economic incentives, market opportunities, and technological access in shaping farmers' adoption behavior within the proposed smart decision-making ecosystem.

5.3 Key Determinants of Participation

This section provides a detailed analysis of the most influential individual factors affecting farmers' participation in organic rice farming programs. While the previous section presented the overall dimensions of influence, this section focuses on identifying specific determinants that play a critical role in shaping farmers' decision-making. The results highlight the relative importance of market-driven and resource-based factors, offering deeper insights into the key drivers of farmers' adoption behavior.

Table 3 Key determinants influencing farmers' participation in organic rice farming

Determinant	Mean Score ($\bar{x}$)	Level	Rank
Price of organic rice products	4.66	High	1
High demand in international markets	4.53	High	2
Farm size / landholding capacity	4.44	High	3
Water availability and rainfall conditions	3.23	Moderate	4

Table 3 presents the key determinants influencing farmers' participation in organic rice farming programs. The results indicate that the price of organic rice products is the most influential factor, followed by international market demand and farm size. These findings emphasize the dominant role of economic incentives and market opportunities in shaping farmers' adoption decisions. In contrast, water availability and rainfall conditions show a comparatively lower level of influence, suggesting that environmental factors, while important, are not the primary drivers of participation.

The determinants presented in Table 3 were derived from the major dimensions identified in the conceptual framework, particularly socio-economic, environmental, and institutional and market factors. These variables represent the core components influencing farmers' decision-making within the proposed smart decision-making ecosystem. The findings further confirm that institutional and market-related factors, especially price incentives and market demand, play a dominant role in supporting organic rice farming adoption, while socio-economic and environmental conditions also contribute to farmers' adoption behavior.

5.4 Comparative Analysis of Determinants Influencing Farmers' Decision-Making Across Demographic Groups

This section presents a comparative analysis of the determinants influencing farmers' decision-making across different demographic and farm characteristics. Independent samples t-test and one-way ANOVA were employed to examine whether socio-economic and technological determinants differ significantly among farmer groups based on age, education level, and farm size. The analysis provides deeper insights into how demographic variations influence farmers' adoption behavior within the smart decision-making ecosystem.

Table 4 Comparison of farmers' decision-making determinants by age group

Age Group	Mean ($\bar{x}$)	S.D.	t-value	p-value
Younger farmers (<50 years)	4.08	0.52	2.134	0.035*
Older farmers (≥50 years)	3.92	0.48		

*p < 0.05

The results indicate that younger farmers show a significantly higher level of decision-making toward participation in organic rice farming compared to older farmers ($p < 0.05$). This suggests that younger farmers may be more open to adopting new agricultural practices and innovations.

Table 5 Comparison of technological determinants by education level

Education Level	Mean ($\bar{x}$)	S.D.	F-value	p-value
Primary	3.85	0.51	4.276	0.016*
Secondary	4.02	0.47		
Higher education	4.21	0.45		

*p < 0.05

The analysis reveals a statistically significant difference in technological factors across education levels ($p < 0.05$). Farmers with higher education levels tend to have greater acceptance and utilization of agricultural technologies compared to those with lower education levels.

Table 6 Comparison of farmers' decision-making determinants by farm size

Farm Size	Mean ($\bar{x}$)	S.D.	F-value	p-value
Small (<10 rai)	3.81	0.49	5.112	0.008**
Medium (10–20 rai)	4.02	0.46		
Large (>20 rai)	4.15	0.44		

**p < 0.01

There is a statistically significant difference in decision-making across farm size groups ($p < 0.01$). Farmers with larger farm sizes demonstrate a higher tendency to participate in organic rice farming programs, likely due to their greater resource capacity and ability to manage production risks.

Overall, the comparative analysis demonstrates that socio-economic and technological determinants vary across demographic and farm characteristics. Younger farmers, those with higher education levels, and farmers operating larger farms tend to exhibit stronger adoption-related decision-making tendencies. These findings reinforce the importance of considering demographic diversity within the proposed smart decision-making ecosystem.

5.5 Integrated Smart Decision-Making Framework for Organic Rice Farming Adoption

Based on the findings from socio-economic, technological, environmental, and institutional analyses, this study proposes an integrated smart decision-making framework for organic rice farming adoption. The framework synthesizes the multidimensional determinants influencing farmers' participation and connects them with digital agricultural extension systems and innovation-driven support mechanisms.

The framework consists of four interrelated components. First, socio-economic and market factors, including price incentives, farm size, and international market demand, act as the primary driving forces influencing farmers' motivation to adopt organic rice farming. Second, technological and digital extension components, such as mobile-based agricultural information, online extension services, smart farming applications, and communication platforms, support farmers' access to real-time information and reduce uncertainty in decision-making. Third, environmental and institutional factors, including land suitability, water availability, government support, and certification systems, create enabling conditions that strengthen adoption capacity. Finally, data-driven and innovation-based support systems, including digital advisory services, farm data management, and innovation networks, contribute to more adaptive and informed decision-making processes.

The interaction among these components forms a "Smart Decision-Making Ecosystem," where farmers are not only influenced by traditional economic and social conditions but are also supported by digital technologies and innovation systems that enhance sustainability-oriented agricultural transformation. The framework highlights that effective organic rice adoption requires integrated collaboration among farmers, extension agencies, markets, policymakers, and digital technology providers.

The proposed framework also emphasizes the role of digital agricultural extension in strengthening farmers' learning processes, improving access to information, and increasing confidence in adopting organic farming practices. This integrated ecosystem perspective can serve as a practical guideline for policymakers, agricultural extension organizations, and sustainable agriculture development programs.

6. Conclusion and Discussion

6.1 Conclusion

This study aimed to examine the key determinants influencing farmers' decision-making in participating in organic rice farming programs and to develop an integrated smart decision-making framework within a sustainable and technology-driven agricultural ecosystem.

The findings reveal that farmers' adoption decisions are influenced by multidimensional determinants, particularly socio-economic, technological, environmental, and institutional and market factors. Among these, socio-economic and market-related determinants, especially price incentives, international market demand, and farm size, emerged as the most influential factors affecting farmers' participation in organic rice farming programs. Technological determinants, including access to agricultural information and digital extension support, also demonstrated a significant role in enhancing farmers' adoption behavior.

The comparative analysis further indicates that demographic and farm characteristics contribute to variations in farmers' decision-making tendencies. Younger farmers, those with higher education levels, and farmers operating larger farms exhibited stronger adoption-related decision-making tendencies, suggesting that demographic diversity and resource capacity are important considerations in promoting sustainable agricultural transformation.

In addition to identifying the key determinants influencing farmers' participation, this study successfully developed an integrated smart decision-making framework that combines socio-economic, technological, environmental, and institutional dimensions with digital agricultural extension systems and innovation-driven approaches. The framework demonstrates how digital technologies, market mechanisms, extension services, and innovation networks interact within a smart agricultural ecosystem to support sustainable organic rice farming adoption.

Overall, the findings support the concept of a "Smart Decision-Making Ecosystem," where farmers' adoption behavior is shaped not only by traditional agricultural and economic conditions but also by digital technologies, real-time information access, and collaborative innovation systems. The study highlights the importance of integrating digital agricultural extension, market-oriented support mechanisms, and sustainability-driven policies to enhance farmers' participation in organic rice farming programs.

6.2 Discussion

The results of this study are consistent with previous research indicating that economic incentives are the primary drivers of farmers' adoption of organic agriculture. Studies have shown that price premiums and reliable market access significantly influence farmers' willingness to adopt sustainable farming practices (Pornpratansombat et al., 2011; Thapa & Rattanasuteerakul, 2011). Similarly, Wollni and Andersson (2014) found that market participation and contract arrangements play a critical role in encouraging smallholder farmers to adopt organic production systems. The strong influence of economic factors identified in this study reinforces the importance of developing stable market mechanisms and price guarantees to support organic farming transitions.

In addition, the role of education and technological access identified in this study aligns with the Diffusion of Innovation Theory, which emphasizes that individuals with greater knowledge, access to information, and communication channels are more likely to adopt new practices (Rogers, 2003). Empirical studies also support this finding, indicating that education level and access to extension services significantly enhance farmers' adoption of agricultural innovations (Doss, 2006; Melesse, 2018). The findings suggest that farmers with higher education levels are better able to understand and utilize agricultural technologies, thereby increasing their likelihood of participation.

The influence of farm size on decision-making is also supported by existing literature. Larger farm sizes are associated with greater resource availability and risk-bearing capacity, which facilitate the adoption of new technologies and farming systems (Feder et al., 1985; Knowler & Bradshaw, 2007). This explains why larger-scale farmers in this study exhibit a higher level of participation in organic rice farming programs.

Moreover, the integration of technological and institutional factors in this study highlights the growing importance of digital agricultural extension systems in enhancing farmers' decision-making. Recent studies emphasize that digital tools, data-driven platforms, and smart farming technologies can improve access to information, reduce uncertainty, and support sustainable agricultural development (FAO, 2017; Klerkx et al., 2019). In this context, digital extension services can act as key enablers in transforming traditional farming systems into more adaptive and innovation-driven agricultural ecosystems.

However, the relatively lower influence of environmental factors suggests that farmers may prioritize short-term economic benefits over long-term sustainability considerations. This finding is consistent with previous studies showing that environmental awareness alone is often insufficient to drive adoption unless supported by economic incentives and institutional mechanisms (Knowler & Bradshaw, 2007; Doss, 2006). Therefore, policy interventions should aim to better align environmental sustainability goals with farmers' economic interests.

6.3 Recommendations and Future Research

Based on the findings of this study, several recommendations can be proposed to support sustainable organic rice farming adoption and strengthen the smart decision-making ecosystem.

1. Policy and Practice: Policymakers should strengthen institutional and market support mechanisms, including price guarantees, access to premium and international markets, and certification support systems, to enhance farmers' confidence and participation in organic rice farming programs. Policies should also promote the integration of digital agricultural technologies within sustainable agricultural development strategies.

2. Digital Agricultural Extension: Agricultural extension services should focus on improving farmers' technological capabilities and digital literacy through mobile-based extension platforms, smart farming applications, online learning systems, and real-time agricultural information services. Strengthening digital extension systems can help reduce information gaps and support more adaptive and data-driven decision-making processes among farmers.

3. Targeted Support Programs: Specific support programs should be designed for small-scale farmers, older farmers, and less-educated farmers who may face limitations in accessing technological resources and innovation systems. Capacity-building activities, financial assistance, and community-based learning networks should be promoted to reduce inequality in access to agricultural opportunities.

4. Development of Smart Agricultural Ecosystems: Government agencies, extension organizations, private sectors, and digital technology providers should collaborate to develop integrated smart agricultural ecosystems that connect farmers with markets, innovation networks, advisory services, and digital information platforms. Such collaborative systems can strengthen sustainable agricultural transformation and improve long-term competitiveness.

5. Future Research: Future studies should employ advanced analytical methods, such as multiple regression analysis, structural equation modeling (SEM), or digital adoption modeling, to examine causal relationships among determinants influencing organic rice farming adoption. Longitudinal studies and comparative studies across different regions are also recommended to better understand changes in farmers' decision-making behavior and the long-term impacts of digital agricultural extension systems.

This study employed a purposive sampling method focusing on farmers participating in an organic rice farming program in a specific area of Chiang Rai Province. Therefore, the findings may not be fully generalizable to all farming communities in Thailand. Future studies should expand the study area and apply probability sampling techniques to improve generalizability and external validity.

7. References

Anousack, P., Kruekkum, P., Fongmul, S., & Kanokhong, K. (2024). Factors related to attitudes toward Kai Noi rice production under folk culture in Laos P.D.R. *Maejo Journal of Agricultural Production, 6*(2), 92–99.

Doss, C. R. (2006). Analyzing technology adoption using microstudies: Limitations, challenges, and opportunities. *Agricultural Economics, 34*(3), 207–219.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change, 33*(2), 255–298.

Food and Agriculture Organization. (2017). *The future of food and agriculture: Trends and challenges*. FAO.

Kerdsriseam, S., & Suwanmaneepong, S. (2015). The role of intermediaries in organic rice value chains in Thailand. *Agricultural Economics Studies*.

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS: Wageningen Journal of Life Sciences, 90–91*, 100315.

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy, 32*(1), 25–48.

Melesse, B. (2018). A review on factors affecting adoption of agricultural new technologies in Ethiopia. *Journal of Agricultural Science and Food Research, 9*(3), 1–4.

Pakdeenarong, N., & Hengsadeekul, T. (2020). Organic rice distribution and market structure constraints in Thailand. *Indian Journal of Agricultural Research*.

Panpluem, N., Mustafa, A., Huang, X., Wang, S., & Yin, C. (2019). Measuring the technical efficiency of certified organic rice-producing farms in Yasothon Province, Thailand. *Sustainability, 11*(24), 6974.

Pornpratansombat, P., Bauer, B., & Boland, H. (2011). The adoption of organic agriculture in Thailand. *Journal of Agricultural Extension and Rural Development, 3*(12), 213–221.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Simon, H. A. (1997). *Administrative behavior: A study of decision-making processes in administrative organizations* (4th ed.). Free Press.

Thapa, G. B., & Rattanasuteerakul, K. (2011). Adoption and extent of organic farming in Thailand. *Journal of Agricultural Extension, 15*(1), 1–15.

Wollni, M., & Andersson, C. (2014). Spatial patterns of organic agriculture adoption: Evidence from Honduras. *Ecological Economics, 97*, 120–128.

NEEDS ASSESSMENT FOR KNOWLEDGE AND INNOVATION DEVELOPMENT IN TECHNOLOGY TRANSFER AMONG FARMERS IN SALINITY-AFFECTED AREAS: A CASE STUDY OF BANG BO DISTRICT, SAMUT PRAKAN PROVINCE, THAILAND

Thanapon Prangkratok* and Pakkapong Poungsuk

68036023@kmitl.ac.th and pakkapong.po@kmitl.ac.th

Department of Agricultural Education, School of Industrial Education and Technology,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: 68036023@kmitl.ac.th

ABSTRACT

This study aimed to conduct a needs assessment for knowledge and innovation development in technology transfer among farmers in salinity-affected areas. The research objectives were to (1) examine current conditions, problems, and impacts of seawater intrusion; (2) identify farmers' needs for knowledge and innovation; and (3) analyze the relationships among contextual factors, farmers' needs, perceived usefulness, and technology transfer engagement. A quantitative research approach was employed using a cross-sectional survey design. Data were collected from 46 farmers through a structured questionnaire and analyzed using descriptive statistics, independent samples t-test, one-way ANOVA, and Pearson correlation analysis. The findings revealed that seawater intrusion has significantly affected agricultural systems, resulting in severe soil degradation, reduced productivity, and declining farm income. Farmers demonstrated a high level of need for knowledge and innovation (Mean = 4.50, SD = 0.60), particularly in training and workshops (Mean = 4.70, SD = 0.50) and demonstration-based learning (Mean = 4.63, SD = 0.54). Comparative analysis showed significant differences in farmers' needs according to age and education level ($p < .05$), indicating that demographic characteristics influence farmers' demand for knowledge and innovation development. The results also indicated that perceived usefulness had the strongest relationship with technology transfer engagement ($r = 0.72$), followed by farmers' needs ($r = 0.68$), while contextual factors showed a moderate positive relationship. All key variables were significantly correlated at the .01 level, suggesting that contextual conditions, perceived usefulness, and farmers' needs collectively influence engagement in technology transfer processes. The study concludes that effective technology transfer should be grounded in farmers' actual needs and emphasize participatory, practical, and context-specific learning approaches. These findings provide a foundation for developing context-appropriate innovations and strengthening agricultural sustainability and adaptive capacity in salinity-affected areas.

