ISSN 2822-0412 (ONLINE)

SCSR

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH

VOL.4,No2;(Jul.-Dec.);2025

SOUTHEAST BANGKOK UNIVERSITY

298 SUNPHAWUT ROAD, BANGNA DISTRICT BANGKOK, THAILAND 10260 - WWW.SOUTHEAST.AC.TH

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR

VOL.4, NO.2; Jul. – Dec. ; 2025

ISSN 2822-0412 (Online)

Supply Chain and Sustainability Research (SCSR) is an independently run non-profit journal dedicated to serve the worldwide scientific community through periodical of high-quality and high-impact scholarly, multi, and inter-disciplinary research that broadly resides in the arenas of supply chain and sustainability research. SCSR is committed to provide a platform that disseminates academic work, findings, and knowledge promptly, openly, and freely to all, and thus promote practical and public conversation and communication. By this, SCSR strives to be one of the important supply chain and sustainability journals in the world.

The Purpose: To support and encourage the writing of academic works. Disseminate academic works of faculty, academics and students both internally and externally as well as being a medium for education, research and dissemination of academic knowledge.

The goal is to serve as a hub for scholarly support, knowledge transfer, and dissemination. along with quality research The SCSR strives to publish insightful, innovative, and pertinent research that describes or may have an impact on management and/or innovation within the SCSR framework. Benefits to society, the community, and the country as a whole are frequently published in electronic journals by the SCSR. is diverse and interdisciplinary in character. The magazine accepts essays on all topics related to management as well as those relevant to innovation, regardless of discipline or subject area.

SCSR uses a “double-blind peer review system,” meaning that the authors do not know who the reviewers are, and the reviewers do not know who the authors are. All submitted manuscripts are to be reviewed by three expert reviewers per paper. Reviewers are chosen because of their expertise in the topic area and/or methodology used in the paper. Each article is judged based solely on its contribution, merits, and alignment with the journal’s mission. Should any revision be required, our instructions to authors are designed to move authors towards a successfully published article.

This journal is a semiannual publication, issued twice a year:

- Issue 1: January to June
- Issue 2: July to December

Website: https://so08.tci-thaijo.org/index.php/SCSR

All Correspondence should be addressed to: scsr@southeast.ac.th

ISSN 2822-0412 (Online)

Greetings from Editor-in-Chief: Supply Chain and Sustainability Review (SCSR)

The application of sustainability issues to supply chain management, logistics, transportation, and various optimization methods has been increasingly popular in recent years. One of the numerous issues that supply chain management encounters on an ongoing basis is operating in a sustainable manner. The goal of the SCSR is to investigate the use of sustainability in supply chain management, operation management, logistics, transportation, healthcare management, and fuzzy sets theory. The first issue of SCSR is to serve this purpose as how sustainable development must go hand in hand with logistics and supply chain management.

We invite academics from a variety of management-related disciplines to submit original, high-quality research papers that primarily address sustainability-management-related challenges and contribute to the SCSR's mission. The articles in the SCSR will emphasize both theoretical and empirical research. Literature reviews, conceptual theory development, qualitative survey research, such as case studies, and quantitative empirical methodologies may all be included in academic papers. SCSR rules must be adhered to by all submitted papers.

In view of current disruptions in global supply chains (e.g., chip crisis), the implications of supply chains for the climate and biodiversity discourse, new supply chain laws to increase social responsibility, and technological innovations (e.g., blockchain), supply chain management has become an imperative for global business.

In this issue, 7 Article papers are presented.

1) Towards a Net-Zero Future: The Multifaceted Role of Universities in Accelerating Carbon Neutrality and Climate Action

2) Adoption of Sales Force Automation Systems in Supply Chain Management: A Technology Acceptance Model Perspective

3) AI Enables Schools and Enterprises to Cooperate to Explore a new Model of Cultivating multi-Disciplinary Talents in E-commerce Based on the investigation and research of Trueland Information Technology (Shanghai) Co., Ltd

4) Vehicle-Drone Collaborative Delivery: A Systematic Literature Review and Future Research Agenda

5) Cultural Landscape Field Dynamics and Symbolic Transmutation: A Co-constitutive Analysis of Mount Fuji's Natural Ontology and Cultural Semiosis in Transregional Epistemologies

6) Research on the Impact of "Artificial Intelligence" on Economy and Employment under the Background of Low Birth Rate

7) Implementation of Multimodal LLM Agents and Biomechanical Analysis for Remote Elderly Healthcare in Taiwan: A Case Study

The current issue and full text archive of this journal is available on Supply Chain and Sustainability Research at:
https://so08.tci-thaijo.org/index.php/SCSR/index

In addition, we would like to inform you about our next issues (Volume 1 and 2) in 2026. Recent announcement of the call for papers is accessible on the SCSR website. This issue marks the debut of the SCSR and its birth. It is my pleasure to address you on this occasion. I would like to express a warm welcome to the SCSR readership on behalf of the SCSR Editorial Team. I would like to thank our authors, editors, and anonymous reviewers, who have all voluntarily contributed to the journal's success. Without your participation, this initial issue would not exist.

We look forward to receiving your contributions.

Jirasek Trimetsoothorn
Editor-in-Chief

Editorial Team

Editors

Contents

The current issue and full text archive of this journal is available on Supply Chain and Sustainability Research at:
https://so08.tci-thaijo.org/index.php/SCSR/index

Towards a Net-Zero Future: The Multifaceted Role of Universities in Accelerating Carbon Neutrality and Climate Action

Qingzi Li*

National Institute of Development Administration, Thailand
148 Serithai Road, Klong-Chan, Bangkapi, Bangkok THAILAND 10240

*Corresponding author, Email: 273020237qq@gmail.com

Received: Sep 21, 2025 / Revised: Dec 18,2025 / Accepted: Dec 18,2025

Abstract

The escalating global climate crisis necessitates urgent and coherent actions across all sectors of society. Higher education institutions (HEIs), with their unique positioning at the intersection of knowledge generation, talent development, and civic engagement, are critical catalysts in the transition to a net-zero emissions future. This paper examines the multidimensional roles and strategic pathways through which universities can significantly advance carbon neutrality and climate action. By synthesizing existing literature and drawing on in-depth comparative case studies of Southeast Bangkok University (Thailand) and Beijing Jiaotong University (China), this study proposes an integrated conceptual framework that positions HEIs simultaneously in four complementary roles: (1) Innovation Engines, driving low-carbon research and technology development; (2) Operational Benchmarks, demonstrating carbon-neutral campus management; (3) Educational Pioneers, leading curriculum transformation and sustainability education; and (4) Community Hubs, fostering public engagement and cross-sector collaboration.

The analysis identifies significant implementation barriers, including financial constraints, methodological challenges in Scope 3 emissions accounting, organizational inertia, and difficulties in measuring indirect impact. Moreover, the comparative cases reveal how institutional mission, resources, and regional context shape distinct but equally viable climate strategies - ranging from localized, context-sensitive approaches to technology- and policy-oriented pathways. The study concludes with strategic recommendations for policymakers and university leaders to embed carbon neutrality into institutional cores, emphasizing the necessity of context-specific strategies that leverage institutional strengths and foster collaboration between research-intensive and regional universities. This research contributes to both theoretical understanding and practical implementation of comprehensive climate action in higher education globally, offering a refined framework for designing, evaluating, and scaling university-led initiatives in support of a net-zero future.

Keywords: Carbon neutrality; Climate change; Higher education institutions; Sustainability governance; Climate action; Net-zero transition; University leadership

อนาคต Net-Zero กับบทบาทหลากหลายของมหาวิทยาลัยในการเร่งความเป็นกลางทางคาร์บอนและการขับเคลื่อนการรับมือการเปลี่ยนแปลงสภาพภูมิอากาศ

ชิงจื่อ หลี่*

สถาบันบัณฑิตพัฒนบริหารศาสตร์, ประเทศไทย
148 ถนนเสรีไทย แขวงคลองจั่น เขตบางกะปิ กรุงเทพมหานคร 10240

*(ผู้ประสานงานเผยแพร่) Corresponding author, Email: 273020237qq@gmail.com

บทคัดย่อ

วิกฤตการณ์สภาพภูมิอากาศโลกที่ทวีความรุนแรงขึ้นนั้นเรียกร้องให้มีการดำเนินการอย่างเร่งด่วนและสอดคล้องกันในทุกภาคส่วนของสังคม สถาบันอุดมศึกษา (HEIs) ซึ่งมีสถานะพิเศษอยู่ที่จุดตัดของการสร้างองค์ความรู้ การพัฒนาบุคลากร และการมีส่วนร่วมทางสังคม ถือเป็นตัวเร่งปฏิกิริยาที่สำคัญในการเปลี่ยนผ่านสู่อนาคตของการปล่อยก๊าซเรือนกระจกสุทธิเป็นศูนย์ บทความนี้จะตรวจสอบบทบาทหลายมิติและแนวทางเชิงกลยุทธ์ที่มหาวิทยาลัยใช้เพื่อขับเคลื่อนความเป็นกลางทางคาร์บอนและดำเนินการด้านสภาพภูมิอากาศได้อย่างมีนัยสำคัญ ด้วยการสังเคราะห์วรรณกรรมที่มีอยู่และการใช้กรณีศึกษาเชิงเปรียบเทียบเชิงลึกของมหาวิทยาลัยกรุงเทพตะวันออกเฉียงใต้ (ประเทศไทย) และมหาวิทยาลัยเจียวทงปักกิ่ง (ประเทศจีน) การศึกษานี้จึงได้นำเสนอกรอบแนวคิดแบบบูรณาการที่วางตำแหน่งให้สถาบันอุดมศึกษามีบทบาทเสริมซึ่งกันและกันสี่ประการพร้อมกันดังนี้ (1) เครื่องยนต์นวัตกรรม ขับเคลื่อนการวิจัยและการพัฒนาเทคโนโลยีคาร์บอนต่ำ (2) มาตรฐานการดำเนินงาน แสดงให้เห็นการจัดการมหาวิทยาลัยที่เป็นกลางทางคาร์บอน (3) ผู้บุกเบิกทางการศึกษานำการปรับเปลี่ยนหลักสูตรและการศึกษาด้านความยั่งยืน และ (4) ศูนย์กลางชุมชน ส่งเสริมการมีส่วนร่วมของสาธารณะและความร่วมมือข้ามภาคส่วน การวิเคราะห์นี้ชี้ให้เห็นถึงอุปสรรคสำคัญในการนำไปปฏิบัติ ซึ่งรวมถึงข้อจำกัดทางการเงิน ความท้าทายด้านระเบียบวิธีวิจัยในการบัญชีการปล่อยก๊าซเรือนกระจกประเภทที่ 3 ความเฉื่อยขององค์กร และความยากลำบากในการวัดผลกระทบทางอ้อม กรณีศึกษาเปรียบเทียบเผยให้เห็นว่า ภารกิจของสถาบัน ทรัพยากร และบริบทระดับภูมิภาค มีส่วนกำหนดกลยุทธ์ด้านสภาพภูมิอากาศที่แตกต่างกัน แต่สามารถนำไปปฏิบัติได้จริงไม่แพ้กัน ซึ่งมีตั้งแต่แนวทางที่เน้นบริบทเฉพาะที่ไปจนถึงแนวทางที่เน้นเทคโนโลยีและนโยบาย

การศึกษานี้ได้สรุปด้วยข้อเสนอแนะเชิงกลยุทธ์สำหรับผู้กำหนดนโยบายและผู้นำมหาวิทยาลัย เพื่อฝังความเป็นกลางทางคาร์บอนให้อยู่ในแกนหลักของสถาบัน โดยเน้นย้ำถึงความจำเป็นของกลยุทธ์ที่จำเพาะเจาะจงกับบริบท ซึ่งใช้ประโยชน์จากจุดแข็งของสถาบัน และส่งเสริมความร่วมมือระหว่างมหาวิทยาลัยที่เน้นการวิจัยกับมหาวิทยาลัยในระดับภูมิภาค งานวิจัยนี้มีส่วนช่วยทั้งความเข้าใจเชิงทฤษฎีและการนำไปปฏิบัติจริงของการดำเนินการด้านสภาพภูมิอากาศอย่างครอบคลุมในระดับอุดมศึกษาทั่วโลก โดยนำเสนอกรอบแนวคิดที่ได้รับการปรับปรุงสำหรับการออกแบบ การประเมินและการขยายผลโครงการริเริ่มที่นำโดยมหาวิทยาลัยเพื่อสนับสนุนอนาคตสุทธิเป็นศูนย์

คำสำคัญ: ความเป็นกลางทางคาร์บอน, การเปลี่ยนแปลงสภาพภูมิอากาศ, สถาบันอุดมศึกษา, ธรรมาภิบาลความยั่งยืน, การดำเนินการด้านสภาพภูมิอากาศ, การเปลี่ยนผ่านสู่สุทธิเป็นศูนย์, ความเป็นผู้นำของมหาวิทยาลัย

Introduction

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2022) issues a stark warning: only immediate, rapid, and large-scale reductions in greenhouse gas emissions can limit global warming to 1.5°C above pre-industrial levels. In response, achieving net-zero emissions has emerged as a paramount global objective that requires transformative changes across all societal sectors. Within this context, higher education institutions represent both significant contributors to climate change and essential agents of solution.

HEIs collectively influence over 250 million students worldwide (UNESCO, 2021) and possess substantial carbon footprints through their campus operations, research activities, and supply chains. Simultaneously, they hold unique capabilities to drive climate action through their educational mission, research expertise, operational scale, and community engagement. While many universities have made voluntary commitments through initiatives like the Talloires Declaration and Second Nature's Climate Commitment, systematic implementation of comprehensive climate strategies remains inconsistent and often fragmented across the sector.

This paper addresses this implementation gap by developing a holistic framework for university climate action and examining its application across different institutional contexts. Through comparative case analysis, it explores how varied institutional missions and resources shape climate strategies and outcomes. The research aims to provide both theoretical grounding and practical guidance for universities seeking to maximize their contribution to global decarbonization efforts while fulfilling their educational and societal missions.

Theoretical Framework and Literature Review

The conceptual foundation for university climate action draws from multiple theoretical traditions. Early literature on sustainability in higher education focused predominantly on environmental management systems and operational efficiencies (Shriberg, 2002; Velazquez et al., 2006). This evolved toward more strategic approaches incorporating carbon accounting and climate action planning (Levy & Marans, 2012; Klein-Banai & Theis, 2013).