Keywords: Needs assessment, Technology transfer, Salinity-affected agriculture, Bang Bo district, Thailand

1. Statement of the Problem

Agriculture remains a vital sector for food security and rural livelihoods, particularly in developing countries such as Thailand. However, agricultural systems in coastal and low-lying areas are increasingly threatened by environmental changes, especially seawater intrusion driven by climate change, sea-level rise, and land subsidence. This phenomenon significantly degrades soil quality by increasing salinity levels, thereby reducing crop productivity and farm income

(Intergovernmental Panel on Climate Change [IPCC], 2023; Food and Agriculture Organization [FAO], 2022). In Thailand, coastal provinces have experienced rising soil salinity, leading to long-term agricultural constraints and declining sustainability, particularly for sensitive crops such as medicinal plants (Land Development Department, 2019; Office of Agricultural Economics, 2023).

Soil salinity has been widely recognized as a critical factor affecting plant growth, reducing yields, and increasing production costs. Previous studies have shown that farmers in salinity-affected areas often face limited access to appropriate knowledge and technologies, which constrains their adaptive capacity and long-term sustainability (Pretty, 2018; Zhang et al., 2024). Although knowledge and innovation—such as organic soil improvement and locally adapted agricultural practices—are considered essential strategies for sustainable agriculture (United Nations, 2023), their effectiveness depends largely on how well they are transferred and adopted by farmers. The Diffusion of Innovations theory emphasizes that perceived usefulness and compatibility are key determinants of adoption (Rogers, 2003), while participatory approaches highlight the importance of aligning innovations with farmers' needs and local contexts (Leeuwis & Van den Ban, 2004).

However, existing studies have primarily focused on the technical development and effectiveness of agricultural innovations, while limited attention has been given to farmers' actual knowledge needs, perceived usefulness, and engagement in technology transfer processes (Rogers, 2003; Leeuwis & Van den Ban, 2004). In particular, there remains insufficient understanding of how contextual factors, farmers' needs for knowledge and innovation, and perceived usefulness interact to influence farmers' participation in technology transfer in salinity-affected areas (Pretty, 2018; Zhang et al., 2024). This gap limits the development of context-appropriate knowledge and innovation strategies that effectively respond to local farming conditions and farmers' real needs. Furthermore, previous research has rarely integrated contextual conditions, farmers' needs, perceived usefulness, and technology transfer engagement within a single analytical framework (Witkin & Altschuld, 1995; Rogers, 2003). As a result, there is still a lack of empirical evidence explaining how these variables are interconnected and how they collectively influence farmers' adoption and utilization of agricultural innovations in salinity-affected communities.

Therefore, this study aims to conduct a needs assessment for knowledge and innovation development in technology transfer among farmers in salinity-affected areas. Guided by Needs Assessment Theory (Witkin & Altschuld, 1995), Diffusion of Innovations (Rogers, 2003), and participatory technology development frameworks, the study seeks to (1) examine current conditions, problems, and impacts of seawater intrusion; (2) identify farmers' needs for knowledge and innovation; and (3) analyze the relationships among contextual factors, farmers' needs, perceived usefulness, and technology transfer engagement. The findings are expected to provide a foundation for designing context-appropriate innovations and effective technology transfer strategies, thereby supporting sustainable agriculture and contributing to broader development goals, including the United Nations Sustainable Development Goals (United Nations, 2015).

2. Objectives

2.1 To examine the current conditions, problems, and impacts of seawater intrusion on agricultural practices among farmers in salinity-affected areas.

2.2 To identify farmers' needs for knowledge and innovation related to soil management and sustainable agricultural practices in salinity-affected areas.

2.3 To analyze the relationships among contextual factors, farmers' needs, perceived usefulness, and technology transfer engagement.

3. Conceptual Framework of the Study

3.1 Conceptual Framework of the Study

This study is guided by an integrative conceptual framework combining Needs Assessment Theory (Witkin & Altschuld, 1995), Diffusion of Innovations Theory (Rogers, 2003), and Participatory Technology Development approaches (Leeuwis & Van den Ban, 2004). These theories were integrated to explain how contextual conditions and farmers' needs influence engagement in technology transfer processes in salinity-affected agricultural areas.

Needs Assessment Theory emphasizes the identification of gaps between existing conditions and desired conditions in knowledge, skills, and agricultural practices (Witkin & Altschuld, 1995). In the context of this study, the theory is used to examine farmers' needs for knowledge and innovation related to soil salinity management, sustainable farming practices, and agricultural problem-solving. The theory supports the identification of priority areas for knowledge and innovation development based on farmers' actual needs.

Diffusion of Innovations Theory explains how innovations are communicated, perceived, and adopted within a social system (Rogers, 2003). The theory suggests that perceived usefulness, compatibility, accessibility of information, and communication channels are important factors influencing the adoption and utilization of innovations. In this study, the theory is used to explain farmers' engagement in technology transfer processes and their willingness to adopt agricultural knowledge and innovations.

Participatory Technology Development approaches emphasize the importance of involving farmers and local communities in the development and transfer of agricultural innovations (Leeuwis & Van den Ban, 2004). Participatory approaches support the idea that technology transfer is more effective when innovations are aligned with local conditions, farmers' experiences, and community contexts. This perspective is particularly important in salinity-affected areas where farming conditions are highly context-specific.

Based on these theoretical foundations, the conceptual framework consists of four key variables:

1. Contextual Factors (Environmental conditions, socio-economic characteristics, and farming situation)
2. Farmers' Needs for Knowledge and Innovation (Knowledge gaps, and innovation needs related to salinity management)
3. Perceived Usefulness and Technology Transfer Factors (Information accessibility, compatibility with local conditions, training opportunities, and social support)
4. Technology Transfer Engagement (Farmers' participation in training, access to agricultural information, and utilization of agricultural knowledge and innovations)

The framework proposes that contextual factors influence farmers' needs for knowledge and innovation. These needs subsequently affect perceived usefulness and other technology transfer factors, which in turn influence farmers' engagement in technology transfer processes. The relationships among these variables were analyzed using descriptive statistics and Pearson correlation analysis, as illustrated in Figure 1.

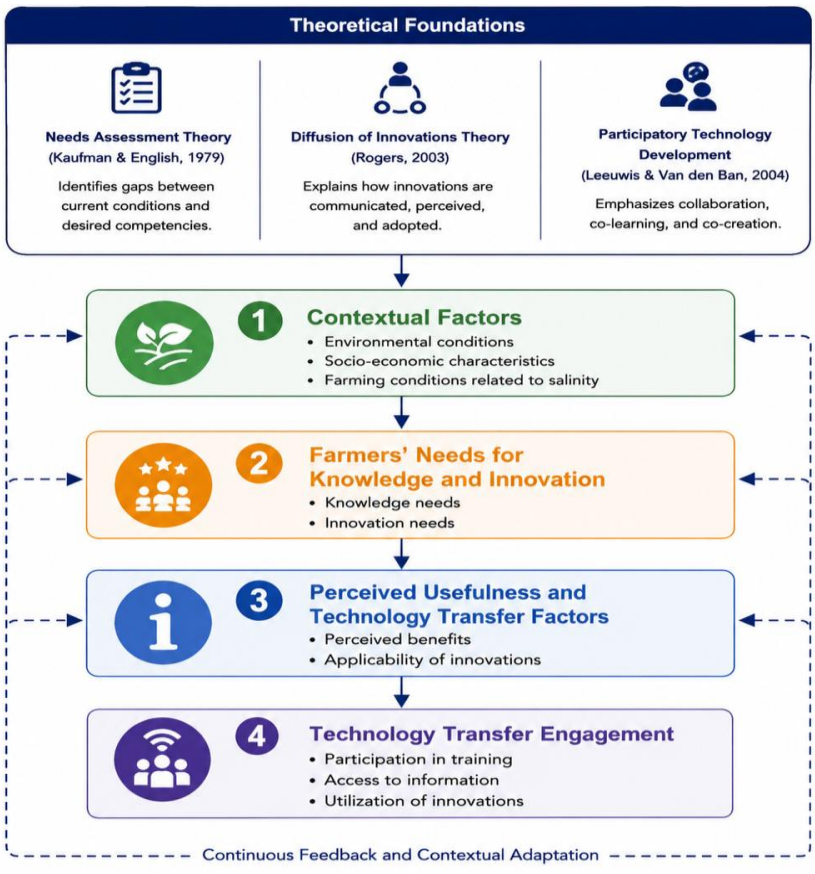

Figure 1 Conceptual framework of the study

3.2 Definitions of Key Variables

To ensure clarity and consistency in data analysis, the key variables used in this study are defined as follows:

1. Contextual Factors refer to environmental and socio-economic conditions related to salinity-affected agriculture, including seawater intrusion severity, farming conditions, and farmers' general characteristics.

2. Farmers' Needs refer to the levels of demand for knowledge and innovation related to soil management, agricultural improvement, and technology transfer in salinity-affected areas.

3. Perceived Usefulness refers to farmers' perceptions regarding the benefits and applicability of agricultural knowledge, innovations, and technology transfer activities for improving farming practices and productivity.

4. Technology Transfer Engagement refers to farmers' participation in training activities, access to agricultural information, and utilization of agricultural knowledge and innovations.

4. Research Methodology

This study employed a quantitative research approach using a survey design to assess farmers' needs for knowledge and innovation in technology transfer within salinity-affected areas. The methodology was designed to systematically examine current conditions, problems, and factors influencing farmers' access to and engagement with technology transfer mechanisms.

4.1 Research methodology

A cross-sectional survey design was adopted for this study. The research focused on farmers in salinity-affected areas engaged in agricultural production under conditions of soil salinity. The study area was purposively selected as Bang Bo District, Samut Prakan Province, due to its

exposure to seawater intrusion and salinity-related agricultural conditions. According to the Samut Prakan Provincial Agricultural Office (2026), the target population consisted of 1,035 agricultural households.

The sample group consisted of 46 farmers who voluntarily participated in the research activities and expressed interest in agricultural knowledge and technology transfer related to salinity management. Participants were selected using purposive sampling to ensure their direct experience with salinity-affected farming conditions and relevance to the research objectives.

4.2 Research procedure

The research was conducted in four main stages. First, a comprehensive review of related literature and theoretical frameworks was undertaken to establish the conceptual framework. Second, a structured questionnaire was developed based on the research objectives and validated by experts for content validity. Third, data were collected from the selected sample group through field surveys. Finally, the collected data were analyzed and interpreted in accordance with the research objectives and conceptual framework.

4.3 Data Collection

Data were collected using a structured questionnaire as the primary research instrument. The questionnaire consisted of five sections: (1) demographic and socio-economic characteristics; (2) current farming conditions and environmental context; (3) problems and impacts of seawater intrusion; (4) farmers' needs for knowledge and innovation; and (5) access to and use of technology transfer mechanisms. The instrument was examined for content validity by three experts in agricultural education, agricultural extension, and sustainable agriculture. The Index of Item–Objective Congruence (IOC) values of all items were higher than 0.80, indicating that the questionnaire items were highly consistent with the research objectives and considered appropriate for data collection.

The reliability of the instrument was tested through a pilot study with 30 farmers who had similar characteristics to the target population. Cronbach's alpha coefficient was greater than 0.80, indicating good internal consistency and acceptable reliability of the questionnaire. Data were collected through direct field surveys with farmers in salinity-affected areas.

4.4 Data Analysis

Data were analyzed using both descriptive and inferential statistics. Descriptive statistics, including frequency, percentage, mean, and standard deviation, were used to describe general characteristics and identify levels of needs among farmers. Inferential statistics were employed to further analyze the data. Independent samples t-test and one-way analysis of variance (ANOVA) were used to examine differences in farmers' needs across demographic groups. In addition, Pearson correlation analysis was conducted to investigate relationships among contextual factors, farmers' needs, perceived usefulness, and technology transfer engagement. The results were interpreted in alignment with the conceptual framework to provide insights for future knowledge and innovation development.

The interpretation of mean scores was based on a five-point Likert scale using the following criteria: 4.21–5.00 = very high, 3.41–4.20 = high, 2.61–3.40 = moderate, 1.81–2.60 = low, and 1.00–1.80 = very low (Best, 1981).

5. Results

This section presents the results of the study in accordance with the research objectives. The findings are organized into three parts: (1) current conditions, problems, and impacts of seawater intrusion; (2) farmers' needs for knowledge and innovation; and (3) factors influencing farmers' engagement with technology transfer.

Table 1 shows that most farmers are elderly with small-scale farming systems located in salinity-prone areas. A large proportion (91.30%) reported being affected by seawater intrusion

for more than 10 years, with high to very high severity. The impacts are substantial, with over 65% experiencing yield losses exceeding 70% and more than half reporting significant income reduction. In addition, most farmers lack knowledge of soil quality and have never conducted soil testing, reflecting a critical gap in technical knowledge. Although farmers attempt to cope through the use of organic fertilizers and commercial soil, the majority remain dissatisfied, indicating that existing practices are insufficient to address the problem effectively.

Table 1 Current conditions, problems, and impacts of seawater intrusion (n = 46)

Indicator	Category	Frequency (n)	Percentage (%)
General Characteristics			
Age	Below 40 years	6	12.50
(Mean = 56.42, SD = 11.37)	40–59 years	24	53.10
	60 years and above	16	34.40
Education Level	Primary education	18	39.10
	Secondary/Vocational	21	45.70
	Higher education	5	10.90
Farming Characteristics			
Average farm size	5.63 rai	-	-
Herbal crop area	1.30 rai	-	-
Location of farmland	Near coastal areas	38	54.30
	Near water sources	16	22.90
Seawater Intrusion Problem			
Experience of seawater intrusion	Yes	42	91.30
Duration of problem	More than 10 years	42	91.30
Severity level	High	25	54.30
	Very high	17	37.00
Occurrence period	Throughout the year	33	71.70
Crop Impacts			
Plant symptoms	Stunted growth	21	14.70
	Leaf yellowing	16	11.20
	Crop failure	37	25.90
	No germination	33	23.10
Production Impacts			
Yield reduction	More than 70%	30	65.20
Income reduction	More than 60%	25	54.30
Soil and Knowledge Issues			
Soil problems	Salinity	42	33.10
	Low fertility	37	29.10
Knowledge of soil quality	Do not know	42	91.30
Soil testing experience	Never tested	46	100.00

Table 2 shows that farmers reported a high overall level of need for knowledge and innovation (Mean = 4.50, SD = 0.60), indicating a consistently strong demand among respondents. The

relatively low standard deviation values across most items (SD ranging from 0.50 to 0.68) suggest that farmers' responses are fairly homogeneous, reflecting a similar perception of needs within the study group.