Theoretical underpinnings for comprehensive university climate action include: The Living Lab Concept: This framework conceptualizes university campuses as experimental platforms for testing and demonstrating sustainable technologies and behaviors (Evans et al., 2015; Bossert et al., 2020). It emphasizes the integration of operational sustainability with teaching and research functions. The Triple Helix Model: This approach highlights the intersection of university, industry, and government in driving innovation (Etzkowitz & Leydesdorff, 2000), particularly relevant for technology development and policy translation in climate action. Whole Institution Approach: This perspective advocates for embedding sustainability across all university functions—curriculum, research, operations, and community engagement—rather than treating it as an add-on initiative (Mader & Rammel, 2015; Sterling et al., 2013). Despite these theoretical advances, implementation remains challenged by disciplinary silos, financial constraints, and inadequate metrics for assessing impact beyond direct emissions (Leal Filho et al., 2019). Our integrated framework addresses these gaps by conceptualizing four complementary roles that universities can simultaneously fulfill in advancing climate action.

Research Methodology

This study employs a mixed-methods approach combining systematic literature review with comparative case study analysis. The literature review encompassed peer-reviewed articles, university climate action plans, and international reports published between 2000-2023, identified through Scopus, Web of Science, and Google Scholar databases using keyword searches related to 'university,' 'higher education,' 'carbon neutrality,' and 'climate action.'

The case study selection followed a most-different design, purposefully selecting institutions with contrasting characteristics to explore how different contexts shape implementation approaches

• Southeast Bangkok University: A regional comprehensive university in Thailand emphasizing teaching and community engagement

• Beijing Jiaotong University: A research-intensive technical university in China with strong industry and government ties

Data collection included document analysis of climate action plans, sustainability reports, and institutional websites; quantitative analysis of emissions data where available; and scholarly publications related to each institution's sustainability initiatives. All analyzed data were obtained from publicly available sources, and no confidential or sensitive information was involved, thus not requiring institutional review board approval. The comparative analysis focused on identifying common patterns, distinctive approaches, and contextual factors influencing implementation effectiveness across the four roles outlined in our framework.

Findings and Discussion

4.1 The Four-Dimensional Framework in Practice

Our analysis reveals how universities operationalize the four interconnected roles: As Innovation Engines: Research-intensive universities like Beijing Jiaotong excel in developing patented technologies (e.g., energy-efficient rail systems) and establishing specialized research centers. Regional universities like Southeast Bangkok focus on adaptive innovation suited to local contexts (e.g., tropical building cooling solutions).

As Operational Benchmarks: Both institution types face challenges in Scope 3 emissions accounting, particularly for purchased goods and capital investments. Research universities tend to invest more in high-cost technologies (e.g., geothermal systems), while regional institutions emphasize behavioral changes and nature-based solutions (e.g., constructed wetlands).

As Educational Pioneers: Effective curriculum integration requires moving beyond environmental programs to embed climate literacy across all disciplines. Southeast Bangkok demonstrates strong community-engaged learning through its 'living lab' approach, while Beijing Jiaotong emphasizes technical training and policy education.

As Community Hubs: Universities leverage their convening power differently based on institutional positioning. Research universities influence national policy and industry standards, while regional institutions serve as local demonstration centers and knowledge resources for their immediate communities.

4.2 Case Studies: Comparative Analysis

Southeast Bangkok University exemplifies a context-sensitive, localized approach to climate action. The university has implemented several innovative measures including photovoltaic systems that serve dual purposes of clean energy generation and educational tools, passive cooling architecture adapted to tropical conditions, and constructed wetlands for stormwater management and biodiversity enhancement. These efforts reflect a resource-conscious model that combines operational sustainability with pedagogical innovation, positioning the institution as a community-engaged sustainability demonstrator.

Beijing Jiaotong University demonstrates a technology- and policy-oriented approach. Its comprehensive strategy features building-integrated photovoltaics (BIPV), geothermal systems utilizing ground-source heat pumps, and a sophisticated smart energy management platform. Leveraging its specialized expertise in transportation, the university has pioneered energy-efficient rail technologies and intelligent scheduling algorithms that have been adopted nationally. The establishment of a Carbon Neutrality Research Institute fosters interdisciplinary collaboration and aligns campus initiatives with national carbon targets.

Table 1 Comparative Case Analysis: Southeast Bangkok University and Beijing Jiaotong University

Dimension	Southeast Bangkok University	Beijing Jiaotong University
Energy & Infrastructure	PV installations, passive cooling, ecological wetlands	BIPV, geothermal systems, smart energy management
Research Emphasis	Tropical sustainability; ecological engineering	Low-carbon transport; smart grids; industrial application
Governance Approach	Cross-functional working groups	Dedicated research institute; technical offices
Community Engagement	Local demonstrations; community partnerships	National policy advice; industry collaboration

4.3 Implementation Barriers and Enablers

Common barriers across institutions include:

- Methodological challenges in Scope 3 emissions accounting and reporting
- Financial constraints limiting capital-intensive investments
- Organizational silos hindering cross-functional collaboration
- Measurement difficulties in assessing educational and research impact on emissions reduction

Key enabling factors identified:

- Leadership commitment from senior administration and governing boards
- Stakeholder engagement involving students, faculty, staff, and community partners

• Strategic alignment with institutional mission and core functions

• External partnerships with government, industry, and peer institutions

Conclusion and Implications

This study demonstrates that universities can effectively contribute to climate action through four complementary roles: as innovation engines, operational benchmarks, educational pioneers, and community hubs. Rather than adopting a one-size-fits-all approach, institutions should develop context-specific strategies aligned with their distinctive missions, resources, and contexts.

Theoretical Implications: Our integrated framework advances theoretical understanding by synthesizing previously disparate strands of literature on university sustainability. It provides a coherent conceptual model for analyzing and designing comprehensive climate action strategies across diverse institutional contexts.

Practical Implications: For university leaders, our findings highlight the importance of:

- Developing comprehensive carbon accounting that includes Scope 3 emissions.
- Creating interdisciplinary structures to bridge operational, educational, and research functions.
- Leveraging institutional strengths rather than replicating approaches from dissimilar universities.
- Building long-term partnerships with community, industry, and government stakeholders.

Policy Recommendations: For policymakers and higher education associations:

- Develop standardized methodologies for measuring and reporting university emissions, particularly Scope 3.
- Create funding mechanisms specifically for university climate infrastructure and research.

Incorporate climate action metrics into university accreditation and quality assurance frameworks

- Facilitate networking and knowledge-sharing across different types of institutions to enable learning across diverse approaches.

Limitations and Future Research: This study's limitations include its focus on two case institutions and reliance on publicly available documents. While this approach provides rich qualitative insights, the findings may have limited generalizability to all types of higher education institutions, particularly small private colleges or vocational schools. Future research should expand to include more diverse geographic and institutional contexts, investigate longitudinal impacts of climate initiatives, and develop robust methods for quantifying universities' indirect contributions to societal decarbonization. Additionally, further investigation into the implementation challenges and failures that may not be captured in publicly reported data would provide a more comprehensive understanding.

As institutions dedicated to knowledge generation and societal improvement, universities have both the responsibility and capability to lead in the global transition to a net-zero future. By fully embracing their multifaceted roles, they can significantly accelerate climate progress while fulfilling their educational missions.

References

Bossert, L., Kleiber, T., & Bienge, K. (2020). University living labs as vehicles for sustainability transformation. *International Journal of Sustainability in Higher Education, 21*(7), 1471–1489.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From national systems and 'Mode 2' to a triple helix of university-industry-government relations. *Research Policy, 29*(2), 109–123.

Evans, J., Jones, R., Karvonen, A., Millard, L., & Wendler, J. (2015). Living labs and co-production: University campuses as platforms for sustainability science. *Current Opinion in Environmental Sustainability, 16*, 1–6.

IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report*. Cambridge University Press.

Klein-Banai, C., & Theis, T. L. (2013). Quantitative analysis of factors affecting greenhouse gas emissions at institutions of higher education. *Journal of Cleaner Production, 48*, 29–38.

Leal Filho, W., et al. (2019). Sustainable Development Goals and sustainability teaching at universities: Falling behind or getting ahead of the pack? *Journal of Cleaner Production, 232*, 285–294.

Levy, B. S., & Marans, R. W. (2012). Towards a carbon neutral university: The case of the University of Michigan. *International Journal of Sustainability in Higher Education, 13*(1), 72–82.

Mader, C., & Rammel, C. (2015). Transforming higher education for sustainable development. In *Handbook of Higher Education for Sustainable Development* (Vol. 1, pp. 1–10).

Shriberg, M. (2002). Institutional assessment tools for sustainability in higher education. *Higher Education Policy, 15*(2), 177–188.

Sterling, S., Maxey, L., & Luna, H. (2013). *The sustainable university: Progress and prospects*. Routledge.

UNESCO. (2021). *Education for sustainable development: A roadmap*. United Nations Educational, Scientific and Cultural Organization.

Velazquez, L., Munguia, N., Platt, A., & Taddei, J. (2006). Sustainable university: What can be the matter? *Journal of Cleaner Production, 14*(9–11), 810–819.

Adoption of Sales Force Automation Systems in Supply Chain Management: A Technology Acceptance Model Perspective

Lee, Cheng-Chung[1*]
Phitchaya Wannaphongcharoen[2]

[1*]Distinguished Associate Professor New Energy Vehicles and Modern Aviation College
Guangzhou Institute of Science and Technology
638 Xingtai Road 3, Taihe Township, Baiyun District Guangzhou 510540, China
[2]Faculty of Management Science Nakhonratchasima Rajabhat University, Thailand
340 Suranarai Road, Nai Mueang Subdistrict, Mueang Nakhon Ratchasima District, Nakhon Ratchasima Province

*Corresponding author, Email: a0933458580@gmail.com

Received: Sep 3, 2025 / Revised: Dec 18,2025 / Accepted: Dec 18,2025

Abstract

The purposes of this study were to 1) apply the Technology Acceptance Model (TAM) for sales force in the supply chain system by integrating external variables, namely Self-Efficacy and Organizational Support, 2) examine their effects on Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) and, 3) investigate users' attitudes and intention to use. The instruments were questionnaires. The sample was 288 employees working in the automotive supply chain industry. The statistical analysis was Structural Equation Modeling (SEM). The results showed that Self-Efficacy had a significant positive effect on PEOU, while Organizational Support positively influenced PU. Both PEOU and PU indirectly affected intention to use through users' attitudes. This study not only confirmed the suitability of TAM in the supply chain context but also provided practical implications that supported organizations in driving their digital transformation.

Keywords: Technology Acceptance Model, Supply Chain Management, Sales Force Automation, Self-Efficacy Organizational Support

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

การยอมรับการใช้ระบบอัตโนมัติสำหรับงานขายในระบบห่วงโซ่อุปทาน: มุมมองตามกรอบแนวคิดแบบจำลองการยอมรับเทคโนโลยี

ลี เฉิงจง[1*]
พิชญา วรรณพงศ์เจริญ[2]

[1*]สถาบันวิทยาศาสตร์และเทคโนโลยีกว่างโจว สาธารณรัฐประชาชนจีน
638 ถนนซิงไท่ 3 ตำบลไท่เหอ อำเภอไป๋หยุน เมืองกว่างโจว 510540 สาธารณรัฐประชาชนจีน
[2]คณะวิทยาการจัดการ มหาวิทยาลัยราชภัฏนครราชสีมา ประเทศไทย
340 ถนนสุรนารายณ์ ตำบลในเมือง อำเภอเมืองนคราชสีมา จังหวัดนครราชสีมา

*(ผู้ประสานงานเผยแพร่) Corresponding author, Email: a0933458580@gmail.com

บทคัดย่อ

งานวิจัยนี้มีจุดประสงค์ 1) เพื่อประยุกต์ใช้แบบจำลองการยอมรับเทคโนโลยี (Technology Acceptance Model: TAM) สำหรับงานขายในระบบห่วงโซ่อุปทาน โดยผนวกรวมตัวแปรภายนอก ได้แก่ การรับรู้ความสามารถของตนเอง (Self-Efficacy) และการสนับสนุนจากองค์กร (Organizational Support) 2) เพื่อศึกษาผลกระทบที่มีต่อการรับรู้ความง่ายในการใช้งาน (Perceived Ease of Use: PEOU) และการรับรู้ประโยชน์ที่ได้รับ (Perceived Usefulness: PU) 3) เพื่อศึกษาทัศนคติของผู้ใช้ และความตั้งใจในการใช้งาน ข้อมูลถูกรวบรวมผ่านแบบสอบถาม กลุ่มตัวอย่างคือ ผู้ปฏิบัติงานในห่วงโซ่อุปทานอุตสาหกรรมยานยนต์ จำนวน 288 คน สถิติที่ใช้ในการวิเคราะห์คือ โมเดลสมการเชิงโครงสร้าง (Structural Equation Modeling: SEM) ผลการวิจัยเชิงประจักษ์ชี้ว่า การรับรู้ความสามารถของตนเองส่งผลเชิงบวกอย่างมีนัยสำคัญต่อ PEOU ขณะที่การสนับสนุนจากองค์กรส่งผลเชิงบวกต่อ PU นอกจากนี้ PEOU และ PU ยังส่งผลทางอ้อมต่อความตั้งใจในการใช้งานผ่านทัศนคติของผู้ใช้ งานวิจัยนี้ไม่เพียงยืนยันความเหมาะสมของ TAM ในบริบทห่วงโซ่อุปทานเท่านั้น แต่ยังนำเสนอข้อเสนอเชิงปฏิบัติที่เป็นประโยชน์ต่อการขับเคลื่อนการเปลี่ยนผ่านสู่ดิจิทัลขององค์กรอีกด้วย

คำสำคัญ: แบบจำลองการยอมรับเทคโนโลยี การจัดการห่วงโซ่อุปทาน ระบบอัตโนมัติสำหรับงานขาย การรับรู้ความสามารถของตนเอง การสนับสนุนจากองค์กร

Introduction

Research Background and Motivation

Driven by the rise of smart manufacturing and the accelerating transition toward electric vehicles, supply chain management in the automotive industry is undergoing profound digital transformation challenges. As customer demand for digitalized services continues to grow, firms are compelled to integrate the entire customer journey - from test-driving experiences and purchasing processes to after-sales services—in order to deliver timely and efficient service responses. To address these emerging demands, many enterprises have actively implemented

The current issue and full text archive of this journal is available on Supply Chain and Sustainability Research at: https://so08.tci-thaijo.org/index.php/SCSR/index

Sales Force Automation (SFA) systems, aiming to enhance sales process efficiency, information transparency, and cross-departmental collaboration.

Nevertheless, practical experience has shown that if employees lack sufficient operational confidence or fail to perceive organizational support in terms of institutional mechanisms, resource allocation, and managerial encouragement, SFA systems may risk becoming symbolic tools rather than delivering their intended benefits, despite substantial financial and human investments. Consequently, this study focuses on identifying the key factors influencing employees' acceptance of SFA systems. The findings are expected to provide both theoretical contributions and managerial insights, offering valuable guidance for advancing digital transformation in the automotive supply chain context.

Literature Review

Technology Acceptance Model (TAM)

Proposed by Davis (1989), the Technology Acceptance Model (TAM) aims to explain how users' perceptions of perceived usefulness (PU) and perceived ease of use (PEOU) influence their attitudes and behavioral intentions toward technology adoption. Due to its parsimonious structure and high explanatory power, subsequent researchers have developed extended versions such as TAM2, TAM3, and the Unified Theory of Acceptance and Use of Technology (UTAUT), incorporating external variables such as social influence, facilitating conditions, and experience to better capture real-world applications (Venkatesh & Davis, 2000). In recent years, TAM has been widely applied in the fields of information systems and digital technology adoption, consistently demonstrating its effectiveness in explaining users' acceptance intentions and behaviors (Burton-Jones & Hubona, 2006). Within the supply chain management context, digital tools such as Sales Force Automation (SFA) systems have been extensively implemented. TAM thus provides a systematic theoretical framework to examine how employees, under the influence of organizational support and self-efficacy, form perceptions, attitudes, and adoption intentions toward new systems, ultimately shaping the success of digital transformation.

Supply Chain Management (SCM)

The core of Supply Chain Management (SCM) lies in coordination, integration, and information flow, with the ultimate objective of enhancing overall operational efficiency and customer value through effective planning and execution (Chopra & Meindl, 2016). With the intensification of global market competition and increasingly diverse customer demands, digital technologies have become indispensable foundations of supply chain operations, particularly in ensuring information transparency, real-time decision-making, and cross-organizational collaboration. Recent studies emphasize that the introduction of digital tools not only improves internal efficiency but also strengthens upstream and downstream collaboration, thereby enhancing supply chain resilience and agility (Queiroz et al., 2019). Against this backdrop, the application of SFA systems holds significant importance. Beyond supporting sales units in managing customer information and tracking sales opportunities, SFA facilitates information sharing between manufacturers and distributors, shortens response times, and improves overall supply chain performance.

Accordingly, SCM contexts not only provide the foundation for SFA to demonstrate its value but also constitute the essential setting for examining employees' adoption intentions in this study.

Sales Force Automation (SFA)

Sales Force Automation (SFA) systems are designed to support the daily activities of sales personnel, encompassing functions such as customer relationship management, sales opportunity tracking, performance analysis, and knowledge management. Boujena, Johnston, and Merunka (2009) argue that SFA enhances customer information transparency and improves the quality of customer interactions, thereby promoting sales performance and customer satisfaction. However, Avlonitis and Panagopoulos (2005) found that when employees lack confidence in system usage or fail to perceive its actual value to their work, SFA may be reduced to a symbolic managerial tool, incapable of delivering its intended benefits. Consequently, SFA adoption is not merely a technological challenge but is also shaped by multiple dimensions, including human factors, institutional design, and organizational culture. Prior research highlights that the successful implementation of SFA requires organizational leadership to provide sufficient institutional support, training resources, and technical assistance to enhance employee acceptance and willingness to use the system. Otherwise, adoption initiatives risk failure due to resistance or underutilization. Hence, within the supply chain management context, the value of SFA lies not only in improving process efficiency but also in effectively integrating individual employee characteristics with organizational support.

Self-Efficacy

Originating from Bandura's (1997) social cognitive theory, self-efficacy refers to an individual's belief and confidence in their ability to successfully complete specific tasks. Self-efficacy not only influences the degree of effort and persistence an individual invests but also determines whether they display proactive behavior and problem-solving capabilities when confronted with challenges. Research indicates that employees with high self-efficacy are more motivated to learn and better equipped to overcome difficulties in system operation when adopting new technologies (Compeau & Higgins, 1995). Within the framework of TAM, self-efficacy has been widely validated as a critical determinant of PEOU, since individuals with higher self-efficacy generally perceive new systems as easier to use, thereby enhancing their attitudes and behavioral intentions toward adoption. Moreover, self-efficacy may indirectly affect PU, as individuals who can successfully operate a system are more likely to recognize its contribution to work efficiency. Therefore, in the implementation of SFA systems under supply chain management contexts, self-efficacy emerges as a pivotal psychological construct influencing user acceptance and the success of digital transformation initiatives.

Organizational Support

The theory of Perceived Organizational Support (POS), initially proposed by Eisenberger et al. (1986), focuses on how employees perceive the extent to which their contributions are valued and supported by their organizations. The theory posits that when employees recognize organizational commitment through institutional design, resource allocation, and managerial care, their organizational commitment and work motivation are enhanced, thereby increasing their willingness to embrace organizational changes. Subsequent studies have confirmed that POS not only strengthens employees' psychological safety but also reduces their resistance to adopting new systems (Rhoades & Eisenberger, 2002). In the implementation of SFA systems, organizations that provide adequate training, technical support, and policy encouragement enable employees to better perceive the system's usefulness (PU), which in turn fosters positive attitudes and continuous usage intentions. Accordingly, organizational support plays a critical role in promoting user acceptance during information system adoption and diffusion processes, further increasing the likelihood of successful application of digital tools within supply chain management contexts.

Research Methodology

Research Context and Participants

This study is conducted within the context of the automotive industry supply chain, encompassing both the manufacturing sector (corporate headquarters and regional operational units) and the distribution sector (showroom sales consultants, field sales representatives, and after-sales service advisors). As these practitioners rely directly on Sales Force Automation (SFA) systems in their daily operations, their acceptance and willingness to use such systems provide a valid reflection of the actual effectiveness and practical outcomes of technological tool adoption in supply chain management settings.

Research Framework

The Technology Acceptance Model (TAM) serves as the theoretical foundation of this study, with self-efficacy and organizational support incorporated as external variables to examine their effects on perceived ease of use (PEOU) and perceived usefulness (PU). These cognitive evaluations, in turn, are expected to shape users' attitudes and subsequently influence behavioral intention. The research context specifically focuses on supply chain management within the automotive industry, with the adoption of SFA systems as the central subject of investigation. This design not only validates the applicability of TAM in digital transformation initiatives within supply chains but also sheds light on the critical factors influencing employees' adoption of emerging information technologies.

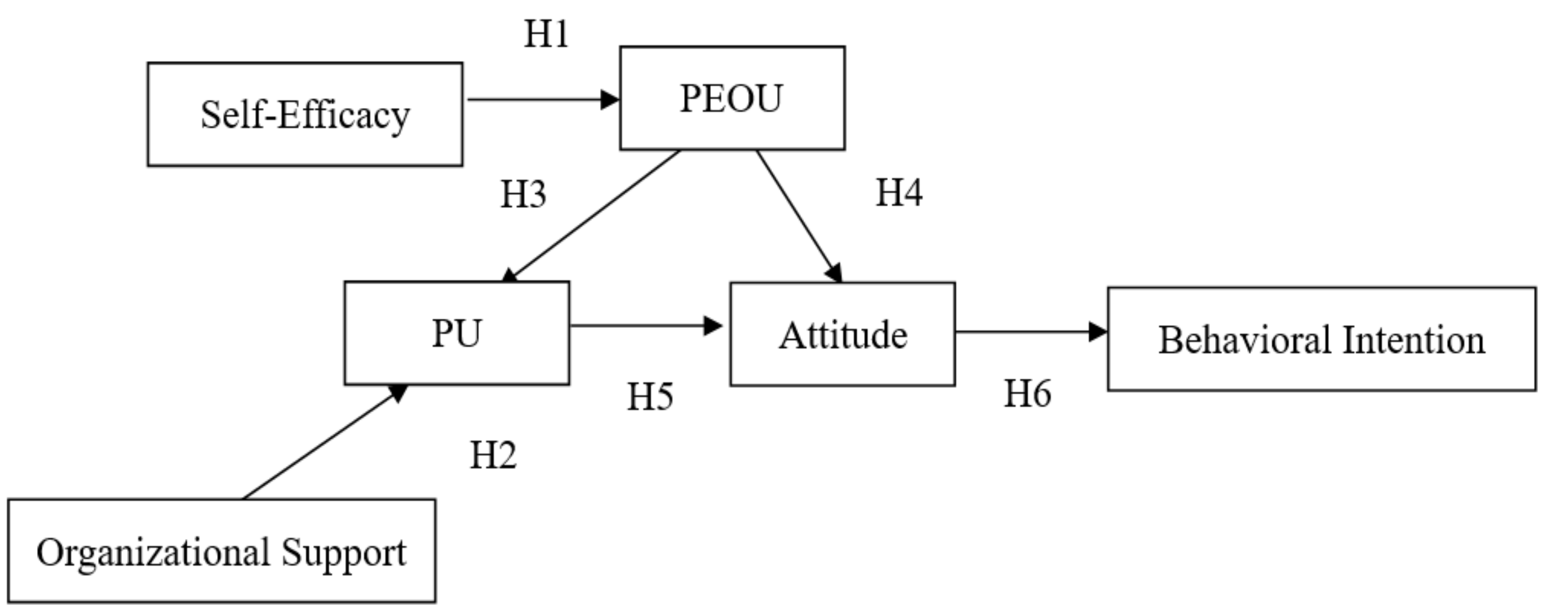

Figure 1. Conceptual Framework of the Study

Research Hypotheses

Building upon the aforementioned theoretical foundations and literature review, this study adopts the Technology Acceptance Model (TAM) as its core framework, while incorporating self-efficacy and organizational support as external variables to examine their influence on perceived ease of use (PEOU), perceived usefulness (PU), attitude, and behavioral intention. Based on the proposed research framework, the following hypotheses are developed:

A. H1: Self-efficacy positively influences PEOU.

B. H2: Organizational support positively influences PU.

C. H3: PEOU positively influences PU.

D. H4: PEOU positively influences attitude.

E. H5: PU positively influences attitude.

F. H6: Attitude positively influences behavioral intention.

G. H7: Within the supply chain management context, the adoption of SFA systems strengthens the explanatory power of TAM.

Taken together, these hypotheses form a comprehensive research model that encompasses external variables (self-efficacy and organizational support), cognitive evaluations (PEOU and PU), attitudinal responses, and behavioral intention. The model aims to validate the applicability of TAM within supply chain management settings and to further evaluate its theoretical significance and practical implications in the process of digital transformation, thereby providing the foundation for subsequent empirical analyses.

Research Instruments

A. Questionnaire Design

The questionnaire used in this study was adapted and developed based on relevant literature, covering six constructs: self-efficacy, organizational support, perceived ease of use (PEOU), perceived usefulness (PU), attitude, and behavioral intention. All items were measured using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree) to ensure comparability and consistency in measurement. To establish content validity, the questionnaire was reviewed by three academic scholars and two industry experts. A pilot test with 30 respondents was subsequently conducted to evaluate semantic clarity and preliminary reliability, with revisions made according to the feedback received. The finalized questionnaire served as the foundation for subsequent reliability and validity assessments, as well as for the empirical analysis using structural equation modeling (SEM).

Questionnaire Survey

The formal survey employed stratified convenience sampling, targeting both manufacturing and distribution personnel within the automotive supply chain. A total of 320 questionnaires were distributed, yielding 288 valid responses, resulting in an effective response rate of 90%. The survey was administered through both online questionnaires and on-site meeting sessions. To ensure compliance with ethical standards, anonymity and voluntary participation were emphasized throughout the data collection process, thereby enhancing the credibility and reliability of the research data.

Data Analysis Methods

A. Descriptive Statistics: Descriptive analyses were conducted on demographic variables such as gender, age, and job position to present the structural characteristics and representativeness of the sample, thereby facilitating subsequent statistical inferences.

B. Reliability and Validity Analysis: The quality of the measurement model was assessed using Cronbach's α, Composite Reliability (CR), and Average Variance Extracted (AVE) to confirm that each construct exhibited satisfactory reliability and convergent validity.

C. Confirmatory Factor Analysis (CFA): CFA was performed using AMOS to examine the factor loadings of individual items and to evaluate the overall model fit, ensuring that the measurement model demonstrated both convergent and construct validity.

D. Structural Equation Modeling (SEM): SEM was employed to test the hypothesized causal relationships among latent variables, while simultaneously assessing the model's fit indices to evaluate the explanatory power and theoretical adequacy of the proposed research framework.

Empirical Analysis

Demographic Profile of Respondents

To present the structural characteristics of the sample, the demographic distribution of respondents is summarized in Table 1.

Table 1. Demographic Profile of Respondents

Variable	Category	Frequency	Percentage
Gender	Male	170	59.00%
	Female	118	41.00%
Age	20–30 years	85	29.50%
	31–40 years	120	41.70%
	Above 41 years	83	28.80%
Position	Manufacturer staff	110	38.20%
	Distributor staff	178	61.80%

The sample covers distributions across gender, age, and job position, demonstrating a balanced structure with adequate representativeness and explanatory power for subsequent analysis.

Reliability and Validity Analysis

All constructs achieved Cronbach's α values above the recommended threshold, indicating that the measurement scale possesses strong stability and internal consistency, thereby providing a reliable basis and statistical support for subsequent model validation and empirical analysis.

Table 2. Reliability and Validity Tests

Construct	Cronbach's α	AVE	CR
Self-Efficacy	0.89	0.65	0.91
Organizational Support	0.87	0.61	0.9
PEOU	0.88	0.64	0.9
PU	0.91	0.68	0.92
Attitude	0.86	0.71	0.89
Behavioral Intention	0.9	0.73	0.92

The results show that Cronbach's α values ranged from 0.86 to 0.91, CR values from 0.89 to 0.92, and AVE values from 0.61 to 0.73. All values exceeded the recommended thresholds, confirming that the measurement instrument demonstrates satisfactory reliability and convergent validity. These results suggest that the constructs effectively capture the underlying latent variables and provide a solid foundation for subsequent SEM validation.

Confirmatory Factor Analysis (CFA)

Confirmatory factor analysis (CFA) was conducted using AMOS to examine the factor loadings of measurement items and the overall model fit, thereby confirming the reliability, validity, and adequacy of the measurement model.

Table 3. Results of Confirmatory Factor Analysis

Construct	Example Item	Factor Loadings Range	CR	AVE
Self-Efficacy	I can proficiently operate the SFA system	0.72–0.85	0.91	0.65
Organizational Support	The company provides sufficient resources to assist	0.70–0.83	0.9	0.61
PEOU	The SFA system is easy to learn and use	0.73–0.87	0.9	0.64
PU	The SFA system improves work efficiency	0.74–0.88	0.92	0.68
Attitude	I hold a positive attitude toward the SFA system	0.75–0.86	0.89	0.71
Behavioral Intention	I am willing to continue using the SFA system	0.77–0.87	0.92	0.73

The CFA results indicate that the factor loadings of all constructs ranged from 0.70 to 0.88, exceeding the recommended threshold of 0.50. Composite reliability (CR) values ranged from 0.89 to 0.92, and average variance extracted (AVE) values ranged from 0.61 to 0.73. All indices met the suggested standards, confirming that the measurement model demonstrates satisfactory reliability, convergent validity, and construct validity.