The highest level of need was observed in technology transfer activities, particularly training and workshops (Mean = 4.70, SD = 0.50), followed by demonstration-based learning (Mean = 4.63, SD = 0.54). These low SD values indicate strong agreement among farmers regarding the importance of participatory and practical learning approaches. In terms of knowledge content, soil salinity management (Mean = 4.60, SD = 0.55) and organic soil mixing methods (Mean = 4.52, SD = 0.58) were identified as priority needs, with relatively small variability, suggesting that these needs are widely shared among respondents.

Overall, the findings demonstrate that farmers not only have high levels of need but also exhibit consistent perceptions across different dimensions. The combination of high mean scores and low standard deviation values highlights the urgency and commonality of these needs, emphasizing the importance of developing targeted knowledge and innovation programs that respond effectively to farmers' priorities.

Table 2 Farmers' needs for knowledge and innovation (n = 46)

Needs Dimension	Mean	SD	Level
Soil Management Knowledge			
Soil improvement techniques	4.45	0.62	High
Organic soil mixing methods	4.52	0.58	High
Soil salinity management	4.60	0.55	High
Agricultural Innovation			
Use of organic inputs	4.38	0.66	High
Development of local materials	4.41	0.63	High
Simple agricultural technologies	4.35	0.68	High
Technology Transfer Needs			
Training/workshops	4.70	0.50	Very High
Demonstration activities	4.63	0.54	Very High
Access to extension services	4.50	0.60	High
Overall	**4.50**	**0.60**	**High**

Table 3 shows that the overall level of factors influencing farmers' engagement with technology transfer is high (Mean = 4.44, SD = 0.62), indicating that these factors play a significant role in shaping farmers' participation. The relatively low standard deviation values (SD ranging from 0.55 to 0.68) suggest a consistent perception among farmers regarding the importance of these factors.

Among the dimensions, perceived usefulness ranked the highest, particularly the usefulness of knowledge for farming (Mean = 4.60, SD = 0.55), indicating that farmers are more likely to engage with technology transfer when they perceive clear benefits. Information accessibility, especially training opportunities (Mean = 4.55, SD = 0.58), also showed a very high level, reflecting the importance of accessible learning channels. Compatibility with existing practices and local conditions also scored highly, suggesting that farmers prefer technologies that align with their current practices and environmental context.

Overall, the findings highlight that effective technology transfer depends not only on access to information but also on perceived usefulness, contextual relevance, and social support. The

combination of high mean scores and relatively low variability indicates that these factors are commonly recognized among farmers and should be carefully considered in designing future knowledge and innovation interventions.

Table 3 Factors influencing farmers' engagement with technology transfer (n = 46)

Factor Dimension	Mean	SD	Level
Information Accessibility			
Access to agricultural information	4.35	0.66	High
Access to extension services	4.40	0.63	High
Availability of training opportunities	4.55	0.58	Very High
Perceived Usefulness			
Usefulness of knowledge for farming	4.60	0.55	Very High
Ability to improve productivity	4.50	0.60	High
Compatibility			
Compatibility with existing practices	4.42	0.62	High
Suitability to local conditions	4.48	0.59	High
Social Support			
Support from community/network	4.30	0.68	High
Support from government agencies	4.38	0.64	High
Overall	**4.44**	**0.62**	**High**

Table 4 presents the ranking of farmers' needs for knowledge and innovation based on mean scores. The results indicate that training and workshops were ranked as the highest priority need (Mean = 4.70, SD = 0.50), followed by demonstration activities (Mean = 4.63, SD = 0.54) and soil salinity management (Mean = 4.60, SD = 0.55). These findings suggest that farmers place the greatest importance on practical and participatory learning approaches that can be directly applied to their farming practices.

The relatively low standard deviation values across all items (SD ranging from 0.50 to 0.68) reflect a high level of consensus among farmers regarding priority needs for knowledge and innovation development.

Overall, the combination of high mean scores and low standard deviation values indicates that farmers not only have high levels of need but also share similar perceptions regarding priority areas. This highlights the importance of focusing on practical training, demonstration-based learning, and soil management knowledge as key components for future knowledge and innovation development.

Table 4 Ranking of farmers' needs for knowledge and innovation (n = 46)

Needs Item	Mean	SD	Level	Rank
Training and workshops	4.70	0.50	Very High	1
Demonstration activities	4.63	0.54	Very High	2
Soil salinity management	4.60	0.55	Very High	3
Organic soil mixing methods	4.52	0.58	High	4
Access to extension services	4.50	0.60	High	5
Development of local materials	4.41	0.63	High	7
Soil improvement techniques	4.45	0.62	High	6
Use of organic inputs	4.38	0.66	High	8
Simple agricultural technologies	4.35	0.68	High	9

Table 5 presents the comparison of farmers' needs for knowledge and innovation across different age groups. The findings revealed that farmers aged 60 years and above reported the highest level of needs (Mean = 4.67, SD = 0.55), followed by those aged 40–59 years (Mean = 4.48, SD = 0.58), while farmers aged below 40 years reported the lowest level of needs (Mean = 4.32, SD = 0.64). The one-way ANOVA results showed a statistically significant difference among age groups ($F = 3.12$, $p < .05$), indicating that farmers' needs for knowledge and innovation varied across age groups. The relatively low standard deviation values indicate a high level of consensus among respondents within each age group.

Table 5 Comparison of farmers' needs by age group (n = 46)

Age Group	n	Mean	SD	F	p-value
Below 40 years	6	4.32	0.64		
40–59 years	24	4.48	0.58	3.12	0.048*
60 years and above	16	4.67	0.55		

Note: *p < .05

Table 6 presents the comparison of farmers' needs for knowledge and innovation across different education levels. The results show that farmers with higher education levels reported the highest level of needs (Mean = 4.65, SD = 0.55), followed by those with secondary education (Mean = 4.50, SD = 0.58), and primary education or lower (Mean = 4.35, SD = 0.62). The one-way ANOVA results indicate a statistically significant difference among the groups ($F = 3.45$, $p < .05$). Post-hoc analysis using the Least Significant Difference (LSD) test revealed that farmers with higher education levels have significantly greater needs compared to those with primary education, while no significant difference was found between primary and secondary education groups. The relatively low standard deviation values (SD ranging from 0.55 to 0.62) indicate a high level of consensus among respondents within each group. These findings imply that education level plays an important role in shaping farmers' awareness and demand for knowledge and innovation in agricultural development.

Table 6 Comparison of farmers' needs by education level (n = 46)

Education Level	n	Mean	SD	F	p-value
Primary or lower	20	4.35	0.62		
Secondary	21	4.50	0.58	3.45	0.039*
Higher education	5	4.65	0.55		

Note: *p < .05

Table 7 presents the correlation matrix among the key variables, including contextual factors, farmers' needs, perceived usefulness, and technology transfer engagement. The results show that all variables are positively correlated at a statistically significant level ($p < .01$), indicating that these factors are interrelated in influencing farmers' behavior in salinity-affected areas.

Farmers' needs exhibit a strong positive correlation with technology transfer engagement ($r = 0.68$), suggesting that higher levels of need are associated with greater participation in knowledge and technology transfer activities. Notably, perceived usefulness demonstrates the strongest relationship with engagement ($r = 0.72$), indicating that farmers are more likely to adopt and utilize innovations when they perceive clear and tangible benefits.

Contextual factors show moderate positive correlations with farmers' needs (r = 0.52) and engagement (r = 0.50), reflecting the influence of environmental and socio-economic conditions on both demand and participation. Additionally, the positive relationship between farmers' needs and perceived usefulness (r = 0.65) demonstrates that when farmers recognize the practical benefits and applicability of innovations, their demand for knowledge and technology increases accordingly. The mean scores of all variables are at a high level (Mean ranging from 4.20 to 4.55), indicating generally strong perceptions among farmers. The standard deviation values (SD ranging from 0.58 to 0.65) are relatively low, indicating a high level of consensus in responses across the sample group. Overall, the findings highlight that perceived usefulness and farmers' needs are key determinants influencing engagement with technology transfer processes.

Table 7 Correlation matrix among key variables (n = 46)

	Variables	Mean	SD	1	2	3	4
1	Contextual Factors	4.20	0.65	1.00			
2	Farmers' Needs	4.50	0.60	0.52**	1.00		
3	Perceived Usefulness	4.55	0.58	0.48**	0.65**	1.00	
4	Technology Transfer Engagement	4.44	0.62	0.50**	0.68**	0.72**	1.00

Note. **p < .01 (2-tailed).

6. Conclusion and Discussion

6.1 Conclusion

This study aimed to assess the current conditions, farmers' needs, and factors influencing engagement with technology transfer among farmers in salinity-affected areas. The findings reveal that seawater intrusion has had significant and persistent impacts on agricultural systems, particularly in terms of soil degradation, reduced productivity, and declining farm income. The majority of farmers have experienced long-term exposure to salinity problems and continue to rely on limited and often ineffective coping strategies, reflecting constraints in knowledge, resources, and access to appropriate technologies.

The results further indicate that farmers exhibit a high level of need for knowledge and innovation, particularly in areas related to soil salinity management, organic soil improvement, and practical agricultural techniques. Training, workshops, and demonstration-based learning were identified as the highest priority needs, highlighting farmers' preference for participatory and hands-on approaches rather than theoretical knowledge. The consistency of responses, reflected in relatively low standard deviation values, suggests that these needs are widely shared across the study population.

The comparative analysis further revealed that farmers' needs for knowledge and innovation differed significantly across demographic groups, particularly age and education level. Farmers aged 60 years and above reported higher levels of need compared with younger farmers, while farmers with higher education levels demonstrated significantly greater demand for knowledge and innovation than those with lower educational backgrounds. These findings suggest that demographic characteristics influence farmers' awareness, perceptions, and demand for agricultural knowledge and innovation development.

In addition, the study demonstrates that farmers' engagement with technology transfer is significantly associated with both their perceived needs and perceived usefulness of innovations. Correlation analysis indicates that perceived usefulness has the strongest relationship with engagement, followed by farmers' needs, while contextual factors show a moderate influence.

These findings suggest that farmers are more likely to adopt and utilize innovations when they perceive clear benefits and when the technologies align with their actual needs and local conditions.

The findings also highlight that contextual factors, including environmental and socio-economic conditions, are positively associated with farmers' needs and engagement in technology transfer processes. This indicates that farmers experiencing more severe salinity-related problems tend to demonstrate greater demand for practical knowledge, innovation, and adaptive support mechanisms.

Overall, the study highlights that effective technology transfer in salinity-affected areas should be grounded in a thorough understanding of farmers' needs and contextual realities. The findings provide important empirical evidence to support the design of knowledge development programs, innovation interventions, and participatory technology transfer strategies that are tailored to farmers' priorities. Such approaches are essential for enhancing agricultural sustainability, strengthening farmers' adaptive capacity, and supporting long-term development goals, including sustainable agriculture and climate resilience.

6.2 Discussion

The findings of this study provide important insights into the challenges and opportunities of technology transfer in salinity-affected agricultural areas. The results confirm that seawater intrusion has significantly affected agricultural production systems, particularly in terms of soil degradation, declining productivity, and reduced farm income. These findings are consistent with global evidence indicating that environmental stressors, such as soil salinity and climate change, are major constraints to sustainable agriculture and require adaptive management strategies (Intergovernmental Panel on Climate Change [IPCC], 2023; Food and Agriculture Organization [FAO], 2022). In the Thai context, similar findings have been reported, indicating that coastal farmers face soil salinity problems and limited access to soil management knowledge, which constrain their adaptive capacity (Land Development Department, 2019). This underscores the importance of developing context-specific knowledge and innovation to support agricultural resilience in the face of increasing climate uncertainty and environmental stress.

The findings related to farmers' needs reveal a strong demand for practical and participatory learning approaches, particularly training, workshops, and demonstration activities. This supports Needs Assessment Theory, which emphasizes that development interventions should be grounded in the actual needs of target groups (Witkin & Altschuld, 1995). The preference for hands-on learning is also consistent with agricultural extension studies indicating that experiential and demonstration-based approaches enhance farmers' understanding and adoption of new practices (Leeuwis & Van den Ban, 2004; Pretty, 2018). In Thailand, similar evidence suggests that participatory training and farmer-centered extension approaches can significantly improve knowledge transfer effectiveness and technology adoption (Office of Agricultural Economics, 2023). These findings highlight the importance of interactive and context-based learning processes in agricultural development, particularly in fostering long-term technology adoption among smallholder farmers.

The comparative analysis additionally revealed significant differences in farmers' needs across demographic groups, particularly age and education level. Older farmers and those with higher education levels demonstrated greater needs for knowledge and innovation development. This finding may reflect differences in farming experience, awareness of environmental impacts, and the ability to recognize the importance of adaptive agricultural practices. Previous studies have similarly reported that demographic characteristics, especially education level and farming

experience, significantly influence farmers' perceptions, learning behavior, and technology adoption capacity (Rogers, 2003; Zhang et al., 2024). The findings suggest that technology transfer programs should consider demographic diversity when designing learning activities and extension strategies.

The results further indicate that perceived usefulness has the strongest relationship with technology transfer engagement, followed by farmers' needs, while contextual factors show a moderate influence. This finding strongly supports the Diffusion of Innovations theory, which posits that perceived benefits are a key determinant of technology adoption (Rogers, 2003). Recent empirical studies have also confirmed that perceived usefulness plays a critical role in farmers' adoption of agricultural technologies (Zhang et al., 2024; Chen et al., 2024). Additionally, the moderate influence of contextual factors aligns with research indicating that environmental and socio-economic conditions shape farmers' decision-making processes and access to innovation systems (United Nations, 2023). These findings suggest that technology transfer strategies should emphasize not only accessibility but also the perceived value and applicability of innovations.

The correlation analysis also demonstrated that contextual factors were positively associated with both farmers' needs and technology transfer engagement. This suggests that farmers experiencing more severe environmental and production-related problems are more likely to seek knowledge, participate in training activities, and engage with innovation systems. These findings are consistent with studies emphasizing that environmental pressures and livelihood risks can motivate farmers to adopt adaptive learning and innovation behaviors (Pretty, 2018; United Nations, 2023). Therefore, technology transfer interventions should be designed in a manner that directly responds to local environmental conditions and farmers' real-world farming challenges.

Furthermore, the strong relationship between farmers' needs and engagement highlights the importance of needs-driven and participatory approaches in agricultural development. This finding is consistent with Participatory Technology Development, which emphasizes the role of farmers as active participants in the innovation process (Leeuwis & Van den Ban, 2004). In addition, recent studies have shown that collaborative networks among farmers, researchers, and institutions facilitate knowledge co-creation and enhance the diffusion of innovations in rural areas (Chen et al., 2024). Therefore, top-down approaches to technology transfer may be less effective compared to participatory and context-sensitive strategies. Despite the important findings, this study has some limitations that should be acknowledged. First, the study was conducted within a specific geographical area, namely Bang Bo District, Samut Prakan Province, which may limit the generalizability of the findings to other salinity-affected regions. Second, the sample size was relatively small and based on purposive sampling, which may not fully represent all farmers in the study area. In addition, the cross-sectional nature of the study reflects farmers' perceptions and conditions during a specific period of time and may not capture long-term changes in technology adoption and adaptive behaviors.