Hypothesis Testing (SEM Results)

Structural equation modeling (SEM) was employed to examine the path relationships of the proposed hypotheses and to evaluate the overall model fit, thereby confirming the explanatory power and statistical robustness of the theoretical framework.

Table 4. Results of SEM Path Analysis

Hypothesis	Path	β	t - value	Result
H1	Self-Efficacy ⟶ PEOU	0.51***	8.21	Supported
H2	Organizational Support ⟶ PU	0.34**	6.05	Supported
H3	PEOU ⟶ PU	0.39***	7.11	Supported
H4	PEOU ⟶ Attitude	0.28**	4.97	Supported
H5	PU ⟶ Attitude	0.46***	9.02	Supported
H6	Attitude ⟶ Behavioral Intention	0.55***	10.35	Supported
H7	SFA under SCM context ⟶ Model Explanatory Power	Significant improvement	—	Supported

The model fit indices demonstrated satisfactory levels: $\chi^2/df = 2.05$, CFI = 0.94, TLI = 0.93, and RMSEA = 0.050, all of which met recommended academic thresholds. These results indicate that the structural model exhibits good fit and statistical robustness, thereby effectively explaining SFA adoption behavior within the context of supply chain management.

Conclusion

Research Conclusions

Grounded in the Technology Acceptance Model (TAM), this study investigated the determinants influencing employees' adoption of Sales Force Automation (SFA) systems within the context of supply chain management, and employed structural equation modeling (SEM) for empirical validation. The findings confirmed support for all proposed hypotheses, thereby demonstrating the applicability of TAM in the domain of supply chain digital transformation, while also highlighting the critical role of individual characteristics and organizational support in shaping system adoption.

A. Self-efficacy significantly enhances perceived ease of use (PEOU), suggesting that employees with higher confidence and operational ability perceive the system as easier to use, thereby lowering learning barriers and facilitating continuous utilization.

B. Organizational support positively influences perceived usefulness (PU), indicating that when employees receive institutional, resource-based, and managerial support, they are more likely to recognize the tangible benefits of SFA systems in improving work efficiency and performance.

C. PEOU not only directly affects PU but also indirectly influences behavioral intention through PU and attitude, underscoring its multiple mediating roles in transforming ease-of-use perceptions into actual adoption intentions.

D. Both PU and PEOU significantly strengthen user attitude, and a positive attitude, in turn, further enhances behavioral intention, underscoring the central role of attitude in linking cognitive evaluations with behavioral tendencies.

E. Within the supply chain management context, the implementation of SFA systems enhances the explanatory power of TAM, thereby validating its theoretical contribution while also underscoring its practical implications for digital transformation and cross-organizational collaboration.

In sum, the results demonstrate that individual characteristics (self-efficacy), organizational contextual factors (organizational support), and cognitive evaluations (PEOU and PU) jointly shape employee attitudes and behavioral intentions. PEOU and PU not only serve as mediators within the model but also reinforce the linkage between attitude and behavioral intention. Most importantly, the introduction of SFA systems in supply chain management contexts not only validates the applicability of TAM but also reveals the pivotal roles of human factors and organizational support in the process of digital transformation, thereby offering dual contributions to both theory and practice.

Managerial Implications

Based on the research findings, the following managerial recommendations are proposed for the automotive industry and other supply chain enterprises undertaking digital transformation and information system implementation:

A. Enhance employee digital training: Organizations should provide continuous training on the operation of SFA systems to strengthen employees' self-efficacy and reduce resistance toward new technologies.

B. Institutionalized support and resource allocation: The effectiveness of SFA usage should be incorporated into performance evaluations, while ensuring sufficient technical support and time resources to enable employees to effectively utilize the system.

C. Leadership demonstration and encouragement: Managers should take the initiative to adopt and promote SFA, setting an example that fosters a positive usage climate and further influences employee attitudes.

D. Promote supply chain integration: SFA systems should not be limited to single departmental use but rather serve as a central tool for supply chain information flows, fostering collaboration between manufacturers and distributors, enhancing decision-making transparency, and improving customer satisfaction.

Limitations and Future Research Directions

Although this study validates the applicability of the Technology Acceptance Model (TAM) in the adoption of Sales Force Automation (SFA) systems and provides both theoretical and practical insights, several limitations should be acknowledged:

A. Sample scope limitation: The study focused exclusively on the supply chain of the Taiwanese automotive industry. The findings may thus be influenced by industry-specific characteristics. Future research could extend the scope to other industries or conduct cross-national comparative studies to enhance generalizability.

B. Limited external variable design: This study incorporated only self-efficacy and organizational support as external variables, without considering other potentially influential factors such as digital literacy, psychological safety, or cross-departmental collaboration. Future research may include additional constructs to strengthen the explanatory power of the model.

C. Methodological limitation: This study employed cross-sectional survey data, which restricts the ability to capture dynamic changes in system adoption over time. Future studies could adopt longitudinal research designs or mixed-method approaches, integrating qualitative interviews with actual system usage records, to provide a more comprehensive understanding.

References

Avlonitis, G. J., & Panagopoulos, N. G. (2005). Antecedents and consequences of CRM technology acceptance in the sales force. *Industrial Marketing Management, 34*(4), 355–368. https://doi.org/10.1016/j.indmarman.2004.09.021

Bandura, A. (1997). *Self-efficacy: The exercise of control*. W. H. Freeman. https://psycnet.apa.org/record/1997-08589-000

Boujena, O., Johnston, W. J., & Merunka, D. (2009). The benefits of sales force automation: A customer's perspective. *Journal of Personal Selling & Sales Management, 29*(2), 137–150. https://www.researchgate.net/publication/261645502

Burton-Jones, A., & Hubona, G. S. (2006). The mediation of external variables in the technology acceptance model. *Information & Management, 43*(6), 706–717. https://www.sciencedirect.com/science/article/pii/S0378720606000300

Compeau, D. R., & Higgins, C. A. (1995). Computer self-efficacy: Development of a measure and initial test. *MIS Quarterly, 19*(2), 189–211. https://doi.org/10.2307/249688

Chopra, S., & Meindl, P. (2016). *Supply chain management: Strategy, planning, and operation* (6th ed.). Pearson. https://www.researchgate.net/publication/327890174

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://www.jstor.org/stable/249008

Eisenberger, R., Huntington, R., Hutchison, S., & Sowa, D. (1986). Perceived organizational support. *Journal of Applied Psychology, 71*(3), 500–507. https://doi.org/10.1037/0021-9010.71.3.500

Queiroz, M., Wamba, S. F., & Queiroz, J. (2019). Blockchain adoption in supply chain management: Empirical evidence from an emerging economy. *International Journal of Production Research, 57*(7), 2025–2043. https://doi.org/10.1080/00207543.2018.1552076

Rhoades, L., & Eisenberger, R. (2002). Perceived organizational support: A review of the literature. *Journal of Applied Psychology, 87*(4), 698–714. https://www.researchgate.net/publication/232493553

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

AI Enables Schools and Enterprises to Cooperate to Explore a new Model of Cultivating multi-Disciplinary Talents in E-commerce Based on the investigation and research of Trueland Information Technology (Shanghai) Co., Ltd

Changwei Yang[1*]
Baramee Wannaphongcharoen[2]

[1*] Zhejiang Dongfang Polytechnic, ZheJiang Wenzhou, China
433, Jinhai 3rd Avenue, Wenzhou Economic & Technological Development Zone, Zhejiang Province, China 325025
[2]Wongchavalitkul University, Nakhon Ratchasima, Thailand
84 Moo 4, Mittraphap-Nong Khai Rd., Ban Ko Subdistrict, Mueang District, Nakhon Ratchasima, Thailand

*Corresponding author, Email: y591246235@163.com

Received: Sep 11, 2025 / Revised: Dec 18,2025 / Accepted: Dec 18,2025

Abstract

The paper expounds the challenges and opportunities faced by talent training in the AI era, and emphasizes the urgency of cultivating e-commerce composite talents and the necessity of industry-education integration. This paper analyzes the new model framework and the key points of curriculum system reconstruction from the aspects of target positioning, curriculum system and teaching method. The influence of AI technology development on the development of e-commerce education is expounded. The practical experience of building a training system and faculty construction for e-commerce majors in school-enterprise cooperation points out the future development direction of AI enabling school-enterprise collaborative creation of e-commerce multi-disciplinary talents.

Key words: AI empowerment, school-enterprise collaboration, e-commerce talent training, multi-disciplinary talents, digital transformation of education

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

ปัญญาประดิษฐ์เปิดโอกาสให้สถานศึกษาและภาคธุรกิจร่วมมือกัน เพื่อสำรวจรูปแบบใหม่ในการพัฒนาบุคลากรสหสาขาวิชาในอีคอมเมิร์ซ โดยอ้างอิงจากการศึกษาและวิจัยของบริษัท บริษัท ทรูแลนด์ อินฟอร์เมชั่น เทคโนโลยี (เซี่ยงไฮ้) จำกัด

ฉางเว่ย หยาง[1*]
บารมี วรรณพงศ์เจริญ[2]

[1*] เจ้อเจียงตงฟางโปลีเทคนิค เจ้อเจียงเหวินโจว, สาธารณรัฐประชาชนจีน
433, Jinhai 3rd Avenue, เขตพัฒนาเศรษฐกิจและเทคโนโลยีเหวินโจว, มณฑลเจ้อเจียง
[2]มหาวิทยาลัยวงษ์ชวลิตกุล, ประเทศไทย
84 หมู่ 4 ถ.มิตรภาพ-หนองคาย ต.บ้านเกาะ อ.เมือง จ.นครราชสีมา 30000

*(ผู้ประสานงานเผยแพร่) Corresponding author, Email: y591246235@163.com

บทคัดย่อ

บทความนี้อธิบายถึงความท้าทายและโอกาสที่การฝึกอบรมบุคลากรต้องเผชิญในยุคปัญญาประดิษฐ์ และเน้นย้ำถึงความเร่งด่วนในการพัฒนาบุคลากรเชิงบูรณาการด้านอีคอมเมิร์ซ รวมถึงความจำเป็นการบูรณาการระหว่างอุตสาหกรรมและการศึกษา โดยวิเคราะห์กรอบรูปแบบใหม่และประเด็นสำคัญของการปรับโครงสร้างระบบหลักสูตร จากมุมมองของการกำหนดเป้าหมาย ระบบหลักสูตร และวิธีการสอน พร้อมทั้งอธิบายถึงอิทธิพลของการพัฒนาเทคโนโลยี AI ต่อการพัฒนาการศึกษาอีคอมเมิร์ซ ประสบการณ์เชิงปฏิบัติในการสร้างระบบการฝึกอบรมและการพัฒนาคณาจารย์สำหรับสาขาอีคอมเมิร์ซภายใต้ความร่วมมือระหว่างสถานศึกษาและภาคธุรกิจ ได้ชี้ให้เห็นทิศทางการพัฒนาในอนาคตของการใช้ AI เพื่อเสริมสร้างความร่วมมือระหว่างสถานศึกษาและภาคธุรกิจในการสร้างบุคลากรสหสาขาวิชาในอีคอมเมิร์ซ

คำสำคัญ: การเสริมพลังด้วยปัญญาประดิษฐ์ ความร่วมมือระหว่างสถานศึกษาและภาคธุรกิจ การฝึกอบรมบุคลากรด้านอีคอมเมิร์ซ บุคลากรสหสาขาวิชา การเปลี่ยนผ่านดิจิทัลของการศึกษา

Introduction

The rapid advancement of AI technology is profoundly reshaping talent demand in the field of E-commerce, It will also face the challenge and opportunity of training compound talents in e-commerce. With the continuous expansion of the global talent gap in artificial intelligence, New requirements have been put forward for the traditional e-commerce education mode in universities. The key challenge is how to cultivate composite talents who possess a solid programming foundation, are proficient in AI algorithm applications, and demonstrate strong

The current issue and full text archive of this journal is available on Supply Chain and Sustainability Research at: https://so08.tci-thaijo.org/index.php/SCSR/index

business acumen. In this context, the integration of industry and education has moved from policy advocacy to practical necessity, and become an important way to solve the contradiction of talent supply side.

The university and the enterprise jointly build a talent training base, Schools and enterprises jointly build talent training bases, and reconstruct "AI+ e-commerce" courses and practical training innovations through school-enterprise cooperation, Explore the AI-enabled school-enterprise collaborative e-commerce talent training model which deeply integrates digital marketing and software technology (Cheng, Liu, & Liu, 2025), It not only solves the pain point of disconnection between theory and practice in traditional education, Through the empowerment of AI technology, It has realized the comprehensive innovation of teaching scene, ability evaluation and career development, and provided a new model for e-commerce talent training that can be replicated.

AI empowers the innovation of collaborative training mode between universities and enterprises

Model framework and core elements

Artificial intelligence empowers school education reform, First of all, artificial intelligence technology should be used to cultivate students' internal motivation and build a new paradigm of self-driven learning; Secondly, by developing large education models for educational scenarios, we can empower efficient and personalized education; Finally, promote the transformation of teachers and students' roles and improve their ability and quality (Du, Fu, Wang, et al., 2025). The AI-enabled school-enterprise collaborative training model of "True land Ltd.", A "trinity" system innovation has been constructed, which is guided by industrial demand, driven by AI technology and carried by education, innovation The talent training path should be reconstructed around its three core elements. We will actively explore the optimization plan of business talent training through school-enterprise cooperation and continue to cultivate a large number of multi-skilled e-commerce talents with higher education background for the country (Han & Liu, 2024)

(1) Reconstruct target positioning Different from the unidirectional ability model of traditional E-commerce talent, A new model of three-dimensional ability composite of "technology + business + data", It is committed to cultivating integrated talents who "master the ability of intelligent marketing system development, business data analysis and full-link digital operation". This positioning enables graduates to be competent in front-end development, algorithm optimization and other technical positions, It can also control e-commerce operation, digital marketing and other business scenarios, and significantly improve employment competitiveness.

(2) Reform of teaching system Reconstruct the "modular + dynamic update" mechanism (see Table 1) Transforming real enterprise projects into teaching resources, that is, breaking down the intelligent marketing cloud platform with modules such as intelligent website construction, intelligent promotion and data tracking into teaching units, Schools and enterprises jointly build "AI+ e-commerce" curriculum group. We will deepen the integration of industry and education in "positions, courses, competitions and certificates" to promote high-quality development of vocational education in the new era (Han, Pan, & Wang, 2024). That is, the course assignments can participate in the national college students' competition, and the excellent works can be directly transformed into enterprise service plans, forming a closed loop of "learning-practice-output".

Build a teaching scene that integrates virtual and real in a way that breaks through the limitation of time and space. Schools and enterprises build training rooms to connect the needs of enterprises into the classroom in

The current issue and full text archive of this journal is available on Supply Chain and Sustainability Research at: https://so08.tci-thaijo.org/index.php/SCSR/index

real time. Under the guidance of teachers and enterprise mentors, the student team completed the whole process of practical combat from demand analysis, algorithm development to promotion and operation, Make the learning process seamless with the work process.