Overall, the findings suggest that effective technology transfer in salinity-affected areas requires an integrated approach that combines needs-based planning, participatory learning, and the promotion of perceived benefits of innovations. Such approaches are essential for strengthening farmers' adaptive capacity, improving agricultural sustainability, and supporting long-term development goals, including food security and climate resilience.

7. Suggestions

7.1 Practical Application of the Research Findings

Based on the findings, the study suggests that knowledge and innovation development for farmers in salinity-affected areas should emphasize practical and participatory approaches. Training programs should be designed to focus on soil salinity management, organic soil improvement, and the use of locally available materials, as these were identified as priority needs. Demonstration-based learning and field-based workshops are recommended to enhance farmers' understanding and facilitate real-world application.

In addition, extension services and relevant agencies should improve accessibility to knowledge and technology transfer mechanisms by developing farmer-centered communication channels and localized learning platforms. The integration of participatory approaches, where farmers actively engage in knowledge co-creation, is expected to enhance adoption and sustainability. These strategies are feasible and can be implemented through collaboration among government agencies, academic institutions, and local communities.

The findings further suggest that technology transfer programs should consider demographic differences among farmers, particularly age and education level, when designing learning activities and extension strategies. Older farmers and farmers with higher education levels demonstrated greater needs for knowledge and innovation, indicating the importance of differentiated and flexible learning approaches tailored to farmers' characteristics and learning capacities.

Furthermore, since perceived usefulness showed the strongest relationship with technology transfer engagement, extension activities should emphasize practical benefits, real-world applicability, and visible outcomes of agricultural innovations. Farmers are more likely to adopt innovations when they perceive clear advantages in productivity improvement, soil management, and income stability.

7.2 Suggestions for Further Development

7.2.1 Enhance practical and continuous training programs. Future initiatives should emphasize the development of continuous and participatory training programs, particularly those incorporating demonstration-based learning. Such approaches are expected to strengthen farmers' capacity to effectively apply knowledge and innovations in managing agricultural practices within salinity-affected areas.

7.2.2 Develop context-specific guidelines and support systems. There is a need to develop clear, practical, and context-sensitive guidelines for soil salinity management and agricultural innovation. These efforts should be complemented by strengthening extension services and establishing community-based learning centers to support ongoing knowledge exchange and capacity building.

7.2.3 Promote adaptive and localized technology transfer models. Future development programs should focus on adaptive technology transfer approaches that respond directly to environmental conditions and contextual factors in salinity-affected communities. Participatory and community-based innovation systems should be strengthened to encourage farmer engagement and long-term sustainability.

7.2.4 Extend research to innovation development and evaluation. Future research should move beyond needs assessment toward the development and experimental evaluation of appropriate innovations and technology transfer models. This includes the integration of digital agriculture and smart farming technologies to enhance long-term sustainability and adaptive capacity in salinity-affected farming systems.

8. Acknowledgements

The author would like to express sincere gratitude to Dhonburi Rajabhat University for providing financial support for graduate studies. Special thanks are also extended to Ms. Nok-Iang Kimyong for her kind assistance and coordination in facilitating field data collection under the project entitled "Development of Products from Household Waste Materials to Enhance Local Community Economy." This work was conducted as part of Sub-project P1, "Enhancing Grassroots Economy Based on the Sufficiency Economy Philosophy," implemented by Dhonburi Rajabhat University.

9. References

Best, J. W. (1981). *Research in education* (4th ed.). Prentice-Hall.

Chen, X., Li, Y., & Zhang, H. (2024). Collaborative innovation networks and agricultural technology adoption in rural areas. *Technological Forecasting and Social Change, 198*, 122987.

Department of Marine and Coastal Resources. (2021). *Report on coastal erosion and seawater intrusion in Thailand*. Ministry of Natural Resources and Environment.

Food and Agriculture Organization of the United Nations. (2022). *The state of the world's land and water resources for food and agriculture 2021: Systems at breaking point*. FAO. https://doi.org/10.4060/cb7654en

Food and Agriculture Organization. (2022). *The state of food and agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. FAO. https://doi.org/10.4060/cb9479en

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*. IPCC. https://www.ipcc.ch/report/ar6/syr/

Land Development Department. (2019). *Manual for saline soil management for agriculture*. Ministry of Agriculture and Cooperatives.

Leeuwis, C., & Van den Ban, A. W. (2004). *Communication for rural innovation: Rethinking agricultural extension* (3rd ed.). Blackwell Science.

Office of Agricultural Economics. (2023). *Agricultural statistics of Thailand 2023*. Ministry of Agriculture and Cooperatives.

Pretty, J. (2018). Intensification for redesigned and sustainable agricultural systems. *Science, 362*(6417), eaav0294. https://doi.org/10.1126/science.aav0294

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Samut Prakan Provincial Agricultural Office. (2026). *Basic agricultural information of Samut Prakan Province*. Ministry of Agriculture and Cooperatives.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. United Nations. https://sdgs.un.org/2030agenda

United Nations. (2023). *Global sustainable development report 2023: Times of crisis, times of change*. United Nations. https://sdgs.un.org/gsdr/2023

Witkin, B. R., & Altschuld, J. W. (1995). *Planning and conducting needs assessments: A practical guide*. Sage Publications.

Zhang, Y., Wang,L., & Chen, J. (2024). Factors influencing farmers' adoption of agricultural technologies: Evidence from developing countries. *Humanities and Social Sciences Communications, 11*, 1023.

Zhang, Y., Wang, N., Li, X., & Chen, J. (2024). Technology adoption and sustainable agricultural adaptation under environmental stress conditions: Evidence from salinity-affected farming systems. *Journal of Rural Studies, 105*, 103210. https://doi.org/10.1016/j.jrurstud.2024.103210

DIGITAL HEALTH COMMUNICATION FOR ONLINE PUBLIC RELATIONS TO PROMOTE AWARENESS ON HEALTH RISKS OF SMOKING AMONG UNDERGRADUATE STUDENTS

Chadatarn Auesirisophon, Tapanat Buttirachai, Pimmada Jitthawesrisuk, Kuntida Thamwipat*, Pornpapatsorn Princhankol, and Teerawan Opasbut

chadatarn.aue@kmutt.ac.th, tanapat.but@kmutt.ac.th, pimmada.jit@kmutt.ac.th, kuntida.tha@kmutt.ac.th, pornpapatsorn.pri@kmutt.ac.th, and teerawan.opa@kmutt.ac.th

Department of Educational Communications and Technology,
Faculty of Industrial Education and Technology,
King Mongkut's University of Technology Thonburi,
Bangkok 10140 Thailand

*Corresponding Author E-mail: kuntida.tha@kmutt.ac.th

ABSTRACT

The purposes of this research were 1) to develop a digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook ,2) to evaluate the quality of the developed digital media package, 3) to assess audience perception toward the developed digital media package, and 4) to examine audience satisfaction with the developed digital media package. The research instruments included ;1) the digital media package for online public relations on the dangers of smoking, 2) content and media quality assessment forms, 3) a perception assessment form, and (4) a satisfaction assessment form. The sample group consisted of followers of the Facebook fan page "KMUTT Health Care Unit," selected using accidental sampling from undergraduate students who had viewed the developed digital content and voluntarily completed the questionnaire. A total of 50 respondents participated in the study. The statistical methods used for data analysis were frequency distribution and standard deviation. The results revealed that the developed media comprised three sets of infographic posters and one set of video content. Expert evaluation indicated that the content quality was at a very good level, while the media presentation quality was at a good level. In addition, the audience's perception and satisfaction toward the digital content were both at the highest level. These findings demonstrate that the developed digital media package is effective and practical for online public relations implementation. Furthermore, presenting health-related information through infographics and music-based video clips can enhance perception and satisfaction, particularly among adolescent audiences.

Keywords: Digital health communication, Dangers of smoking, Online platform, Public relations

1. Statement of the Problem

Social media integrates information and communication technologies to enable diverse forms of content creation, dissemination, and interaction. The widespread use of the internet, smartphones, and mobile devices has accelerated its adoption by public and private organizations for internal communication, public relations, and public engagement. In the context of technological convergence, social media has become a key source of information and a platform for two-way communication, allowing users to both produce and consume content. It facilitates interaction within online

communities, supports information gathering and news monitoring, and provides access to diverse sources, experts, and audiences. Despite these advantages, the rapid pace of technological change presents challenges, particularly regarding the growing role of social media data in organizational communication and news dissemination. (Chunrattanakul & Kalyanamitra, 2022) The rising use of e-cigarettes among adolescents is evident in both developed and developing countries. In Australia, nearly 30% of adolescents aged 12–17 have tried e-cigarettes, with reported declines in physical fitness. Similarly, a national survey in Malaysia found that approximately 15% of adolescents aged 13–17 used e-cigarettes in 2022. These trends indicate that e-cigarette use has become a significant public health concern rather than a marginal issue. Moreover, the extensive promotion of e-cigarettes through social media poses challenges for public health regulation, revealing limitations in governmental oversight in protecting young people from high-risk products. (Warijan & Nuraini, 2025)

Although the WHO Framework Convention on Tobacco Control has been integrated into Thailand's National Tobacco Control Strategy (NTCS) for over three decades, ongoing policy evaluation remains crucial to enhance its effectiveness. Key findings indicate that NTCS implementation can be strengthened through improved coordination, systematic monitoring, capacity development, adequate funding, and policy dissemination. Notably, policy dissemination has been hindered by one-way communication approaches, underscoring the need for two-way communication to enhance stakeholder engagement. In addition, limited innovation in tobacco control highlights the importance of establishing knowledge-sharing mechanisms to support more effective and adaptive policy implementation. (Phetphum et al.,2025) At the Bangkok Tobacco Product Control Committee Meeting No. 1/2024, chaired by Assoc. Prof. Tavida Kamolvej, e-cigarettes and drugs were identified as urgent policy issues, with enforcement constrained by limited legal awareness among practitioners. Key measures included the World No Tobacco Day 2024 campaign "#E-cigarettes: Stop the lies," the issuance of Bangkok's tobacco control guidelines, joint enforcement operations seizing over 5 million baht in e-cigarette products, and a resolution requiring educational institutions to monitor and report drug and e-cigarette use through an online system to strengthen surveillance and policy implementation. (Public Relations Office, Bangkok, 2024) Consequently, raising awareness through targeted digital health communication is essential to counteract these risks.

King Mongkut's University of Technology Thonburi (KMUTT), through its Health Care Unit,(2025) serves as a central hub for providing health services and promoting wellness among its academic community. Historically, health PR within the university primarily relied on physical bulletin boards and static posters, which often resulted in limited information reach among digital-native students. To address this gap, this study developed a digital media package —comprising three infographics ("The Dangers of Smoking," "The Dangers of E-cigarettes," and "4 Stages of Lung Destruction") and a video content titled "The Hidden Hands of Smoke"—specifically for dissemination via the "KMUTT HEALTH CARE UNIT" Facebook page. A digital media package refers to a systematically designed collection of digital media contents developed to communicate specific messages to a target audience across online platforms. In this study, the content was developed to meet the organization's need to communicate with Generation Z undergraduate students. Infographic posters and short hip-hop-style video clips were selected due to their accessibility and alignment with the target audience's media consumption behavior. The primary objective of this study was to develop a high-quality digital media package specifically designed for online public relations regarding the dangers of smoking. By integrating various forms of digital media, such as infographics and video content, the research aimed to modernize the communication tools of the Health Care Unit at King Mongkut's University of Technology Thonburi, ensuring that health information is presented in a format that is both engaging and easily accessible to a digital-native audience. Another significant objective was to evaluate the quality of the developed digital content through systematic expert validation. This process involved assessing both the accuracy of the medical information and the effectiveness of the media presentation. By establishing a rigorous evaluation framework, the study

sought to ensure that the public relations materials meet professional standards and provide reliable, evidence-based information to the university community.

Furthermore, the study aimed to assess the perception of the target audience towards the developed digital media package. This objective focused on understanding how students and staff interpret and internalize the information regarding smoking and e-cigarette hazards. By measuring perception levels, the research intended to determine if visual digital media can successfully enhance awareness and influence the cognitive understanding of health risks in a way that traditional posters could not. Lastly, the research sought to evaluate the satisfaction of the target audience with the implementation of digital public relations on online platforms. This objective was designed to measure the practicality and user-friendliness of using social media as a health communication channel. Understanding audience satisfaction is crucial for confirming that the digital approach is an effective and sustainable solution for future health promotion initiatives within the university setting. This study followed the ADDIE instructional design model (Thamwipat &Princhankol ,2022) to ensure the effectiveness and systematic development of the educational materials.

2. Objectives

This research has four objectives as follows:

2.1 To develop a digital media package for online public relations on health risks of smokingfor the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook.

2.2 To evaluate the quality of the developed digital media package.

2.3 To assess audience perception toward the developed digital media package.

2.4 To examine audience satisfaction with the developed digital media package.

3. Research Methodology

The digital media package includes four sets of public relations media: three sets of infographic posters (Health risks of Smoking, Health risks of E-cigarettes, and 4 Stages of Lung Destruction) and one video content titled "The Hidden Hands of Smoke". This study employed the following research methodology.

3.1 Data Collection Instruments

A quality assessment form for evaluating the developed digital media package. The research instrument was a five-point Likert scale questionnaire (1 = lowest, 5 = highest), consisting of three main sections for the content quality evaluation form, and four main sections for the media presentation quality evaluation form.

A perception assessment form measuring the sample group's perception of the developed digital media package. The research instrument was a five-point Likert scale questionnaire (1 = lowest, 5 = highest), consisting of 10 sub-items, categorized according to four digital media package.

A satisfaction assessment form measuring the sample group's satisfaction with the developed digital media package. The research instrument was a five-point Likert scale questionnaire (1 = lowest, 5 = highest), consisting of three main sections.

All research instruments were validated using the Index of Item-Objective Congruence (IOC) by three experts in measurement and evaluation, yielding IOC values ranging from 0.50 to 1.00.

3.2 Population & The sample group

The target population consisted of 4,900 followers of the "KMUTT Health Care Unit" Facebook fan page (as of April 16, 2026). This population was used to examine the digital media package for online public relations on the dangers of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook.

The sample group used in this study consisted of followers of the KMUTT Health Care Unit. A total of 50 participants were selected using accidental sampling. These were undergraduate

students at KMUTT who follow the 'KMUTT Health Care Unit' Facebook fan page ,who viewed the digital content on the platform and voluntarily agreed to complete the evaluation.

3.3 The Development Process

The development of the digital media package followed the ADDIE Model (Thamwipat & Princhankol,2022) , which consists of five systematic stages:

Analysis: The researchers analyzed the requirements of the KMUTT Health Care Unit to identify core problems and define the necessary information regarding smoking hazards that are concise and easy to understand.

Design: This stage involved determining the media formats consist of infographics and video, as they align with HCU KMUTT's need to communicate effectively with Generation Z students via convenient, fast, and popular online platforms, consistent with the target audience's media consumption behavior and developing storyboards. The design focused on a visual style (mood & tone) suitable for the Facebook platform's audience.

Development: The digital media package was produced according to the design specifications. The prototypes were then reviewed by the project advisor and experts for quality validation, followed by refinement based on their feedback.

Implementation: The finalized digital media package was published on the "KMUTT Health Care Unit" Facebook fan page. Data were collected from 50 participants who interacted with the media and completed the assessment forms.