Table 1 Trueland Ltd." school-enterprise co-construction curriculum system structure

The type of course	Sample curriculum	AI technology empowerment point	Cultivate competency goals
Professional foundation module	Python data analysis	Automatic code review system	Programming basics, algorithmic thinking
AI + core module of e-commerce	Intelligent recommendation system development	User behavior analysis model	Algorithm design and system development
Business Practice Module	Live e-commerce operation practice	Live data dashboard	Traffic analysis, marketing strategy
Innovation and expansion module	Digital marketing start-up project incubation	Market forecasting model	Traffic analysis, marketing strategy

AI technology drives teaching innovation

The deep application of artificial intelligence technology in the process of talent training is the core difference from traditional school-enterprise cooperation. Coalition of colleges and enterprises has achieved a leapfrog improvement in teaching quality through AI-enabled scenarios.

(1) Intelligent teaching virtual simulation Personalized guidance is realized based on learning behavior data portrait. The system collects data such as code submission frequency, debugging time and error type distribution of students in the development environment in real time, through machine learning algorithm, the report of ability deficiency analysis is generated, and supplementary learning resources are accurately pushed. This data-driven teaching by aptitude promotes the improvement of learning efficiency and effectively solves the traditional classroom teaching problem of "Go side by side".

A digital twin training environment is built for high-risk practices such as e-commerce high-concurrency scenarios and marketing campaign planning. Students can configure server clusters, design promotions, and observe system performance in real time through stress test models in the virtual space. In the practice of "virtual factory" in school enterprises, the student team completed the whole process of operation from design, printing to production through full-link digital simulation, The feasibility of the scheme is verified in the form of "enterprise bidding-student bidding". This zero-cost trial and error mechanism greatly expands the boundaries of practice, making it possible to develop complex system development capabilities.

(2) Digital portrait of professional ability the multi-dimensional ability assessment model is introduced to break through the limitation of traditional test paper assessment. school-enterprise cooperation project collects multi-dimensional data such as students' technical ability development, team cooperation and communication ability,

and innovative thinking ability of the scheme, Generate a dynamic capability radar chart. This portrait not only serves as feedback for the learning process but also becomes a precise matching tool for enterprise recruitment. The employment matching degree of graduates using this portrait is greatly improved, and the training period of enterprises is shortened.

School-enterprise cooperation promotes the remodeling of e-commerce majors

Synergistic reconstruction of curriculum system

The school and enterprises have innovatively constructed a "three double" joint education mechanism (see Table 2) and an "course competition position" integrated course system transforms the real job ability requirements of enterprises into modular course groups.

(1) AI-driven collaborative education

Table 2 Triple double" joint design

dimension, dimensionality	mode of execution	Case support
Dual governance	The university and the enterprise jointly establish the training objectives and curriculum system of the industrial college	"Whole network real scene training room"
Dual mentorship	Enterprise engineers undertake practical courses, and university teachers participate in enterprise technology breakthroughs	"Teacher integration" mechanism
Two scenario practices	The AI studio on campus simulates the enterprise environment + enterprise internship	Build a "double base" for practice

(2) Project-based development of courses

Core courses of e-commerce majors are fully integrated into AI technology application scenarios. In the courses of "New Media Operation" and "Economic Management" jointly built by the school and the enterprise, Add user behavior prediction algorithm, content generation model and other practical links. Add user behavior prediction algorithm, content generation model and other practical links, Through the analysis of real business cases, students can master the whole process of AI-enabled marketing content creation. The course assignment requires the design of intelligent promotion plan around local characteristic products, and the excellent scheme can be directly applied to the actual operation of enterprises, The cooperation between universities and enterprises realizes the deep connection of "homework as business plan, classroom as post".

"Three-stage progressive" project training. Students start with modular micro-projects in their freshman year, such as using Python to crawl product reviews; To the development of subsystems in the second year, such as building personalized recommendation engine; Then to the comprehensive business projects in my junior year, such as designing intelligent marketing solutions for small and medium-sized enterprises. Students are provided with desensitized business data from small businesses, so that students can face the challenges of traffic fluctuations, user behavior tracking and churn warning in real business environment. user behavior tracking and churn warning in the real business environment. Enterprises integrate big data AI algorithms and cloud computing technologies such as IaaS/PaaS/SaaS architecture to provide dynamic data dashboards and predictive models, In the mode of "data support-ability training-employment output", students are helped to simulate the formulation of marketing strategies and verify their effects, Strengthen data analysis capabilities to respond to real-time market changes.

Innovative design of practical training system

The training process is the most concentrated area of AI empowerment, Enterprises build a capability progression channel through the "job practice platform".

(1) AI+ Real Project Platform Classify the enterprise service requirements of digital platforms and import them into the teaching system. Under the guidance of "dual mentors" of university teachers and enterprise engineers the student team the student team completed the whole process of practical combat from demand analysis, technical solution to implementation and delivery. Summarize the Nanning Vocational and Technical College project, The intelligent marketing system integrates modules such as short video automatic generation and regional user portrait analysis to help enterprises improve their online sales experience. By integrating students into the process of creating real business value, their sense of professional identity and technical mission are greatly enhanced.

(2) Competition transformation and innovation platform Establish a mechanism for the transformation of achievements "promoting innovation through competition". The requirements of China's International "Internet Plus" College Students Innovation and Entrepreneurship Competition and other competitions are organically combined with the technical breakthrough needs of enterprises, The core algorithm is applied to the enterprise overseas promotion system. The competition not only exercises students' technological innovation ability, but also cultivates business thinking and team spirit.

(3) Training base rotation mechanism Implement the "rotating and alternating" training of "innovation workshop in school + enterprise practice center". We are committed to market demand orientation and promote interdisciplinary, cross-field and cross-level scientific and technological innovation and personnel training (Li, Zhu, & Xie, 2023) In the early stage, students master the tool chain and development process in the school base, and later enter the enterprise site for practical training (see Figure 1), Participate in the delivery of real customer projects. Enterprise engineers lead students to complete the "festival e-commerce promotion" system stability and other projects, The server resource allocation is optimized by the load prediction algorithm, and the technical challenges in the high-concurrency scenario are experienced. This kind of production environment immersion learning enables students to obtain the core technical experience that is difficult to reach in traditional internship.

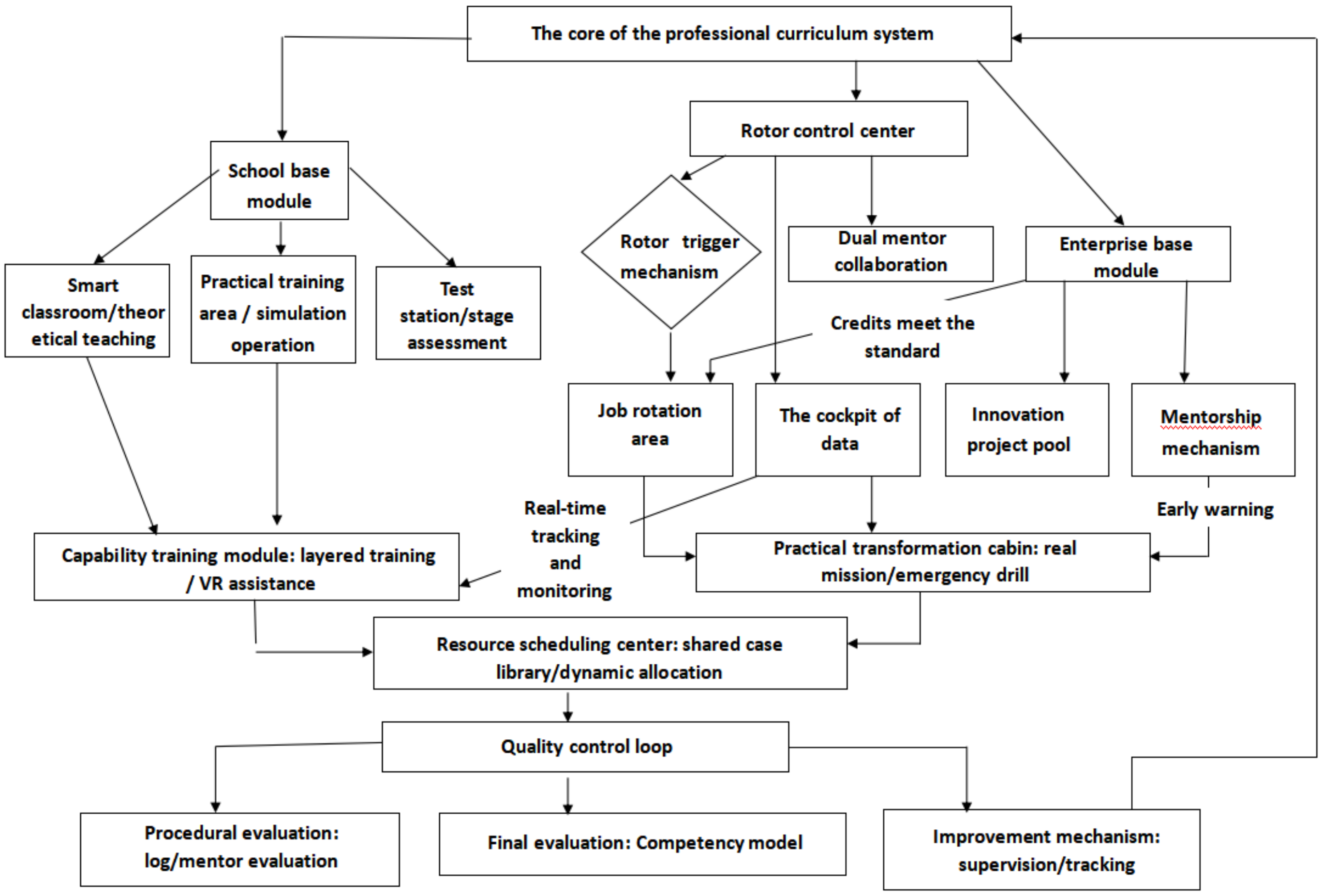

Figure 1 Double base rotation training process

Collaborative construction of teaching staff

In The dual-teacher team is the core element to ensure the quality of training. solves the problem of teacher transformation through the "school-enterprise linkage mechanism".

(1) Improvement of teachers' ability The dual-qualified team is the core factor to ensure the quality of training, and the "school-enterprise linkage mechanism" is used to solve the problem of teacher transformation. Establish a system of mutual appointment and periodic rotation training. On the one hand, university teachers can master the use and teaching ability of enterprise-level tool chains such as intelligent advertising system and user portrait analysis platform through the "AI Marketing Engineer Certification" of enterprises, Outstanding candidates can be promoted to the position of "Vice President of Technology" through assessment; On the other hand, enterprise engineers receive pedagogical methodology training, learn project-based teaching design and implementation skills, and are selected as "industry professors" of the college.

(2) Joint creation mechanism Regularly carry out special seminars on "technology feeding teaching”. School-enterprise cooperative R&D team shared the latest technology trends in intelligent marketing, such as the application of generative AI in advertising creativity, and university teachers turned it into teaching cases and experimental projects. In the university enterprise visit and job expansion activities, the university and enterprises jointly developed cutting-edge courses such as "AIGC Digital Content Production", and timely transformed the technological evolution of enterprises into teaching resources.

Jointly build technical breakthrough teams to serve regional economy, which undertakes the digital marketing needs of small and medium-sized enterprises together with teachers and students, By helping enterprises to solve the pain points such as difficult promotion intervention and low operation transformation, Teachers have accumulated practical experience, and students have gained training in job projects, forming a benign progressive cycle of "teaching-production-innovation".

Evaluation standard docking

In order to give full play to the advantages of industry-education collaboration and comprehensively improve the quality of e-commerce talent training, it is necessary to continuously promote the reform of e-commerce education and build a new model of excellent training; Strengthen the quality assurance mechanism, empower e-commerce talent training; rely on project practice, hone the comprehensive quality of e-commerce talents.

(1) Ability certification system We will implement a dual-track evaluation system of academic certificates and skill level certification. Students are required to pass the "intelligent Marketing Engineer" job competency certification of the enterprise at the same time as they receive the degree certificate. at the same time as they obtain their degree certificates. The certification focuses on technical development such as algorithm implementation, system operation and maintenance such as platform deployment, and business analysis such as ROI evaluation, The design evaluation standard of its core ability makes the talent ability evaluation seamlessly connected with the employment needs of enterprises.

(2) Credit recognition mechanism Establish rules for converting project credits. Students who participate in enterprise e-commerce promotion system development and other projects can get "professional practice" course credits; Awards in provincial-level competitions can replace "innovation and entrepreneurship" credits; Enterprise technology certification can be converted into credits of relevant professional courses. This multi-element identification system, it effectively stimulated the enthusiasm of students to participate in the school-enterprise cooperation "integration of industry and education" project.

Implement challenges and coping strategies

The in-depth implementation of school-enterprise collaboration is faced with management challenges such as organizational barriers and unclear rights and responsibilities, which need to be solved by accelerating institutional innovation.

(1) Optimization of governance structure Establish a new ecology of "teaching, learning, research and management", and meet the educational needs in all scenarios and multi-terminal terminals, including teachers' preparation and teaching, smart classrooms, computer classrooms, etc., Cross-field and cross-level future technology and innovation workshop system, To build a more perfect new model of e-commerce education with Chinese characteristics, so as to solve the structural contradictions in the training of e-commerce talents under the background of scientific and technological revolution and meet the needs of innovative talents in the rapidly changing industry, and provide systematic solutions (Qiao & Gao, 2025)

Set up a "management and operation center" composed of management personnel from both sides of the university and enterprise to be responsible for cooperation plan formulation and resource allocation; To set up an expert committee composed of technical experts and professors to guide teaching and research activities; Establish a working group for the integration of teachers and coordinate the construction of dual-teacher teams. This kind of "school-enterprise integration" governance ensures the professionalism of decision-making and the effectiveness of implementation.

(2) Dynamic adjustment mechanism Through the analysis of the two-level meeting system of quarterly review and annual strategy meeting, we will continue to optimize the cooperation content. Among them, the "quarterly meeting" focuses on solving specific problems such as the need to update training equipment, The annual meeting examines the match between talent training goals and industrial development, Adjust the major direction in time and add AIGC application course module.

Future outlook and optimization direction

The iteration of generative AI and other technologies accelerates, requiring the course update cycle to be shortened to about half a year. Therefore, it is necessary to establish a long-term mechanism of "dynamic balance and rapid response" between schools and enterprises; Add AI ethics modules such as user privacy protection and algorithm bias management to avoid the abuse of technology and the absence of ethics education.

Continuous investment in technical resources

The iteration speed of AI technology poses a severe challenge to the timeliness and advancement of teaching resources.