Evaluation: The data regarding perception and satisfaction were analyzed using descriptive statistics, including Mean ($\bar{x}$) and Standard Deviation (S.D.), to determine the effectiveness of the developed digital content.

Statistical Analysis

The data analysis was conducted by first calculating the Index of Item-Objective Congruence (IOC) to assess content validity based on expert evaluation. Subsequently, data derived from expert evaluations on content quality and media presentation, as well as the sample group's perception and satisfaction, were analyzed using frequency distribution, percentage, Mean, and Standard Deviation.

3.4 Data Analysis

Data were analyzed using the mean and standard deviation. The criteria for interpreting the mean scores were determined by comparing the obtained values with the following scale (LimeSurvey GmbH,2025):

4.51 – 5.00	The Highest / Very good
3.51 – 4.50	High / Good
2.51 – 3.50	Moderate/ Moderate
1.51 – 2.50	Low/ Low
1.00 – 1.50	The Lowest/ The Lowest

4. Results

4.1 Results of the development media

Based on the study on the development of a digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook, the research was completed in accordance with the established research procedures. The results of the study are presented as follows.

The infographic media included three poster-style:

1. An infographic poster entitled "Health risks of Smoking" (1 Set- 4 shares)
2. An infographic poster entitled "Health risks of E-cigarettes" (1 Set- 1 shares)
3. An infographic poster entitled "4 Stages of Lung Destruction" (1 Set- 2 shares)
4. A video content entitled "The Hidden Hands of Smoke." (1 Video- 3 shares and 431 views)

Figure 1 Digital Media Package on the Online Platforms

4.2 Results of the Content Quality Evaluation

Table 1 Results of the content quality evaluation

Assessment Items	Analysis Results		Meaning
	$\bar{x}$	S.D.	
1. Content Aspect	4.84	0.19	Very good
2. Language and Illustration Aspect	4.92	0.14	Very good
3. Public Relations Aspect	4.67	0.58	Very good
Overall Summary	**4.78**	**0.33**	**Very good**

Based on Table 1, the results of the content quality evaluation of the developed digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook, indicated that the overall quality met the established evaluation criteria and was rated at a very good level ($\bar{x}$ = 4.78, S.D. = 0.33).

4.2 Results of the Media Presentation Quality Evaluation

Table 2 Results of the media presentation quality evaluation by experts

Assessment Items	Analysis Results		Meaning
	$\bar{x}$	S.D.	
1. Typography and color usage	4.44	0.19	good
2. Visuals / images	4.67	0.58	Very good
3. Audio / sound	4.22	0.39	Very good
4. Presentation aspect	4.56	0.58	Very good
Overall Summary	**4.47**	**0.51**	**good**

Based on Table 2, the results of the developed digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook, indicated that the overall media presentation quality met the established evaluation criteria and was rated at a good level ($\bar{x}$ = 4.47, S.D. = 0.51).

4.3 Results of the evaluation of the sample group's perceptions

Table 3 Mean and standard deviation of the sample group's perception

Assessment Items	Analysis Results		Meaning
	$\bar{x}$	S.D.	
1. Awareness that smoking hazards negatively affect the cardiovascular and reproductive systems	4.74	0.54	The Highest
2. Awareness of primary prevention: avoiding initiation, early refusal, and learning about hazards during adolescence	4.90	0.30	The Highest
3. Awareness that second-hand smoke affects others, particularly children, pregnant women, and the elderly.	4.76	0.47	The Highest
4. Awareness that e-cigarettes contain toxins causing diseases, affecting brain development, and serving as a gateway to other substances	4.77	0.46	The Highest
5. Awareness of e-cigarette control measures: age restrictions (under 20) and strict regulation of all distribution channels	4.66	0.57	The Highest
6. Awareness that tobacco smoke can cause lung cancer	4.81	0.44	The Highest

Table 3 (continued)

Assessment Items	Analysis Results		Meaning
	$\bar{x}$	S.D.	
7. Awareness of lung cancer prevention and self-care: avoiding and quitting all forms of smoking (including e-cigarettes)	4.81	0.44	The Highest
8. Awareness of Third-hand smoke: toxic residues remaining on surfaces after smoking that endanger others	4.48	0.84	The Highest
9. Awareness that opening windows cannot eliminate third-hand smoke residues attached to surfaces	4.40	0.86	High
10. Awareness that tobacco smoke affects not only the smoker but also bystanders and the environment	4.79	0.48	The Highest
Overall Summary	**4.71**	**0.58**	**The Highest**

Based on Table 3, the evaluation of the sample group's perception towards the developed digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook, revealed at the highest level ($\bar{x}$ = 4.71, S.D. = 0.58). of perception when compared to the established criteria.

4.4 Results of the evaluation of the sample group's Satisfaction

Table 4 Mean and standard deviation of the sample group's satisfaction

Assessment Items	Analysis Results		Meaning
	$\bar{x}$	S.D.	
1. Content aspect	4.78	0.46	The Highest
2. Visual and Audio aspect	4.70	0.52	The Highest
3. Presentation aspect	4.67	0.57	The Highest
Overall Summary	**4.71**	**0.53**	**The Highest**

Based on Table 4. the satisfaction assessment of the sample group towards the developed digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook, indicated an overall satisfaction at the highest level ($\bar{x}$ = 4.71, S.D. = 0.53) when compared to the established criteria.

5. Conclusion and Discussion

In conclusion, the development of a digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook has demonstrated significant efficacy and professional standards. The systematic implementation of the ADDIE model ensured a rigorous design process, resulting in a diversified media suite that earned a very good quality rating from the expert panel. Furthermore, the deployment of these materials via the institutional social media platform yielded high levels of audience perception and satisfaction. These outcomes provide empirical evidence that the developed media successfully fulfilled the pre-defined research objectives and established quality benchmarks.

The development of a digital media package for online public relations on health risks of smoking for the Health Care Unit, King Mongkut's University of Technology Thonburi (KMUTT) Page Facebook successfully achieved all research objectives, demonstrating high efficacy in both media quality and audience engagement. The expert evaluation, which rated the overall content quality at a very good level ($\bar{x}$ = 4.78, S.D. = 0.33), underscores the importance of using a systematic design framework like the ADDIE model. The high score in media presentation quality ($\bar{x}$ = 4.47, S.D. = 0.51) suggested that the integration of medical facts regarding smoking and e-cigarette hazards into a digital format was handled with professional accuracy. This finding aligns with the study by Naphat et al.,2021, Thamwipat & Princhankol, 2022, Waiwingrob et al., 2023. which emphasized that well-structured digital content by ADDIE Model as a fundamental tool for modern organizational public relations, especially when dealing with complex health information.

Regarding audience perception, the highest level of awareness recorded ($\bar{x}$ = 4.71, S.D. = 0.33). The satisfaction levels also reached the highest level ($\bar{x}$ = 4.71, S.D. = 0.33) indicated that infographics and videos were superior to traditional static posters in a university environment. The visual nature of infographics allowed for the simplification of data on "4 Stages of Lung Damage" and "Dangers of E-cigarettes," making the information more memorable for students. This result was consistent with Binraman et al., 2022, Kaewsomnues, et al.,2023, and Thamwipat et al.,2024. These studies focus on the development of digital content on online platforms, specifically in the form of infographic posters and short videos, to enhance awareness among the target audience. The findings indicated that such content effectively promotes awareness and results in a high level of satisfaction among the sample group, which consisted of undergraduate students. This outcome was consistent with the findings of the present study. Furthermore, the video content "Did You Know Cigarette Smoke Has Hands?" likely played a role in triggering emotional engagement, which is a key factor in successful health advocacy on social media platforms like Facebook, because they support two-way communication and easy information sharing. The positive feedback on the visual appeal and ease of understanding further confirms that the transition from physical bulletin boards to digital content was a necessary step for university health units to remain relevant and effective in their communication efforts.

6. Suggestions

6.1 Recommendations for the Application of Research Findings

The research findings underscore the transformative impact of digital platforms in contemporary institutional health promotion. By transitioning from conventional, static display boards to dynamic infographics and video content, the Health Care Unit effectively bridged the communication gap with a digitally native demographic. The elevated perception scores demonstrate that visual storytelling and structured information design are indispensable tools for enhancing health literacy. In a high-density academic environment, where traditional communication channels frequently experience diminishing returns, these digital interventions provide a more effective method for promoting public health awareness. These digital contents can be conveniently disseminated and further extended across various online platforms of the organization. This is intended to respond to the policy of online public relations communication

through digital content, as well as the policy promoting the well-being of all members of the KMUTT community. Therefore, preventive communication should be collaboratively implemented by responsible units to achieve the organization's desired outcomes.

6.2 Recommendations for Future Research

For future research, it is recommended that health units broaden the scope of digital topics and investigate emerging social media platforms to guarantee sustained longitudinal engagement. The incorporation of interactive elements could further catalyse bidirectional communication between health service providers and the university community, fostering a more collaborative health ecosystem. Ultimately, institutional public relations strategies should prioritise digital content development as a scalable and sustainable framework for public health advocacy, ensuring that critical information remains accessible, cognitively engaging, and impactful for the target audience.

7. References

Binraman, P., Princhankol, P., & Thamwipat, K. (2022). The development of digital infographic content on social media for promoting a product of homemade bakery. *Journal of Learning Innovation and Technology*, 2(2), 68–77. https://ph02.tci-thaijo.org/index.php/JSCI/article/view/250085

Champoonote, C., Kalyanamitra, K., Niyomyaht, S., & Lakkanapichoncha, T. (2022). Human resource development in the age of digital disruption. *Journal of Educational Review Faculty of Education in MCU*, 8(1), 195–208. https://so02.tcithaijo.org/index.php/EDMCU/article/view/248388/167972

Health Care Unit, King Mongkut's University of Technology Thonburi. (2025). *About us*. https://hcu.kmutt.ac.th/th/about-us

Kaewsomnues, A., Jirachai, P., & Thamwipat, K. (2023). Development of an e-exhibition in conjunction with a game-based learning communication activity. *Science, Engineering and Health Studies*, 17, 23040014. https://doi.org/10.69598/sehs.17.23040014

LimeSurvey GmbH. (2025). *Mastering the Likert scale.* https://www.limesurvey.org/th/blog/knowledge/mastering-the-likert-scale-and-analyzing-opinions-with-limesurvey

Naphat, D., Thamwipat, K., & Princhankol, P. (2021). The development of an interactive learning resource along with contents on a social network to promote Bangchan subdistrict of Petchaburi province through the way of Buddhism. *International Education Studies,* 14(6), 1–11. https://ccsenet.org/journal/index. php/ies/article/view/0/45227

Phetphum, C., Wangwonsin, A., Keeratisiroj, O., & Jariya, W. (2025). Qualitative evaluation of Thailand's national tobacco control strategy 2022–2027: Challenges and suggestions for policy implementation. *National Library of Medicine*. https://pubmed.ncbi.nlm.nih.gov/40352806/

Public Relations Office, Bangkok. (2024). *Bangkok follows up on work to protect children and youth from e-cigarettes in response to urgent government policy.* https://pr-bangkok.com/?p=277098

Thamwipat, K., Namaso, K., & Princhankol, P. (2024). A synthesis of research studies on public relations multimedia utilization within an educational institute during the COVID- 19 pandemic: A comparative analysis of textual and data visualization approaches. *Kasetsart Journal of Social Sciences*, 45(2), 433–442. https://so04.tci-thaijo.org/index.php/kjss/article/view/272011

Thamwipat, K., & Princhankol, P. (2022). The design and development of interactive multimedia based on ADDIE model to publicize the Department of Educational Communications and Technology. *The 13th Global Conference on Business and Social Sciences*. https://gcbss.org/CIMSSR2022MALAYSIA/PDF/CIMSSR-00267.pdf

Waiwingrob, P., Thamwipat, K., & Princhankol, P. (2023). Active learning extracurricular activities using digital content to raise awareness of Thai arts and culture among undergraduate students. *Humanities, Arts and Social Sciences Studies*, 23(3), 642–655. https://doi.org/10.14456/hasss.2023.54

Warijan, & Nuraini. (2025). The effect of digital electronic anti-smoking campaigns on adolescents' perceptions and behaviors in middle schools. *Journal of Sustainable Applied Modification Evidence Community*, 2(2), 70–80. https://doi.org/10.69855/samec.v2i2.285

EXAMINING ENGLISH COMMUNICATION CHALLENGES AND REAL-WORLD WORK EXPERIENCE AMONG AIRLINE RESERVATION AND TICKETING STAFF IN THAILAND

Chalobon Nuntitrakarn[1], Thapanee Khemanuwong[1], Ekkapon Phairot[2], Tanassanee Jitpanich[1*], and Nagorn Bunyarit[3]

64614004@kmitl.ac.th, thapanee.kh@kmitl.ac.th, ekkapon.ph@skru.ac.th, tanassanee.ji@gmail.com, and nagorn.bu@kmitl.ac.th

[1]School of Liberal Arts, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand
[2]Faculty of Education, Songkhla Rajabhat University
[3]College of Innovation and Industrial Management, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand

*Corresponding Author E-mail: tanassanee.ji@gmail.com

ABSTRACT

Effective English communication is vital for airline reservation and ticketing staff, who serve as the primary interface for international passengers. Grounded in an English for Specific Purposes (ESP) framework, this quantitative needs analysis investigates communication challenges among 73 Thai reservation personnel using a structured five-point Likert scale questionnaire. The study evaluates real-world tasks, including customer interactions, documentation, and policy interpretation. Descriptive statistics revealed moderate levels of difficulty across three domains: overall communication, linguistic proficiency, and professional English use in documentation and policy contexts. Participants with less than six years of experience reported higher overall challenges (M=3.69, SD=0.43) than those with six or more years of experience (M=3.48, SD=0.53). An independent samples *t*-test indicated that more experienced staff reported significantly lower challenges, specifically in professional English for documentation and policy, $t(71)=2.47$, $p<0.05$, with a moderate effect size ($\eta^2=0.08$). However, no significant differences were found in overall and linguistic challenges, suggesting these difficulties persist regardless of experience level. The findings highlight a discrepancy between workplace demands and perceived competence, particularly in tasks requiring high precision. This underscores the necessity for targeted ESP training that integrates authentic aviation scenarios, industry-specific terminology, and exposure to diverse international accents. Such insights are crucial for developing contextually relevant curricula to improve service quality, operational efficiency, and continuous professional development in the aviation industry.

Keywords: English for Specific Purposes (ESP), Needs analysis, Communication challenges, Airline reservation staff, Workplace communication

1. Statement of the Problem

In the era of globalization, English is the primary lingua franca of international aviation, with the International Civil Aviation Organization (ICAO) mandating proficiency for key personnel (Kim & Elder, 2009; Knoch, 2014). While essential across all aviation roles, English communication remains a significant challenge for Thai personnel, particularly in oral-aural domains (Loedlukthanathan et al., 2020). For reservation and ticketing staff, these difficulties

transcend basic grammar to encompass specialized terminology, pragmatic competence, and accent comprehension—skills critical for managing complex interactions with diverse international passengers (Wasuthalainan, 2010).