(1) Build cloud lab together The scheme of "enterprise providing platform + school supporting terminal" is adopted. The enterprise opens the educational edition of the intelligent marketing cloud platform to the cooperative colleges, and the school builds a basic cloud computing laboratory (see Figure 2). This model avoids the heavy investment of tens of millions of dollars and ensures that students have access to cutting-edge tool chains in the industry. Platform functions are updated in sync with the enterprise production environment. The resources of the university and the enterprise are constantly integrated and optimized, and the theoretical teaching and virtual classroom are connected, The integration of virtual and real, "learning, training, evaluation, research, competition and production" are integrated to cultivate new technical talents with all-round development (Ren, 2025)

(2) Teaching resource co-creation system We will jointly build an "AI+ course resource bank" and cooperate with enterprises to improve the knowledge production system. The enterprise provides technical documents and case templates, and the teacher team develops teaching guides and experimental projects, Students contribute to the innovation and application of practical projects, forming a sustainable and updated teaching resource ecology. In the school-enterprise cooperation project, Excellent student assignments are incorporated into the corporate knowledge base and turned into teaching cases.

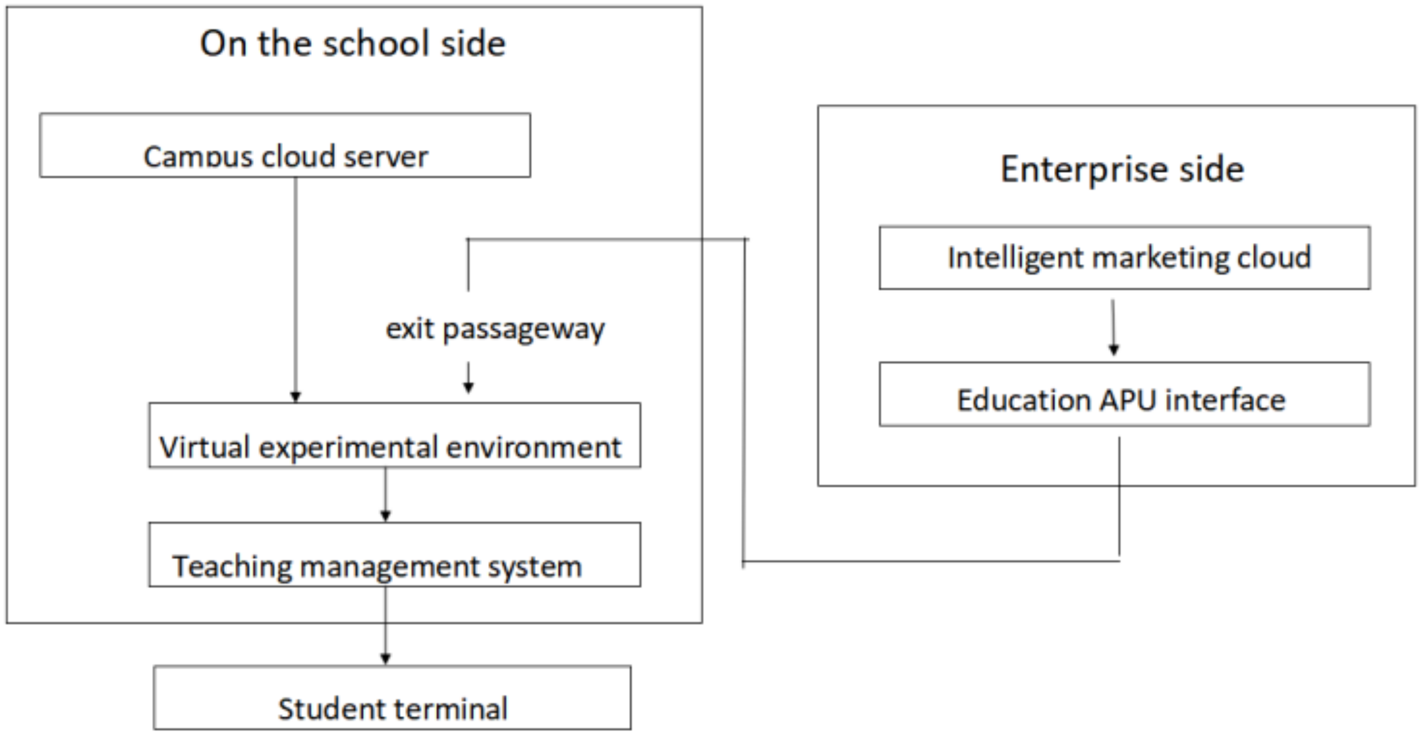

Figure 2 Cloud lab architecture

Deepening direction of technology integration

With the breakthrough of generative AI and other technologies, the school-enterprise collaborative training mode will develop in a more intelligent and personalized direction.

(1) Adaptive learning system Build personalized learning assistant based on large language model. Through the system analysis of students' code style, document writing habits, project design ideas and other multimodal data, Provide real-time programming suggestions, architecture optimization solutions and learning path planning. The "AI teaching assistant" system being explored by schools and enterprises can help teachers realize class situation identification, intelligent teaching diagnosis, and accurate learning situation monitoring. Through "AI assistance", students 'learning, skill deficiency analysis and learning resource recommendation are assisted , and students' operation safety assessment report is generated,[Innovation realizes the new integrated teaching mode of "AI+ teaching assistant, student aid, training aid and management aid" (Wang et al., 2025)

In order to realize basic functions such as class situation recognition and learning situation monitoring, In the future, it will develop into an intelligent partner covering the whole process of teaching, learning, practice and evaluation.

(2) Industry and education metaverse platform The metaverse is a collection of technologies integrated by various digital technologies, which constructs a virtual intelligent world (Yang & Song, 2022). that is highly integrated and linked with the real world. Combine digital twin and extended reality technology to build an immersive teaching space. Enterprises and universities jointly build virtual e-commerce industrial parks, Students participate in the whole industry chain from product design, intelligent production to digital marketing with the help of digitization. Drawing on a number of "digital economy innovation platforms" based on practical training scenarios such as 5G+AR remote maintenance and UAV inspection, we will build an "workshop" for intelligent teaching in the metaverse.

Synergistic upgrading of industry and education ecology

Break through the single school-enterprise cooperation mode and evolve to regional clusters and cross-domain collaboration.

(1) City-wide industry-education consortium According to the indicators of municipal industry-education consortium construction in the Notice of the General Office of the Ministry of Education on the Construction of Municipal Industry-Education Consortium, Referring to successful experiences, we will cooperate with local governments, industry associations and upstream and downstream enterprises to build a regional digital talent training alliance. Schools and enterprises form an ecosystem integrating "education chain, industrial chain and innovation chain", providing students with practical scenarios covering the whole e-commerce industry chain.

(2) International talent training Relying on overseas enterprise resources for enterprise services, a cross-border practice channel will be established. Explore the inclusion of cross-border e-commerce operation into the training system, Student teams can participate in overseas market analysis, multilingual intelligent customer service system development, cross-border payment interface docking and other globalization projects, To cultivate compound talents with international vision and technical ability.

Lifelong education system connection

In the context of accelerated iteration of AI technology, school-enterprise collaboration extends to the whole cycle of career development.

(1) Alumni Competency Preservation Program Establish a technical tracking system for graduates. Enterprises open platform update logs, technical white papers and other resources to the alumni of cooperative colleges and universities. Regularly push industry technology dynamic reports. Excellent alumni can return to the university to participate in the "technology workshop" and share their practical experience in the industry, forming a sustainable development link of "learning-employment-feeding back".

(2) Construction of micro certification system In view of the rapid iteration characteristics of AI technology, modular skill certifications are introduced. Specialized competency certifications, such as "Large Language Model Application Development" and "Cross-platform Intelligent Customer Service Deployment", help employees continuously update their knowledge structure. This "academic education + micro certification" hybrid mode will become the mainstream form of education to cope with technological change.

Conclusion

The practice of school-enterprise cooperation shows that: shows that the collaborative training mode enabled by AI can effectively solve the structural contradiction between supply and demand of E-commerce talents. Through the reconstruction of curriculum system, innovation of training ecology and breakthrough of evaluation mechanism, the deep integration of technical ability and business quality has been realized. Its core value lies in building a sustainable AI+ education ecosystem in which "education empowers industry and industry feeds back to education", so that talent training and technological innovation form a positive cycle.

AI is not merely a teaching tool—it serves as a "connector" that redefines the relationship between industry and education. In the future, we need to use the symbiotic system thinking of "technology, system and ecology" to lead education from knowledge transmission to innovation and reform.

With the deep integration of "AI+ education" technology, school-enterprise collaboration will develop in a more intelligent, personalized and lifelong direction. In view of the requirements of new engineering and the current situation of diversified E-commerce teaching, we adhere to the teaching plan of "theory + training + project", and comprehensively complement the advantages of industry and education, share the interests of various parties, and develop talents in an all-round way (Zhou, 2024) Only in this way can the educational potential of AI be truly released and compound E-commerce talents adapted to the upgrading of digital economy industry be cultivated.

Acknowledgements

This research was supported by two funding projects:

(1) The Fourth Phase of the Ministry of Education’s Supply and Demand Matching Employment Education Project (Project No. 2024122419366), aiming to enhance e-commerce talent training through industry-education integration between Trueland Information Technology (Shanghai) Co., Ltd. and Zhejiang Dongfang Polytechnic

(2) Domestic (Visiting Engineer) Program for colleges and universities in Zhejiang Province (Zhejiang Dongfang Polytechnic) in 2025.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

Cheng, Y., Liu, Y., & Liu, W. (2025). The technological foundation, mechanism of action, and future directions of metaverse in empowering talent cultivation in higher education institutions. *Journal of Fuyang Normal University (Natural Science Edition)*, *42*(1), 96-103. doi:10.14096/j.cnki.cn34-1334/n.2025.03.013

Du, X., Fu, X., Wang, Y., et al. (2025). Teaching reform of introduction to software engineering in the new engineering context. *Computer Education*, (5), 100-104. doi:10.16512/j.cnki.jsjjy.2025.05.027

Han, T., & Liu, Y. (2024, November 30). School-enterprise "marriage" symphony of integration and mutual promotion. *Guangming Daily*.

Han, X., Pan, S., & Wang, Y. (2024). The practice of the 'class-position alignment', 'class-certificate integration', and 'class-competitive integration' teaching models in the film and television post-production synthesis and production course. *Linqu Teaching*, (7), 54-58.

Li, Y., Zhu, G., & Xie, M. (2023). Exploring a collaborative AI innovation talent cultivation model for schools and enterprises based on PaddlePaddle. *Computer Education*, (12), 49-53.

Qiao, S., & Gao, Z. (2025). Artificial intelligence empowering school education reform: Value, limits, and practical approaches. *Journal of Zhejiang Normal University (Social Sciences Edition)*, (4), 101-109. Retrieved from http://kns.cnki.net/kcms/detail/33.1011.c.20250619.1013.006.html

Ren, L. (2025). The realistic dilemma and countermeasures for cultivating outstanding engineers through industry-education integration. *Journal of Hubei University for Nationalities (Philosophy and Social Sciences Edition)*, 1-10. doi:10.13501/j.cnki.42-1328/c.20250611.002

Wang, K., Wang, L., Lin, J., et al. (2025). Exploring new transformations and models of engineering education in the digital intelligence era. *Research on Science and Education Development*, *5*(1), 13-37. doi:10.20105/j.cnki.jstes.2025.01.001

Yang, Q., & Song, W. (2022). An exploration of the optimal scheme for cooperation between schools and enterprises in computer talent training in the era of artificial intelligence. *China Education Informatization*, (7), 34-38.

Zhou, K. (2024). Research on the construction of a six-in-one trade training base integrating production, learning, research, innovation, competition, and service. *Talent Intelligence*, (26), 189-192.

Vehicle-Drone Collaborative Delivery:
A Systematic Literature Review and Future Research Agenda

Xinyu Fan[1], Yantong Jin[1], Shi Peter[2], Nyoman Pujawan[3],
Gang Wu[4], Fang Xu[4], Chaozhe Jiang[5*]

[1,4]Southwest Jiaotong University, Chengdu, China
West High-tech Zone, Chengdu, Sichuan, China
[2]Macquarie University, Sydney, Australia
123 Pitt Street, Sydney NSW, Australia
[3]Universitas Logistik dan Bisnis Internasional, Bandung, Indonesia
54, Sarijadi, Kecamatan Sukasari, Kota Bandung, Jawa Barat, Indonesia
[5] University of Waterloo, Waterloo, Canada
200 University Avenue West Waterloo, Ontario, N2L 3G1, Canada

*Corresponding author, Email: jiangchaozhe@swjtu.edu.cn

Received: Sep 10, 2025 / Revised: Dec 18, 2025 / Accepted: Dec 18, 2025

Abstract

The rise of the low-altitude economy and advances in intelligent technologies have accelerated innovation in last-mile logistics, where Vehicle-Drone Collaborative Delivery (VDCD) has become a promising solution. We systematically review 3,300+ publications and apply VOSviewer-based bibliometric analysis to synthesize research on VDCD. A four-part analytical framework is developed, covering collaboration modes, optimization objectives, problem models, and solution algorithms. The results identify four paradigms of collaboration: synchronous vehicle-drone delivery, parallel delivery, vehicle-supported drone delivery, and drone-supported vehicle delivery. Research objectives have evolved from single goals such as minimizing cost or time toward multidimensional objectives, including service coverage, customer satisfaction, and carbon reduction. Three evolutionary paths in problem modeling are observed-basic formulations, constraint-extended models, and joint optimization models-reflecting growing complexity and cross-layer integration. Algorithmic approaches fall into three main streams: exact methods, heuristics, and metaheuristics, with emerging trends in hybridization, distributed mechanisms, and adaptive strategies. Finally, this paper outlines potential directions for optimizing VDCD systems through technological innovation, policy support, and scenario-specific design, providing valuable insights for future research and practical implementation.