From an English for Specific Purposes (ESP) perspective, identifying these challenges is vital for developing targeted training that enhances service quality (Hutchinson & Waters, 1987). However, while extensive research has focused on pilots and cabin crew, the communicative needs of ground-based reservation and ticketing staff remain underexplored. Addressing this gap, the present study employs a quantitative needs analysis to examine challenges across three domains: overall communication, linguistic hurdles, and professional documentation. By investigating the influence of work experience, this research provides evidence-based insights for training design and human resource development within the aviation sector.

2. Research Questions

RQ1: To what extent do airline reservation and ticketing staff experience overall challenges?

RQ2: Is there a statistically significant difference in overall challenges, English linguistic challenges, and professional English use in documentation and policy context between the two work experience groups of airline reservation and ticketing staff?

Hypotheses

H_0: There is no statistically significant difference between the two work experience groups in terms of overall challenges, English linguistic challenges, and professional English use in documentation and policy contexts.

H_1: There is a statistically significant difference between the two work experience groups in terms of overall challenges, English linguistic challenges, and professional English use in documentation and policy contexts.

3. Conceptual Framework

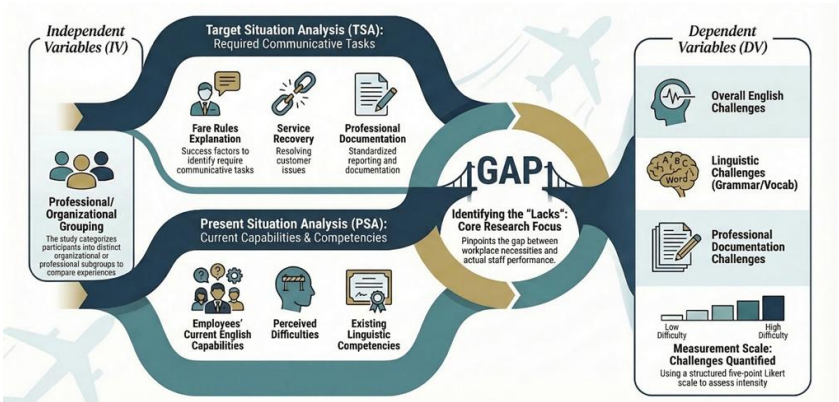

Figure 1 Conceptual Framework: ESP Needs Analysis: TSA–PSA Model

The conceptual framework of this study is grounded in the Needs Analysis (NA) paradigm within English for Specific Purposes (ESP), examining the nexus between workplace communicative demands and employee competencies. This framework integrates Target Situation Analysis (TSA) and Present Situation Analysis (PSA) to identify "lacks"—the discrepancies between required professional standards and current proficiency (Dudley-Evans & St. John, 1998; Hutchinson & Waters, 1987).

TSA defines the competencies essential for airline reservation and ticketing, encompassing the management of diverse accents, fare condition explanations, and accurate documentation.

These tasks necessitate not only grammatical precision but also specialized vocabulary, pragmatic competence, and the ability to perform under cognitive and temporal pressure (Basturkmen, 2010; Long, 2005). Conversely, PSA assesses employees' current proficiency and self-perceived competence within real-world contexts (Richterich & Chancerel, 1980).

The intersection of TSA and PSA identifies specific gaps, categorized into three domains: overall communication challenges, linguistic hurdles, and professional English use in documentation and policy. By synthesizing these elements, the framework informs the development of targeted ESP interventions aimed at enhancing communicative effectiveness and organizational performance within the aviation sector (Hyland, 2006; ICAO, 2010).

4. Literature Review

English for Specific Purposes and Workplace Communication

English for Specific Purposes (ESP) addresses learners' needs within distinct academic or professional domains, prioritizing functional language use over broad proficiency (Dudley-Evans & St John, 1998; Hutchinson & Waters, 1987). In professional contexts, communicative competence transcends grammatical accuracy to encompass discourse conventions, pragmatic proficiency, and performance under operational constraints (Canale & Swain, 1980; Koester, 2010).

In the aviation sector, English functions as the primary *lingua franca*, facilitating global interaction (Moder, 2013). Research in Thailand indicates that airline personnel face significant challenges in real-time oral-aural tasks despite adequate grammatical knowledge (Prachanant, 2012; Wongsuriya, 2020). Beyond information exchange, these interactions necessitate sociopragmatic competence and intercultural awareness for effective relationship management and conflict resolution (Celce-Murcia, 2007). Furthermore, frontline staff operate under systemic pressures, including time constraints, unpredictability, and emotional labor (Hochschild, 1983; Phithakphongphan, 2016). High-stakes tasks, such as managing service disruptions, often exceed the scope of general language training (Estival et al., 2016). Consequently, aviation-specific English proficiency remains a critical operational resource linked directly to safety, efficiency, and passenger satisfaction (ICAO, 2010).

Needs Analysis in ESP

Needs analysis is a foundational principle of English for Specific Purposes (ESP), informing curriculum design, materials development, and program evaluation (Dudley-Evans & St John, 1998). This process identifies discrepancies between a learner's current communicative competence and the linguistic demands of their target professional context (Long, 2005). Traditionally, it is structured through Target Situation Analysis (TSA), which defines workplace requirements and discourse conventions, and Present Situation Analysis (PSA), which assesses learners' current proficiency and perceived difficulties (Hutchinson & Waters, 1987). Together, TSA and PSA provide a comprehensive understanding of both objective professional demands and subjective learner experiences (Hyland, 2006).

Research indicates that workplace communication challenges transcend grammatical limitations; they are shaped by contextual factors such as task complexity, cognitive load, time pressure, and institutional expectations (Skehan, 1998). Since these multifaceted variables are often omitted from standardized assessments, survey-based methodologies are widely employed to examine practitioners' perceived difficulties within authentic, real-world settings (Dörnyei & Taguchi, 2010).

English Communication Challenges in Service Industries

Service-oriented communication is dynamic and customer-centric, requiring real-time management of inquiries and complaints while maintaining professionalism. Such demands impose significant linguistic and emotional pressure on non-native speakers (Hochschild, 1983; Koester, 2010). Key challenges include listening comprehension, particularly when encountering unfamiliar accents and rapid speech (Prachanant, 2012), alongside limited vocabulary and grammatical uncertainty that constrain precise expression (Skehan, 1998). Among Thai airline personnel, difficulty in decoding diverse international accents is strongly associated with communication breakdowns and increased anxiety during peak operations (Wongsuriya, 2020).

Furthermore, pragmatic competence—encompassing politeness, formality, and intercultural empathy—is critical for effective service (Taguchi, 2009). These challenges are exacerbated by real-world constraints, such as time pressure and multitasking, which limit clarification opportunities (Estival et al., 2016). Ultimately, such communicative gaps can lead to operational errors and significant reputational risks (ICAO, 2010).

English Use in Aviation Reservation and Ticketing

Airline reservation personnel perform a critical frontline function, managing complex bookings and service disruptions (Wirtz & Lovelock, 2016). Their role necessitates multimodal interaction across telephonic, face-to-face, and written channels (Moder, 2013). Unlike standardized operational roles, reservation staff engage in dynamic, customer-driven discourse with high emotional intensity (Estival et al., 2016). Telephonic communication is particularly demanding due to the absence of visual cues, requiring superior discourse management (Hutchby, 2001), while simultaneous system operations increase cognitive load and communication risks (Sweller, 1988). Furthermore, precision in written documentation is vital, as errors in institutional systems can incur significant financial or regulatory consequences (Hyland, 2019).

Research on workplace communication challenges yields divergent results; some studies suggest that experience mitigates difficulties, while others indicate that systemic demands produce uniform challenges across groups (Phithakphongphan, 2016; Wongsuriya, 2020). Methodologically, non-significant findings warrant cautious interpretation, emphasizing the use of effect sizes to determine practical significance and inform targeted training interventions (Cohen, 1988; Ellis, 2010; Field, 2013).

5. Research Methodology

5.1 Research Design

To investigate English communication challenges among airline reservation and ticketing staff in Thailand, this study employed a quantitative cross-sectional survey design, a method widely used to examine relationships and patterns within a population at a single point in time (Cohen et al., 2018; Creswell, 2014). Within this framework, a descriptive–comparative approach was adopted to identify the level and types of communication difficulties encountered in workplace contexts and to examine differences between employees with varying levels of professional experience. This design was particularly suitable for capturing participants' perceptions of current communication demands while enabling systematic measurement and statistical comparison between groups.

5.2 Participants

The target population of this study comprised airline reservation and ticketing staff employed by commercial airlines operating in Thailand during 2025–2026. The sampling frame consisted of customer-facing reservation and ticketing personnel, including call center agents and airport

ticketing counter staff, whose roles require regular use of English in communication with international customers.

A total of 73 participants were included in the study. Participants were recruited using convenience and voluntary sampling due to practical constraints in accessing airline personnel (see Section 5.5 for details of the recruitment procedure). Participants were drawn from multiple operational contexts, including call centers and airport service counters, which may have influenced the types of communication challenges reported. Eligibility criteria required participants to be currently employed in reservation or ticketing roles, to interact regularly with international passengers, and to use English as part of their professional responsibilities. For comparative purposes, participants were grouped according to their work experience: less than six years (n = 30) and six years and above (n = 43). Participation was entirely voluntary, and all responses were collected anonymously.

5.3 Research Instrument

Data were collected via a structured questionnaire developed within the ESP Needs Analysis framework, integrating Target Situation Analysis (TSA) and Present Situation Analysis (PSA) to reflect authentic professional tasks. The instrument comprised two sections: (1) Demographic and Professional Profiles, including work experience and frequency of English use; and (2) Perceived Communication Challenges across three domains: overall reservation tasks, linguistic proficiency (e.g., grammar, accent comprehension), and professional documentation (e.g., emails, record-keeping).

Responses were measured on a five-point Likert scale, ranging from "Very Low" to "Very High" difficulty. To interpret the mean scores, the following criteria were applied: 4.21–5.00 (Very High), 3.41–4.20 (High), 2.61–3.40 (Moderate), 1.81–2.60 (Low), and 1.00–1.80 (Very Low). This structured quantitative approach facilitated comparative statistical analysis across domains and participant groups.

5.4 Validity and Reliability

The validity and reliability of the instrument were established prior to the main study. Content validity was confirmed through expert evaluation by three specialists in English for Specific Purposes, applied linguistics, and aviation communication. The Index of Item–Objective Congruence (IOC) values ranged from 0.67 to 1.00, indicating satisfactory alignment between the items and the research objectives.

A pilot study involving 32 participants with similar characteristics to the target population was conducted to assess clarity and feasibility. Internal consistency reliability was evaluated using Cronbach's alpha. The overall scale demonstrated good reliability ($\alpha = 0.804$), while the documentation domain showed acceptable reliability ($\alpha = 0.728$), and the linguistic domain indicated moderate reliability ($\alpha = 0.614$). These results indicate that the instrument was sufficiently reliable for use in the main study.

5.5 Data Collection

Data collection was conducted between February and March 2026 using an online questionnaire administered via Google Forms. In line with the convenience and voluntary sampling approach, invitations to participate were distributed through internal channels, including HR email announcements, coordination through supervisors, and internal social media platforms (e.g., LINE staff communication groups).

The sampling frame comprised approximately 120 eligible personnel across participating airline units, all of whom were invited to participate. A total of 73 completed responses were obtained, yielding an approximate response rate of 60.8%. Participants represented both call center operations and airport ticketing counters, bringing a range of real-world work experience in handling customer interactions. This diversity provided multiple perspectives on workplace communication; however, differences in job roles may have influenced nature and frequency of the challenges reported. Prior to data collection, participants were informed of the study's purpose,

and informed consent was obtained. Participation was voluntary, and no personally identifiable information was collected, ensuring participant anonymity.

5.6 Ethical Considerations

The study adhered to established ethical principles for research involving human participants. Participation was voluntary, and respondents were informed of their right to withdraw at any time without penalty. No personally identifiable information was collected, and all responses were recorded anonymously. Data were stored securely and used solely for academic purposes, with findings reported in aggregate form to ensure confidentiality.

5.7 Data Analysis

Quantitative data were analyzed using statistical software (SPSS), employing both descriptive and inferential statistics. Descriptive measures, including mean and standard deviation, were used to assess the level of communication challenges across three domains: overall communication, English linguistic challenges, and professional English use in documentation, providing an overview of central tendency and variability.

Inferential analysis was conducted using independent-samples *t*-tests to examine differences between two groups based on work experience (less than six years vs. six years and above). Separate tests were performed for each domain to determine statistically significant differences in mean scores. Assumptions of normality and homogeneity of variance were verified prior to analysis to ensure the appropriateness of the parametric tests.

In addition to statistical significance testing, effect sizes were calculated using Cohen's (1988) to determine the magnitude of differences between the groups. Reporting effect size provides a measure of practical significance and indicates whether observed differences are meaningful beyond statistical significance alone. Cohen's (1988) effect size were interpreted according to conventional benchmarks, with values between 0.01-0.05 considered small, between 0.06 and 0.13 considered medium, and more than 0.13 considered large effects. Statistical significance was set at the .05 level. These procedures enabled a comprehensive examination of both the extent of English communication challenges and differences between groups in relation to the study's objectives.

6. Results

To provide a comprehensive overview of the study's context, this section delineates the demographic characteristics of the participants. A total of 73 individuals participated in the study, with their profiles categorized by various factors, including age, gender, and professional background, to ensure a nuanced understanding of the population under investigation.

Table 1 Participants' demographic information

Demographics	**Category**	**Number of Participants**	**Percentage (%)**
Gender	Female	69	95%
	LGBTQA+	1	1%
	Not specifics	3	4%
Age	Below 30 years	11	15%
	31-40 years	51	70%
	41 years and above	11	15%
Educational Background	Bachelor's Degree	72	99%
	Master's Degree	1	1%

Table 1 (continued)

Demographics	Category	Number of Participants	Percentage (%)
The field of study	Aviation/Air Transport Studies	32	44%
	Languages / Humanities / Arts	20	27%
	Hospitality/Tourism Management	13	18%
	Business Administration/ Management	7	10%
	Others	1	1%
Years of work experience	Less than 6 years	30	41%
	6 years and above	43	69%
Level of position	Officer	54	74%
	Supervisor/Senior Supervisor	19	26%

Total (N=73)

As presented in Table 1, the study comprised a total of 73 participants working in the Thai context. The demographic profile reveals a predominantly female sample (95%). In terms of age, the largest group belongs to the 31-40 years range, accounting for 70%. Regarding educational background, nearly all participants hold a Bachelor's Degree (99%), with 44% having specialized in Aviation or Air Transport Studies. In terms of professional status, the majority of respondents serve as Officers (74%). Crucially, these positions require daily English communication to interact with the predominantly international passenger base, highlighting the English proficiency of their professional roles. Lastly, 69% of the participants possess six years and above of work experience.

The key results of the present study are presented in accordance with each research question as follows.

RQ1: To what extent do airline reservation and ticketing staff experience overall challenges?

The results of descriptive statistics were computed to examine perceived English communication challenges among airline reservation and ticketing staff across three domains: overall communication challenges, English communication challenges, and professional English use in documentation. Responses were recorded on a five-point scale, with higher scores indicating greater perceived difficulty in performing English-mediated job tasks.