Keywords: Vehicle–Drone Collaborative Delivery; Path Planning; Multi-Agent Systems; Logistics Optimization; Intelligent Logistics

การจัดส่งสินค้าร่วมกันระหว่างยานพาหนะและโดรน: การทบทวนวรรณกรรมอย่างเป็นระบบและวาระการวิจัยในอนาคต

ซินหยู่ ฟาน[1], หยานทง จิน[1], ชิ ปีเตอร์[2], นโยมาน ปูจาวัน[3]
แก๊ง หวู่[4], ฟาง ซู[4], เฉาเจ๋อ เจียง[5*]

[1,4]มหาวิทยาลัยเจียวทงภาคตะวันตกเฉียงใต้ เฉิงตู, สาธารณรัฐประชาชนจีน
เขตไฮเทคตะวันตก เฉิงตู เสฉวน, สาธารณรัฐประชาชนจีน
[2]มหาวิทยาลัยแมคควอรี, ซิดนีย์, ออสเตรเลีย
123 ถนนพิตต์, ซิดนีย์ NSW, ออสเตรเลีย
[3]มหาวิทยาลัยโลจิสติกส์และธุรกิจนานาชาติ, บันดุง, อินโดนีเซีย
54, ซารีจาดี เขตซูกาซารี เมืองบันดุง จังหวัดชวาตะวันตก, อินโดนีเซีย
[5*]มหาวิทยาลัยวอเตอร์ลู วอเตอร์ลู แคนาดา
200 ถนนยูนิเวอร์ซิตี อเวนิว เวสต์ เมืองวอเตอร์ลู, ออนแทรีโอ, N2L 3G1, แคนาดา

*(ผู้ประสานงานเผยแพร่) Corresponding author, Email: jiangchaozhe@swjtu.edu.cn

บทคัดย่อ

การเติบโตของเศรษฐกิจระดับต่ำและความก้าวหน้าของเทคโนโลยีอัจฉริยะเร่งรัดนวัตกรรมในด้านโลจิสติกส์ระยะสุดท้าย ซึ่งการจัดส่งสินค้าร่วมกันระหว่างยานพาหนะและโดรน (VDCD) นั้นกลายเป็นการแก้ปัญหาที่มีแนวโน้มดี ทบทวนสิ่งพิมพ์กว่า 3,300 ฉบับอย่างเป็นระบบ และวิเคราะห์บรรณานุกรมด้วยโปรแกรม VOSviewer เพื่อสังเคราะห์งานวิจัยเกี่ยวกับ VDCD มีการพัฒนากรอบการวิเคราะห์สี่ส่วน ครอบคลุมรูปแบบการทำงานร่วมกัน วัตถุประสงค์การเพิ่มประสิทธิภาพ โมเดลปัญหา และอัลกอริทึมในการแก้ปัญหา ผลลัพธ์ระบุกระบวนทัศน์สี่ประการของการทำงานร่วมกัน ได้แก่ การจัดส่งแบบซิงโครนัสระหว่างยานพาหนะโดรนการจัดส่งแบบคู่ขนาน การจัดส่งโดยมีโดรนสนับสนุนยานพาหนะ และการจัดส่งโดยมียานพาหนะสนับสนุนโดรน วัตถุประสงค์ของการวิจัยได้พัฒนาจากเป้าหมายเดียว เช่น การลดต้นทุนหรือเวลา ไปสู่วัตถุประสงค์หลายมิติ ซึ่งรวมถึงการครอบคลุมการให้บริการ ความพึงพอใจของลูกค้า และการลดคาร์บอนมีการสังเกตเส้นทางการพัฒนาสามประการในการสร้างแบบจำลองปัญหา ได้แก่ สูตรพื้นฐานโมเดลที่ขยายข้อจำกัดและโมเดลการเพิ่มประสิทธิภาพร่วม ซึ่งสะท้อนถึงความซับซ้อนที่เพิ่มขึ้นและการบูรณาการข้ามชั้นแนวทางด้านอัลกอริทึมแบ่งออกเป็นสามกระแสหลัก ได้แก่ วิธีการที่แม่นยำ ฮิวริสติก และเมตาฮิวริสติก โดยมีแนวโน้มที่เกิดขึ้นใหม่ในด้านการผสมผสาน กลไกแบบกระจาย และกลยุทธ์แบบปรับตัว สุดท้ายบทความนี้นำเสนอทิศทางที่เป็นไปได้สำหรับการเพิ่มประสิทธิภาพระบบ VDCD ผ่านนวัตกรรมทางเทคโนโลยี การสนับสนุนด้านนโยบาย และการออกแบบเฉพาะสถานการณ์ (Scenario-Specific Design) ซึ่งให้ข้อมูลเชิงลึกที่มีคุณค่าสำหรับงานวิจัยในอนาคตและการนำไปปฏิบัติจริง

คำสำคัญ: การจัดส่งสินค้าร่วมกันระหว่างยานพาหนะและโดรน, การวางแผนเส้นทาง, ระบบหลายตัวแทน, การเพิ่มประสิทธิภาพโลจิสติกส์, โลจิสติกส์อัจฉริยะ

Introduction

The global logistics system is facing unprecedented efficiency bottlenecks and transformation pressures. According to the World Bank, logistics costs account for more than 12% of global GDP, with last-mile delivery costs representing 28–35%. This has become a major constraint on overall supply chain efficiency (Park et al., 2023). The traditional delivery model dominated by fuel-powered vehicles faces multiple challenges. Geographic constraints reduce accessibility in remote areas and disaster response scenarios (Dorling et al., 2017). Meanwhile, the rapid growth of e-commerce has led to a surge in parcel volumes. This increase has further raised the frequency of urban delivery vehicle operations, intensifying both traffic congestion and emissions. Urban logistics vehicles alone contribute about 30% of traffic congestion and 18% of greenhouse gas emissions (Joselow, 2020).

In recent years, with breakthroughs in drone technology and the expansion of application scenarios, research on drone-based logistics delivery has developed rapidly. In 2013, Amazon first announced its drone delivery project and declared that it would enter the stage of practical application by 2017 (Rose, 2013). Soon after Google's GoogleX laboratory launched its Project Wing in 2014 (Stewart, 2014). That same year, the German company DHL successfully tested a drone delivering medicine to a small island inaccessible by truck (Bryan, 2014). However, as applications deepened, the limitations of drones such as low payload capacity and limited endurance became evident. To date, companies including Google, Amazon, DHL, and SF Express have employed drones in delivery operations. Most operate at speeds of 48–64 km/h, with ranges of 16–48 km, and a payload capacity of five kg (Heath, 2015). As a result, when logistics demand and delivery radius expand significantly, the capacity and range constraints of drone systems lead to rising marginal costs and diminishing utility, thus presenting a clear feature of diseconomies of scale.

In summary, VDCD has emerged as a promising paradigm to overcome the efficiency bottlenecks of last-mile logistics, leveraging the complementary strengths of aerial and ground transportation. While existing research has made substantial progress in model design, algorithm development, and scenario exploration, a systematic and integrative perspective is still needed to clarify the evolution path, optimization logic, and future research directions of VDCD. It should be noted that this review did not consider airspace regulation papers outside logistics journals, which may limit the breadth of policy-related insights. To address this gap, this paper provides a comprehensive review and structured analysis. The explicit contributions of this study are as follows:

Comprehensive Framework: We analyze 3,300+ publications and use VOS viewer-based bibliometric to build an integrated framework that links collaborative modes, optimization objectives, problem models, and solution algorithms.

Refined Mode Classification: We categorize VDCD into four representative paradigms and analyze their mechanisms, applications, and performance trade-offs.

Modeling and Optimization Insights: The evolution from basic to constraint-extended and joint optimization models, highlighting the shift from spatial flexibility to cross-layer resource integration, and summarize multi-objective optimization approaches beyond time and cost.

Literature Review

Sources of Literature

This study searched in the Web of Science Core Collection, including the SCI-EXPANDED and SSCI databases. The search was performed using the topic terms ‘UAV” AND “Optimization” AND “vehicle-UAV”. After a strict screening process, conference papers, review articles, and retracted publications were excluded. A total of more than 3,300 journal articles published between 2015 and the first half of 2025 were identified as relevant to the research topic. The results are shown in Figure 1

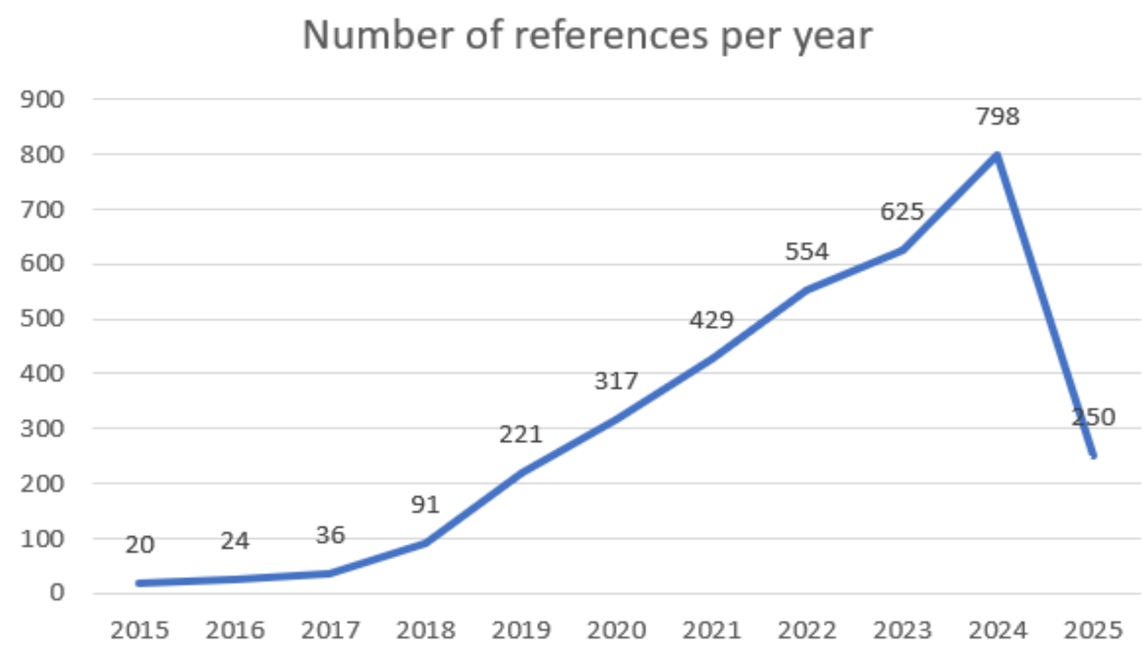

Figure 1 Annual number of published papers

The journal sources mainly include Transportation Research Record, Transportation Research Part A/B/C/D/E, IEEE Transactions on Intelligent Transportation Systems, Transportation Science, IEEE Transactions on Wireless Communications, and IET Intelligent Transport Systems. The research fields cover multiple areas, such as Engineering, Telecommunications, Computer Science, Transportation, Remote Sensing, and Instruments and Instrumentation.

This study employs VOSviewer to conduct bibliometric analysis. The software is based on co-occurrence networks and clustering techniques, which automatically extract and normalize keywords from the literature. It then generates clustering maps according to co-occurrence strength, thereby objectively revealing the structural patterns of research topics. In this analysis, only author-provided keywords were included. The minimum occurrence threshold was set to nine. Out of 8,040 keywords, 287 met this criterion. The top fifteen keywords were autonomous aerial vehicles, optimization, unmanned aerial vehicles, resource management, trajectory optimization, task analysis, wireless communication, internet of things, resource allocation, energy consumption, path planning, energy efficiency, NOMA, trajectory design, and relays. The results are shown in Figure 2 and Figure 3

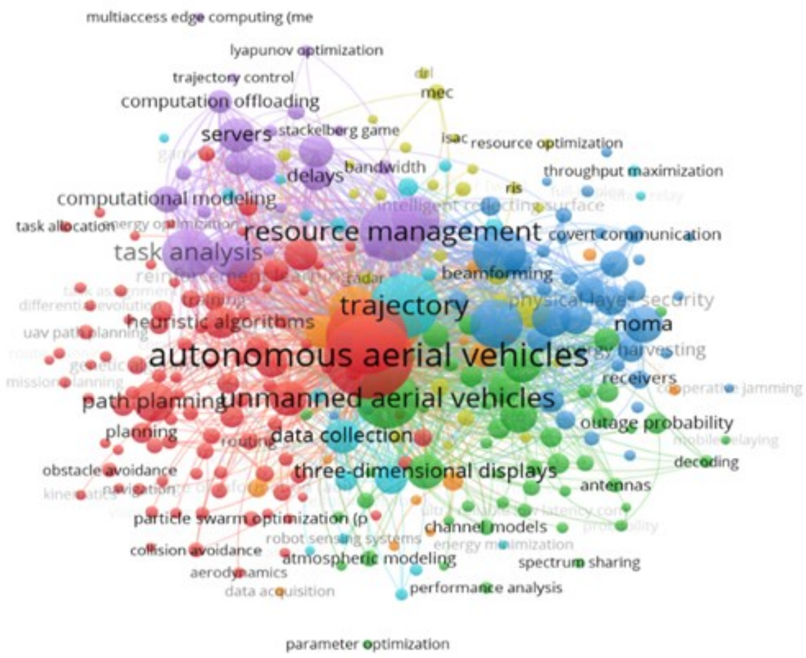

Figure 2 Keyword co-occurrence network

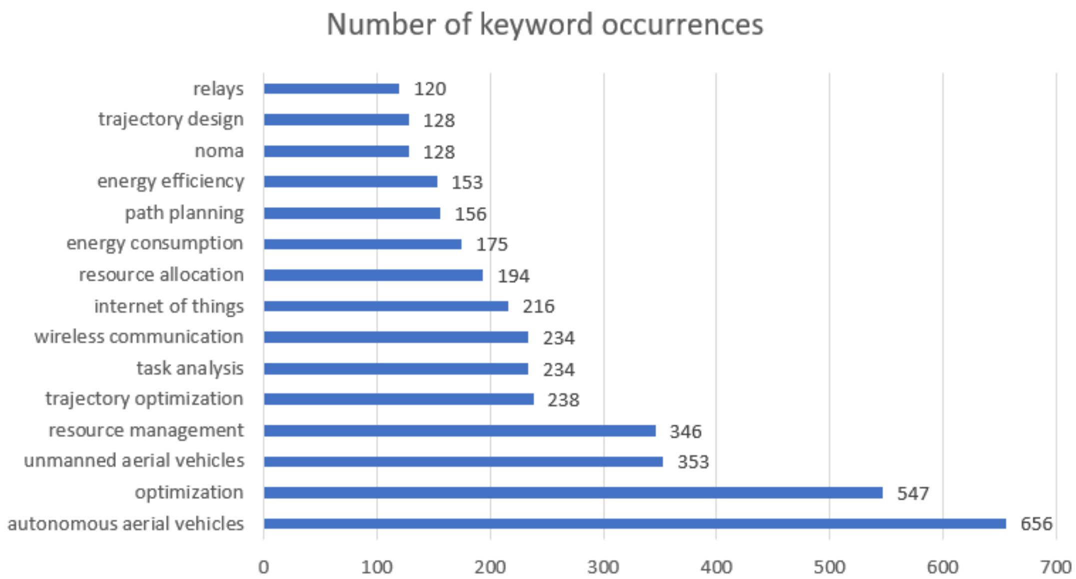

Figure 3 Top fifteen most frequently used keywords

As shown in Figures 2 and 3, the clusters centered on the thematic keyword vehicle-drone collaboration mainly include terms such as optimization, task analysis, resource allocation, and path planning. This indicates that these keywords represent the core research focuses in this field.