Table 2 Results of descriptive statistics (N=73)

Current English Communication Challenges	Mean	SD	Interpretation
1. English linguistic challenges			
1.1 Challenge in identifying appropriate professional English terminology to explain technical airline concepts, such as fare basis.	3.52	0.71	High
1.2 Challenge in the need to provide smooth and coherent English explanations for complex topics in spontaneous interactions.	3.52	0.77	High
1.3 Challenge in managing appropriate tone and register (pragmatics) in English when delivering sensitive information, such as high change fees or cancellation policies and refunds.	3.45	0.91	High
1.4 Challenge in comprehending diverse non-native English accents from international passengers.	3.67	0.88	High

Table 2 (continued)

Current English Communication Challenges	Mean	SD	Interpretation
1.5 Challenge in avoiding linguistic ambiguity in English, such as confusing the word 'fare' vs. 'fair', when providing explanations.	3.67	0.77	High
Average (1.1-1.5)	**3.57**	**0.54**	**High**
2. Professional English use in documentation and policy contexts			
2.1 Challenge in structuring complex legalistic information in English (e.g., refund eligibility) into clear and professional emails or reports.	3.53	0.82	High
2.2 Challenge in ensuring grammatical accuracy and clarity in English when drafting official customer correspondence or internal documents	3.64	0.87	High
2.3 Challenge in developing relevant content and ensuring linguistic precision in English for formal reports.	3.52	0.80	High
2.4 Challenge in interpreting nuanced English terminology (e.g., shall vs. should) within updated technical manuals or policy documents.	3.67	0.67	High
2.5 Challenges in English communication development due to limited training.	3.45	0.82	High
Average (2.1-2.5)	**3.56**	**0.58**	**High**
Overall	**3.57**	**0.50**	**High**

Table 2 presents the descriptive statistics of current English communication challenges among participants (N=73). Overall, the findings indicate that participants experienced a high level of challenges (M=3.57, SD=0.50).

In terms of English linguistic challenges, all items were rated at a high level. The highest mean scores were observed for challenges in comprehending diverse non-native English accents (M=3.67, SD=0.88) and avoiding linguistic ambiguity (M=3.67, SD=0.77). These were followed by difficulties in identifying appropriate professional terminology (M= 3.52, SD=0.71) and providing smooth and coherent explanations in spontaneous interactions (M=3.52, SD=0.77). The lowest mean within this category was associated with managing appropriate tone and register (M=3.45, SD=0.91). The overall mean score for linguistic challenges remained at a high level (M=3.57, SD=0.54).

Similarly, professional English use in documentation and policy contexts was also perceived as highly challenging across all items. The most prominent challenge was related to interpreting nuanced English terminology in technical documents (M=3.67, SD=0.67), followed by ensuring grammatical accuracy and clarity in official correspondence (M=3.64, SD=0.87). Additional challenges included structuring complex legalistic information into clear formats (M=3.53, SD=0.82) and developing relevant and linguistically precise content for formal reports (M=3.52, SD=0.80). The lowest mean score in this domain pertained to challenges arising from limited training in English communication (M=3.45, SD=0.82). The overall mean for this category was also at a high level (M=3.56, SD=0.58).

Taken together, the findings suggest that participants encounter substantial challenges in both linguistic communication and documentation-related English use, particularly in areas requiring nuanced interpretation and precise professional communication.

RQ2: Is there a statistically significant difference in overall challenges, English linguistic challenges, and professional English use in documentation and policy contexts between the two work experience groups of airline reservation and ticketing staff?

To address RQ2, an independent-samples *t*-test was used to analyze the data to determine if there is a statistically significant difference in overall challenges, English linguistic challenges, and professional English use in documentation and policy contexts among the participants between two work experience groups.

Table 3 Results of independent samples *T*-test

Challenges	Less than 6 years (n=30)		6 years and above (n=43)		t	df	Sig. (2-tailed)
	M	SD	M	SD			
1. Overall	3.69	0.43	3.48	0.53	1.79	71	0.08
2. English linguistics	3.62	0.49	3.53	0.58	0.69	71	0.49
3. Professional English use in documentation and policy contexts	3.76	0.53	3.43	0.59	2.47	71	0.02*

*Eta squared=0.08

Table 3 presents the comparison of perceived challenge levels across two different work experience groups. The results indicate that differences in work experience did not significantly affect overall challenges in current English communication and English linguistic challenges. Participants with less than 6 years of experience (M=3.69, SD=0.43) and those with 6 years and above (M=3.48, SD=0.53) had comparable level of overall challenges, t(71)=1.79, $p>0.05$. Similarly, participants with less than 6 years (M=3.62, SD=0.49) and those with 6 years and above (M=3.53, SD=0.58) showed comparable level of English linguistic challenges, t(71)=0.69, $p>0.05$.

The findings suggest that work experience does not play a significant role in reducing perceived challenges in English communication. Both less experienced and more experienced participants reported similarly high levels of overall and linguistic challenges, indicating that these difficulties are common across experience levels rather than being limited to early-career individuals. This may imply that workplace exposure alone is insufficient to substantially improve English communication proficiency, particularly in linguistically demanding contexts. Therefore, targeted training and continuous professional development in English communication may be necessary for employees at all levels of experience.

However, perceived challenges in professional English use in documentation and policy contexts of participants with less than 6 years of experience (M=3.76, SD=0.53) was significantly greater than those with 6 years and above (M=3.43, SD=0.59), t(71)=2.47, $p<0.05$. The effect size of work experience on perceived challenges in professional English use in documentation and policy contexts was moderate (eta squared=0.08)

The results indicate that work experience significantly influences perceived challenges in professional English use in documentation and policy contexts. Participants with less than 6 years of experience reported higher levels of difficulty compared to those with 6 years and above, suggesting that more experienced individuals are better able to manage documentation-related

communication. This may be attributed to greater exposure to formal writing tasks and familiarity with technical and policy-related language over time. The moderate effect size further suggests that work experience has a meaningful, though not dominant, impact on reducing such challenges.

Overall, the results indicate that English communication challenges are broadly shared among airline reservation and ticketing staff, regardless of group classification. Although staff with less work experience consistently reported higher levels of perceived difficulty, the absence of statistically significant differences suggests that workplace communication demands affect employees in both groups in broadly similar ways. Nevertheless, the moderate effect size observed for documentation-related tasks points to a potential area of differential difficulty that may warrant further investigation.

7. Discussion and Conclusion

7.1 Discussion

This study identified a high overall difficulty level (M=3.57, SD=0.50) in English communication among Thai reservation personnel, highlighting that classroom proficiency often diverges from the multifaceted demands of real-world contexts. Findings indicate that English-mediated tasks remain challenging, particularly those that require real-time comprehension and pragmatic precision in authentic workplace interactions. Linguistic hurdles were most pronounced in high-pressure scenarios, where personnel must decode diverse non-native accents and mitigate ambiguity complexities that align with research on the unpredictable nature of global aviation speech patterns (Kim & Elder, 2009; Moder, 2013; Taguchi, 2015).

In documentation-related tasks, participants also reported considerable difficulty with technical terminology and grammatical accuracy. This reflects the highly regulated nature of aviation operations, where even minor linguistic inaccuracies may result in operational inefficiencies or financial consequences (Bhatia, 2004; Evans, 2013). Although no significant differences were observed across most communicative domains, more experienced staff showed significantly greater ease in handling documentation tasks ($\eta^2 = 0.08$). This suggests that workplace experience supports the development of procedural and genre-specific knowledge; however, it does not fully resolve broader communicative challenges in real-time interaction (Forey & Lockwood, 2007). Overall, the findings highlight a persistent mismatch between workplace communication demands and employees' available linguistic resources. This indicates the need for targeted ESP interventions that extend beyond theoretical instruction to include task-based simulations of authentic aviation scenarios, exposure to diverse international accents, and structured practice in professional writing. In this regard, Task-Based Language Teaching (TBLT) offers a pedagogically appropriate approach for aligning language training with the communicative realities of the aviation industry (Ellis, 2003; ICAO, 2010).

The above findings are synthesized in the Aviation ESP Communication Gap Framework (Figure 2), which conceptualizes how workplace communication demands give rise to multidimensional language challenges in airline reservation and ticketing contexts.

Figure 2 The Aviation ESP Communication Gap Framework in Airline Reservation and Ticketing Staff

The figure illustrates the conceptual framework developed from the study findings on English communication challenges among airline reservation and ticketing staff. It shows how workplace contextual demands (e.g., time-sensitive operations, customer diversity, and multi-channel communication tasks) contribute to the emergence of an Aviation ESP communication gap. This gap is conceptualized as comprising three interrelated dimensions: linguistic fluency (e.g., vocabulary, grammar, and pronunciation difficulties), pragmatic competence (e.g., appropriate tone, politeness, and soft skills in customer interaction), and interactional skills (e.g., turn-taking, managing misunderstandings, and repairing communication breakdowns). These communication gaps subsequently lead to workplace communication outcomes, including service delays, passenger misunderstandings, and increased staff stress.

The framework further identifies work experience as a moderating factor. Staff with higher levels of experience are better able to employ coping strategies that mitigate communication breakdowns, whereas less experienced staff tend to experience more severe communication challenges and service disruptions. Overall, the model provides an integrative explanation of how English communication difficulties operate in real-world aviation service contexts and how experiential learning influences communicative effectiveness.

7.2 Conclusion

This study highlights that English communication competence is central to the professional effectiveness of airline reservation and ticketing staff in Thailand. The findings indicate persistent challenges across both spoken and written communication domains, particularly in tasks requiring real-time processing, accuracy, and interactional responsiveness. The lack of significant differences across most communicative domains further suggests that these difficulties are systemic in nature and closely embedded in occupational demands rather than reflecting isolated skill deficiencies.

While work experience contributes significantly to documentation-related proficiency—reflecting the gradual development of procedural awareness and genre-specific competence—it remains insufficient to fully resolve broader communicative challenges in real-time service

interactions. From an English for Specific Purposes (ESP) perspective, these findings underscore the need for targeted, context-sensitive training informed by systematic needs analysis. To bridge the gap between workplace demands and employee capabilities, pedagogical interventions should prioritize task-based and simulation-based approaches that closely replicate authentic aviation communication contexts. Such training should incorporate realistic scenarios, including service recovery, booking modifications, complaint handling, and interaction with diverse international accents.

In addition, sustained organizational support through continuous professional development is essential to enhance employees' communicative confidence, operational efficiency, and overall service quality. Collectively, this study contributes to ESP research by illuminating the multidimensional nature of English use in aviation service work and demonstrating how workplace experience shapes communicative adaptation over time. Future research should further explore the effectiveness of AI-assisted language tools and digital communication support systems in enhancing the communicative performance of aviation personnel operating in increasingly complex global service environments.

8. Suggestions for Future Research

Future research should expand the scope to include a wider range of aviation personnel, particularly ground staff such as cabin crew, ground service staff, and airport operations officers, to provide a more comprehensive understanding of English communication demands across roles. Comparative studies across countries or regions would further illuminate how cultural, organizational, and linguistic factors shape workplace communication challenges.

In addition, future studies should move beyond descriptive approaches by employing experimental or quasi-experimental designs to evaluate the effectiveness of targeted ESP training programs. Longitudinal research could examine the development of English communication competence over time and the impact of sustained training on performance, confidence, and service quality.

Such work would support the development of evidence-based ESP training models aligned with specific job requirements and the evolving needs of the global aviation sector.

9. Pedagogical and Practical Implications

Pedagogical frameworks for aviation personnel should prioritize Task-Based Language Teaching aligned with authentic workplace discourse. Instructional design must integrate aviation-specific lexicons, scenario-based simulations of service encounters, and professional writing proficiency for official documentation. Furthermore, curricula should incorporate service recovery strategies to effectively navigate customer grievances and operational contingencies. Given the industry's globalized nature, exposure to diverse English accents and the cultivation of intercultural communicative competence are imperative. Ultimately, institutional investment in targeted, context-specific training is vital for enhancing service quality, employee confidence, and systemic operational efficiency.

10. Limitations of the Study

This study acknowledges several limitations. The Thai-specific sample and reliance on self-reported data may constrain broader generalizability and introduce response bias. Additionally, the cross-sectional design offers a static perspective, overlooking the longitudinal evolution of communicative competence and workplace demands. Future research should employ multi-

national samples and longitudinal or intervention-based designs to provide more robust, generalizable, and causally informative insights into ESP training efficacy within the global aviation sector.

11. Acknowledgements

The authors express their sincere gratitude to the panel of experts for their invaluable expertise and feedback, which significantly enhanced the rigor of this study. Heartfelt appreciation is extended to all participants for their essential contributions. The authors also acknowledge the School of Liberal Arts, King Mongkut's Institute of Technology Ladkrabang (KMITL), and the participating airline for their institutional support and resources, which were instrumental in the completion of this research.

12. References

Basturkmen, H. (2010). *Developing courses in English for specific purposes*. Palgrave Macmillan.

Bhatia, V. K. (2004). *Worlds of written discourse: A genre-based view*. Continuum.

Canale, M., & Swain, M. (1980). Theoretical bases of communicative approaches to second language teaching and testing. *Applied Linguistics*, *1*(1), 1-47.

Celce-Murcia, M. (2007). Rethinking the role of communicative competence in language teaching. In *Intercultural Language Use and Language Learning* (pp. 41-57). Springer.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). SAGE Publications.

Dörnyei, Z., & Taguchi, T. (2010). *Questionnaires in second language research: Construction, administration, and processing* (2nd ed.). Routledge.

Dudley-Evans, T., & St. John, M. J. (1998). *Developments in English for specific purposes: A multi-disciplinary approach*. Cambridge University Press.

Ellis, P. D. (2010). *The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results*. Cambridge University Press.

Ellis, R. (2003). *Task-based language learning and teaching*. Oxford University Press.

Estival, D., Farris, C., & Molesworth, B. R. (2016). *Aviation English: A lingua franca for pilots and air traffic controllers*. Routledge.

Evans, S. (2013). Designing tasks for the business English classroom. *ELT Journal, 67*(3), 281–293. https://doi.org/10.1093/elt/cct013

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. SAGE Publications.

Forey, G., & Lockwood, J. (2007). "I'd love to put someone in jail for this": An initial investigation of English in the business processing outsourcing (BPO) industry. *English for Specific Purposes, 26*(3), 308–326. https://doi.org/10.1016/j.esp.2006.09.003

Hochschild, A. R. (1983). *The managed heart: Commercialization of human feeling*. University of California Press.

Hutchby, I. (2001). *Conversation and technology: From the telephone to the internet*. Polity Press.

Hutchinson, T., & Waters, A. (1987). *English for specific purposes: A learning-centered approach*. Cambridge University Press.

Hyland, K. (2006). *English for academic purposes: An advanced resource book*. Routledge.

Hyland, K. (2019). *Second language writing* (2nd ed.). Cambridge University Press.

International Civil Aviation Organization (ICAO). (2010). *Manual on the implementation of ICAO language proficiency requirements* (Doc 9835, 2nd ed.).

Kim, H., & Elder, C. (2009). Understanding aviation English as a lingua franca: Perceptions of Korean aviation personnel. *Australian Review of Applied Linguistics*, *32*(3), 23-1.

Knoch, U. (2014). Using subject specialists to validate an ESP rating scale: The case of the International Civil Aviation Organization (ICAO) rating scale. *English for Specific Purposes*, *33*, 77-86.

Koester, A. (2010). *Workplace discourse*. Continuum International Publishing Group.

Loedlukthanathan, S., Premmanisakul, V., Mahasap, N., Apichatiyakul, K., & Griffiths, T. S. (2020). English oral communication skill improvements and needs from foreign tourists engagement perspective as duty notion by Thai airport passenger-handlers and flight attendants of Thai aviation and airports. *Journal of Social Academic*, *13*(2), 19-27.

Long, M. H. (2005). *Second language needs analysis*. Cambridge University Press.

Moder, C. L. (2013). Aviation English. In B. Paltridge & S. Starfield (Eds.), *The handbook of English for specific purposes* (pp. 227–242). Wiley Blackwell.

Phithakphongphan, T. (2016). A study on the needs of English skills of airline ground staff. *Journal of Humanities and Social Sciences, Thaksin University*, *11*(2), 37–54.

Prachanant, N. (2012). Needs and problems of English language use for tourism employees. *English Language Teaching*, *5*(9), 117–125.

Richterich, R., & Chancerel, J. L. (1980). *Identifying the needs of adults learning a foreign language*. Pergamon Press.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Taguchi, N. (2009). Pragmatic competence in Japanese as a second language: Introduction. In N. Taguchi (Ed.), *Pragmatic competence* (pp. 1–18). Mouton de Gruyter.

Taguchi, N. (2015). Instructed pragmatics at a glance: Where instructional studies were, are, and should be going. *Language Teaching, 48*(1), 1–50. https://doi.org/10.1017/S0261444814000263

Wasuthalainan, K. (2010). *Attitudes of ticketing and reservation staff of Bangkok Airways towards in-house English training course* (No. 122559). Thammasat University.

Wirtz, J., & Lovelock, C. (2016). *Services Marketing: People, Technology, Strategy* (8th ed.). World Scientific Publishing.

Wongsuriya, P. (2020). English communication needs of airline ground staff in Thailand. *Journal of Humanities and Social Sciences, Mahasarakham University*, *39*(4), 55-67.

คำสั่งคณะครุศาสตร์อุตสาหกรรมและเทคโนโลยี สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

ที่ e ๕๙/๒๕๖๙

เรื่อง แต่งตั้งคณะกรรมการดำเนินงานโครงการประชุมวิชาการทางการศึกษาระดับนานาชาติ ครั้งที่ ๒๒

เพื่อให้การจัดโครงการประชุมวิชาการทางการศึกษาระดับนานาชาติ ครั้งที่ ๒๒ เรื่อง "Research and Innovation Ecosystem" ภายใต้หัวข้อ "Developing Real-Life Learning Experiences: Technology and AI Driving Research and Innovation ในวันที่ ๒๒ - ๒๓ พฤษภาคม พ.ศ. ๒๕๖๙ เวลา ๐๘.๐๐ - ๑๖.๓๐ น. ณ คณะบริหารธุรกิจ และคณะครุศาสตร์อุตสาหกรรมและเทคโนโลยี ดำเนินไปด้วยความเรียบร้อย มีประสิทธิภาพและเกิดประโยชน์สูงสุด จึงแต่งตั้งผู้มีรายชื่อต่อไปนี้ เป็นคณะกรรมการดำเนินงานฝ่ายต่าง ๆ ดังนี้

๑. คณะกรรมการฝ่ายอำนวยการ

๑. ศาสตราจารย์ ดร.ปริยาภรณ์	ตั้งคุณานันต์	ประธานกรรมการ
๒. รองศาสตราจารย์ ดร.ปิยะ	ศุภวราสุวัฒน์	กรรมการ
๓. รองศาสตราจารย์ ดร.บุญจันทร์	สีสันต์	กรรมการ
๔. ผู้ช่วยศาสตราจารย์พงษ์เกียรติ	จงไตรลักษณ์	กรรมการ
๕. ผู้ช่วยศาสตราจารย์ ดร.พรเทพ	จิวไพโรจน์กิจ	กรรมการ
๖. ผู้ช่วยศาสตราจารย์ ดร.ศราวุธ	อินทรเทศ	กรรมการ
๗. อาจารย์ ดร.ใหม่	เจริญธรรม	กรรมการ
๘. อาจารย์ ดร.อฏฐม	สาริบุตร	กรรมการ
๙. อาจารย์ ดร.ขวัญธิศศรา	อภิสุขสกุล	กรรมการ
๑๐. รองศาสตราจารย์ ดร.ทนงศักดิ์	โสวจัสสตากุล	กรรมการ
๑๑. รองศาสตราจารย์ ดร.สมพล	ดำรงเสถียร	กรรมการ
๑๒. รองศาสตราจารย์ ดร.อมรชัย	ชัยชนะ	กรรมการ
๑๓. อาจารย์ ดร.ภัทราภรณ์	ภัทรรังสฤษฎ์	กรรมการ
๑๔. รองศาสตราจารย์ ดร.สันติ	ตันตระกูล	กรรมการและเลขานุการ

๒. คณะกรรมการฝ่ายต้อนรับและพิธีการ

๑. อาจารย์ ดร.ขวัญธิศศรา	อภิสุขสกุล	ประธานกรรมการ
๒. รองศาสตราจารย์ ดร.ประเสริฐ	เคนพันค้อ	กรรมการ
๓. ผู้ช่วยศาสตราจารย์ ดร.อำภาพรรณ	ตันตินาครกูล	กรรมการ
๔. นางสาวนลินี	รัตนสุวรรณ	กรรมการ
๕. นางสาวจิราพร	เวชพันธ์	กรรมการ
๖. นางสาวศุภิสรา	หนูสม	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านงานพิธีการต่าง ๆ พิธีกรดำเนินรายการ การต้อนรับและอำนวยความสะดวกแก่ผู้เข้าร่วมโครงการ

๓. คณะกรรมการฝ่ายวิชาการ

๑. รองศาสตราจารย์ ดร.สันติ	ตันตระกูล	ประธานกรรมการ
๒. ศาสตราจารย์ ดร.ภัคพงศ์	ปวงสุข	กรรมการ
๓. รองศาสตราจารย์ ดร.ศิริรัตน์	เพ็ชร์แสงศรี	กรรมการ
๔. รองศาสตราจารย์ ดร.ธนินทร์	รัตนโอฬาร	กรรมการ
๕. ผู้ช่วยศาสตราจารย์ ดร.อำภาพรรณ	ตันตินาครกูล	กรรมการ
๖. ผู้ช่วยศาสตราจารย์ ดร.พูลศรี	เวศย์อุฬาร	กรรมการ
๗. ผู้ช่วยศาสตราจารย์ ดร.กันยารัตน์	ศรีวิสทิยกุล	กรรมการ
๘. รองศาสตราจารย์ ดร.จตุรงค์	เลาหะเพ็ญแสง	กรรมการ
๙. ผู้ช่วยศาสตราจารย์ ดร.อภิสักก์	สินธุภัค	กรรมการ
๑๐. รองศาสตราจารย์ ดร.สุริยัณห์	สุภาพวานิช	กรรมการ
๑๑. รองศาสตราจารย์ ดร.ชัยรัตน์	เตชวุฒิพร	กรรมการ
๑๒. รองศาสตราจารย์ ดร.ฐิยาพร	กันตาธนวัฒน์	กรรมการ
๑๓. รองศาสตราจารย์ ดร.พรพิมล	ฉายรัศมี	กรรมการ
๑๔. รองศาสตราจารย์ ดร.วรวิทย์	สมหา	กรรมการ
๑๕. รองศาสตราจารย์ ดร.ประเสริฐ	เคนพันค้อ	กรรมการ
๑๖. ผู้ช่วยศาสตราจารย์ ดร.พิชญ์สินี	มะโน	กรรมการ
๑๗. ผู้ช่วยศาสตราจารย์ ดร.อภิรัฐ	ลิ่มมณี	กรรมการ
๑๘. นางสาวยศสิญา	ธวัชชัยนันท์	กรรมการ
๑๙. นางสาวศุภิสรา	หนูสม	กรรมการ
๒๐. นางสาวแพรชมภู	วังศกาญจน์	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านงานวิชาการ สรุป รวบรวม คัดเลือก พิจารณาบทความ ประสานงานกับผู้ทรงคุณวุฒิในการพิจารณาบทความ เป็นกรรมการในการพิจารณาบทความที่ได้รับรางวัล Best Paper Award และเป็นผู้ดำเนินรายการในห้องนำเสนอผลงาน

๔. คณะกรรมการฝ่ายลงทะเบียน

๑. รองศาสตราจารย์ ดร.ทนงศักดิ์	โสวจัสสตากุล	ประธานกรรมการ
๒. นายไพศาล	สุนทรนนท์	กรรมการ
๓. นางมนต์สินี	พานิช	กรรมการ
๔. นางศิริโฉม	ดำรงเสถียร	กรรมการ
๕. นางรวีวรรณ	มุขแก้ว	กรรมการ
๖. นายมาโนชญ์	ทรัพย์แสนดี	กรรมการ
๗. นางสาววิสันต์	บุญสาร	กรรมการ
๘. นางยุพาพร	มอโท	กรรมการ
๙. นางสาวเสาวลักษณ์	สุกการ	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านการสรุป รวบรวม และจัดเตรียมรายชื่อผู้ลงทะเบียนของโครงการ จัดทำเอกสารลงนามผู้เข้าร่วมโครงการ ผู้นำเสนอผลงาน

๕. ฝ่ายประสานงานห้องนำเสนอผลงานวิจัย

๑. รองศาสตราจารย์ ดร.สันติ	ตันตระกูล	ประธานกรรมการ
๒. นางสาวศิริวรรณ	ฉายศิริ	กรรมการ
๓. นางสาวแพรชมภู	วังศกาญจน์	กรรมการ
๔. นางสาวยศสิญา	ธวัชชัยนันท์	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ติดต่อประสานงานกับผู้เข้าร่วมโครงการ ประสานงานในการควบคุมเวลา และถ่ายภาพในห้องนำเสนอผลงาน

๖. คณะกรรมการฝ่ายอาคารสถานที่

๑. อาจารย์ ดร.อฏฐม	สาริบุตร	ประธานกรรมการ
๒. นายสุปรีชา	จงทอง	กรรมการ
๓. นายนันทิพัฒน์	ต๊ะมี	กรรมการ
๔. นายนิมิต	สาตรปรุง	กรรมการ
๕. นายวัชระพงษ์	โยไซ	กรรมการ
๖. อาจารย์วัชรินทร์	คงพิบูลย์	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านการจัดเตรียมและตกแต่งสถานที่ในการจัดโครงการ และอื่น ๆ ที่เกี่ยวข้อง

๗. คณะกรรมการฝ่ายการเงินและพัสดุ

๑. รองศาสตราจารย์ ดร.บุญจันทร์	สีสันต์	ประธานกรรมการ
๒. นางยุพาพร	มอโท	กรรมการ
๓. นางสาวเสาวลักษณ์	สุกการ	กรรมการ
๔. นางสาวจิราพร	เวชพันธ์	กรรมการ
๕. นางสาวแพรชมภู	วังศกาญจน์	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ดูแลด้านการเงินและการเบิกจ่ายวัสดุที่ใช้ในโครงการ

๘. คณะกรรมการฝ่ายโสตทัศนูปกรณ์ สารสนเทศและประชาสัมพันธ์

๑. อาจารย์ ดร.ใหม่	เจริญธรรม	ประธานกรรมการ
๒. อาจารย์วัชรินทร์	คงพิบูลย์	กรรมการ
๓. นายวรากร	ทองรัศมี	กรรมการ
๔. นายวิชัย	พลอยประเสริฐ	กรรมการ
๕. นายประยุทธ์	ขุนทอง	กรรมการ
๖. นายพีระพล	อินทรีย์วงศ์	กรรมการ
๗. นายบัญชา	ทะไกรราช	กรรมการ
๘. นายปฏิภาณ	สำเนียง	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านจัดเตรียมและอำนวยความสะดวกของอุปกรณ์ทางด้านสารสนเทศ ด้านโสตทัศนูปกรณ์ จัดทำบัตรผู้นำเสนอผลงาน จัดทำประชาสัมพันธ์ ป้ายต่าง ๆ ของโครงการ จัดทำเว็บไซต์ และจัดทำใบประกาศนียบัตร

๙. คณะกรรมการฝ่ายประเมินผล

๑. ผู้ช่วยศาสตราจารย์พงษ์เกียรติ	จงไตรลักษณ์	ประธานกรรมการ
๒. นางสาวนลินี	รัตนสุวรรณ	กรรมการ
๓. นางสาวพัชญ์สิตา	ศิรพรธำรงรัตน์	กรรมการ
๔. นางสาวกาญจนา	เพชรจรูญ	กรรมการ
๕. นางสาวจุฑามาศ	ยิ้มพราย	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านการจัดเตรียมแบบประเมินโครงการและแบบประเมิน Best Paper Award รวบรวม และสรุปผล

๑๐. คณะกรรมการฝ่ายอาหารและเครื่องดื่ม

๑. นางสาวนลินี	รัตนสุวรรณ	ประธานกรรมการ
๒. นายนิมิต	สาตรปรุง	กรรมการ
๓. นางอรทัย	คงจันทร์	กรรมการ
๔. นางสาวเอื้อมอัมพร	เพชรสินจร	กรรมการ
๕. นางสาวณิชชา	กิตติกาญจนภรณ์	กรรมการ
๖. นายตรัส	เคแสง	กรรมการ
๗. นางวิภา	รอดย้อย	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านการจัดเตรียมอาหารว่าง อาหารกลางวันและเครื่องดื่มสำหรับผู้เข้าร่วมโครงการ

๑๑. คณะกรรมการจัดทำเอกสารประกอบการประชุมวิชาการ

๑. รองศาสตราจารย์ดร.ปิยะ	ศุภวราสุวัฒน์	ประธานกรรมการ
๒. นางสาวแพรชมภู	วังศกาญจน์	กรรมการ
๓. นางสาวยศสิญา	ธวัชชัยนันท์	กรรมการ
๔. นางสาวศุภิสรา	หนูสม	กรรมการและเลขานุการ

ปฏิบัติหน้าที่ด้านการตรวจสอบรูปแบบบทความ รวบรวม เรียบเรียง และจัดทำเอกสาร ประกอบการประชุมวิชาการ

ทั้งนี้ ตั้งแต่บัดนี้เป็นต้นไป

สั่ง ณ วันที่ ๑๖ มีนาคม พ.ศ. ๒๕๖๙

(ศาสตราจารย์ ดร.ปริยาภรณ์ ตั้งคุณานันต์)

คณบดีคณะครุศาสตร์อุตสาหกรรมและเทคโนโลยี

๑๖ มี.ค. ๖๙ เวลา ๑๕:๓๓:๐๒ Non-PKI Server Sign-LN

Signature Code : QQBDA-DMAMw-BFAEQ-AMgA0

SIET School of Industrial Education and Technology

KMITL สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

DRLE

School of Industrial Education and Technology,

King Mongkut's Institute of Technology Ladkrabang

1 Chalongkrung Road, Ladkrabang, Bangkok 10520 Thailand