Problem Modeling

Vehicle-drone combined delivery can adopt multiple modes. Both vehicles and drones can participate in deliveries, or one may perform delivery while the other provides support. Based on the different roles of vehicles and drones in the collaborative delivery process, this study, following Otto et al. (2018) and Rojas et al. (2021), categorizes the problem into four types: synchronous delivery by drones and vehicles, parallel delivery by vehicles and drones, vehicle-supported drone delivery, and drone-supported vehicle delivery.

synchronous delivery by drones and vehicles

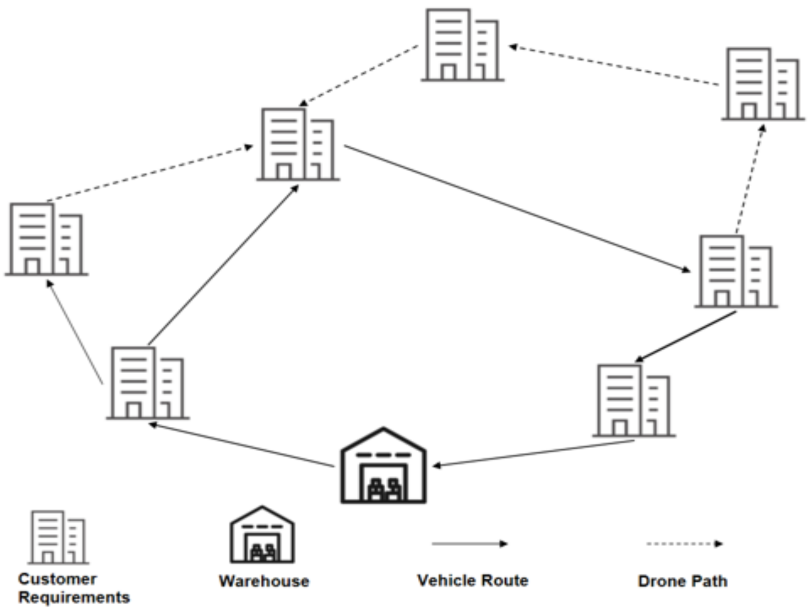

Figure. 4 Diagram of synchronized drone and vehicle delivery operation mode

The vehicle–drone collaborative delivery model is illustrated in Figure 4. In this mode, the vehicle and drones serve their respective customer nodes, with the vehicle carrying one or more drones. Research in this area focuses on the coordinated optimization of vehicle and drone path planning and task execution. The aim is to address drone endurance limitations, spatiotemporal synchronization requirements, and road constraints, while optimizing multiple objectives such as cost, time efficiency, energy consumption, and service coverage. Typically, the vehicle serves as a mobile platform or resupply point for drones. Modeling studies consider scenarios of varying complexity. In basic scenarios, vehicles follow predefined routes while drones take off from the vehicle to serve one or multiple customers before returning. The vehicle must wait at designated times and locations for drone rendezvous. To improve efficiency and coverage, models have evolved. Teimoury et al. (2024) introduced non-customer rendezvous locations, allowing vehicles to meet drones at points other than customer nodes, greatly increasing path planning flexibility. The mobile resupply mode was proposed to overcome fixed stop limitations. While the vehicle moves along roads, drones can take off, land, and receive battery or cargo replenishment, significantly extending service range and continuity (Maini et al., 2019; Gu et al., 2023). Energy management strategies have also been incorporated. Yurek et al. (2021) explored dynamic charging as an alternative to battery replacement to better reflect practical scenarios and reduce downtime. In complex scenarios, multi-objective delivery is considered. Teimoury et al. (2024) allowed drones to visit multiple customers in a single flight. Gu et al. (2023) addressed dynamic demand, requiring models to efficiently update paths in response to real-time delivery requests.

Research has thoroughly demonstrated the significant advantages of the synchronous delivery mode in improving last-mile logistics efficiency. The core of this mode lies in leveraging the collaborative effects at the last-mile stage. Drones can efficiently handle small-batch, multi-trip, and geographically dispersed delivery tasks, effectively compensating for the limitations of ground vehicles in complex road conditions, remote areas, and emergency demand scenarios. Vehicles, in turn, manage mainline transportation and bulk deliveries, achieving complementary use of aerial and ground resources. Integrating drones into the delivery system can reduce last-mile delivery time, minimize vehicle idling and waiting, and enhance system flexibility and robustness while maintaining overall operational stability. An empirical study by Gu et al. (2023) shows that using a single-vehicle, single-drone mobile base station in dynamic scenarios can increase service efficiency by 50% and raise operational profit by 15%, further confirming the feasibility and value of this collaborative delivery mode.

parallel delivery by vehicles and drones

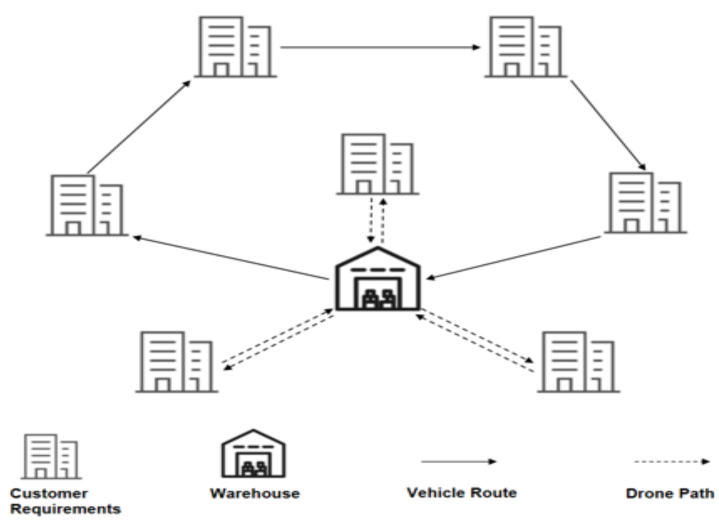

Figure. 5 Diagram of vehicle and drone parallel delivery operation mode

Parallel delivery by vehicles and drones refers to a mode in which both participate in the same delivery task but operate as independent transport units, performing their respective tasks without interference. The operational scheme is illustrated in Figure 5. In this mode, drones depart directly from the distribution center and return, serving nearby customers in a point-to-point manner. Vehicles, on the other hand, carry the entire load at once and deliver to customers in more distant areas. In parallel delivery, drones only pick up items and recharge at the distribution center. There is no need for temporal or spatial coordination with vehicles, which is why this mode is referred to as parallel delivery. This mode demonstrates significant value across diverse scenarios. Edirimanne et al. (2024) used pizza delivery in Sri Lanka as an empirical setting, developing a capacity-constrained VRP drone model. Their results show that this approach outperforms traditional motorcycles and optimized motorcycle systems in terms of travel distance, time, cost, and emissions. For special-demand scenarios, Ramos et al. (2023) focused on dynamic, real-time drug delivery from rural pharmacies in Portugal. They systematically modeled a vehicle–drone collaborative mechanism under dual constraints of real-time order arrivals and strict delivery deadlines. To enhance system robustness, Wang et al. (2021) proposed a multimodal integrated architecture that coordinates truck fleets, mobile drones carried by trucks, and fixed stations multiple traveling salesman problem and location allocation problem model (mTSP-LAP), achieving efficient linkage among heterogeneous nodes. Facing large-scale logistics challenges, Shi et al. (2025) developed a multi-vehicle, multi-drone collaborative framework to address the coupled constraints of drone endurance, payload, and truck load capacity, significantly reducing system energy consumption. Kloster et al. (2023) incorporated fixed drone stations into the multi traveling salesman problem (mTSP), coordinating vehicle routing and drone task scheduling to reduce delivery time while optimizing energy usage. Nguyen et al. (2022) proposed a parallel delivery model Parallel Drone Scheduling Vehicle Routing Problem (PDSVRP) with the core objective of minimizing total operational cost, aiming to improve multiple performance dimensions.

Parallel delivery by vehicles and drones can fully leverage the flexibility of drones and the long endurance and high payload capacity of vehicles. This enables adaptation to multiple scenarios while improving system robustness and wide-area coverage. However, the mode is constrained by drone endurance and payload limits, as well as additional operational costs related to matching vehicle and drone resources and the layout of stations.

vehicle-supported drone delivery

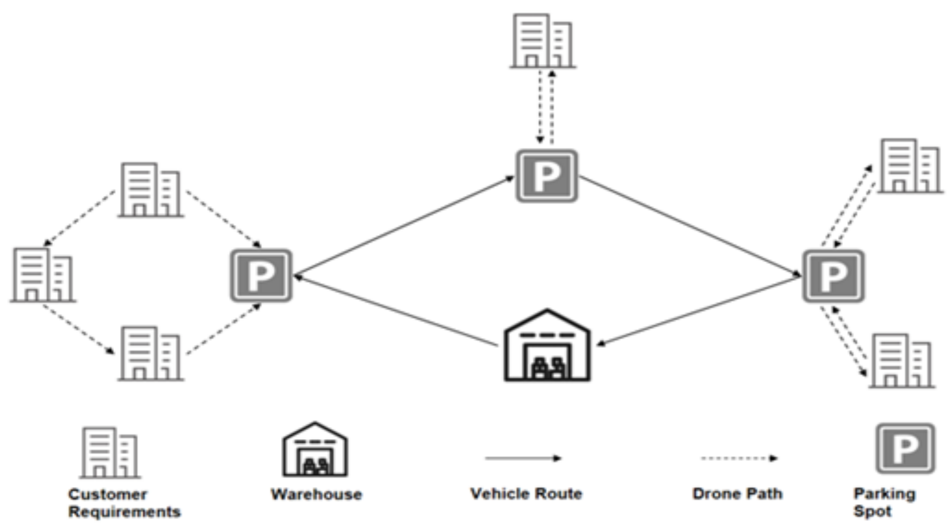

Figure 6 Vehicle secured drone delivery operation model diagram

The vehicle supported drone delivery mode is illustrated in Figure 6. In this mode, drones execute the delivery tasks while vehicles serve as supporting platforms. This mode can be implemented through multiple approaches. Vehicles may act as mobile transport platforms, carrying drones to the task area before drones complete all deliveries (Mathew et al., 2015). They can also function as mobile energy supply stations, significantly extending drone operation time through dynamic charging (Ropero et al., 2019) or vehicle–drone bidirectional energy-sharing mechanisms (Zhu et al., 2024). Vehicles can further integrate with public transportation networks to form multi-level relay hubs. For example, drones may ride on buses to reach remote transfer stations and then complete last-mile delivery using charging stations for battery replacement (Huang et al., 2022). In high-density last-mile delivery scenarios, vehicles may be upgraded to multifunctional mobile bases, serving as cargo storage, take-off/landing platforms, and charging stations to support multiple rounds of drone pick-up and delivery (Mulumba et al., 2024).Meng et al. (2023) proposed the DAPDP model, which overcomes the traditional single-visit limitation by simultaneously integrating multi-visit services, bidirectional pick-up and delivery demand, truck capacity constraints, and load-dependent energy optimization.

At the energy coordination level, Zhu et al. (2024) advanced from basic charging to dynamic energy transfer, optimizing energy utilization efficiency. In terms of coverage, Huang et al. (2022) expanded the service network using public transportation, reducing dependence on infrastructure in remote areas. Regarding operational capability, Meng et al. (2023) integrated multi-visit and synchronized pick-up and delivery requirements, enhancing practical applicability in commercial scenarios. As a result, vehicles transform from single-purpose transport units into core hubs for spatiotemporal coordination and resource sharing. They provide systematic support for drones in long-distance delivery, wide-area continuous operations, and high-density last-mile deliveries, fundamentally extending the operational boundaries and economic feasibility of drone deployment.

drone-supported vehicle delivery.

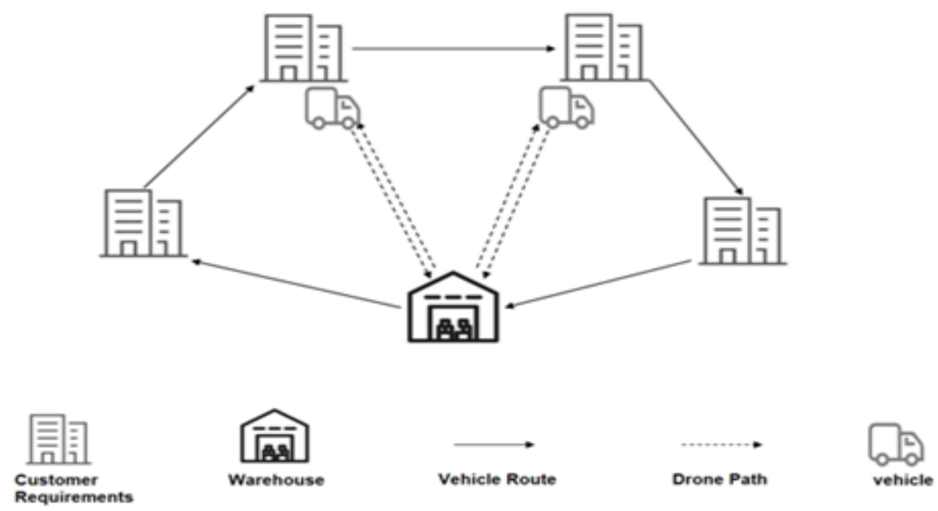

Figure 7 Drone-guaranteed vehicle delivery operation mode diagram

The drone-supported vehicle delivery mode is illustrated in Figure 7. In this mode, vehicles lead the delivery tasks while drones serve as auxiliary tools for cargo replenishment. This mode demonstrates paradigm innovation in key scenarios. In logistics operations, Dayarian et al. (2020) defined it under the comprehensive formulation of the Vehicle Routing Problem with Drone Replenishment (VRPDR). Drones continuously pick up goods from the distribution center to provide real-time replenishment for vehicles enroute, enabling vehicles to exceed their initial load capacity and complete more deliveries within strict time windows. In urban management, Xu et al. (2023) proposed the Vehicle–Drone Collaborative Arc Routing Problem (GVD-ARP) to meet traffic patrol requirements. By leveraging drones to extend monitoring coverage while overcoming endurance constraints, this approach reduces labor costs and improves response speed to emergencies. In emergency scenarios, Gao et al. (2020) developed a spatiotemporal synchronized network integrating drones and mobile charging stations, formally termed the Vehicle Routing Problem with Spatiotemporal Synchronization Network (VRPSN). Coordinated path planning between drones and charging vehicles enhances both equipment utilization and response efficiency in post-disaster search and rescue operations.

The core advancement of such models lies in the flexible scheduling of low-altitude resources. This approach addresses inherent challenges in vehicle delivery, including cargo stock limitations, response delays, and task continuity, ultimately achieving systematic improvements in logistics efficiency, service coverage, and emergency response capability.

Optimization Objectives

The optimization objectives in vehicle–drone collaborative delivery mainly focus on two dimensions: time and cost. Some studies also consider additional factors such as delivery distance, customer satisfaction, and the number of drones.

In terms of time-related optimization objectives, although different studies adopt varying models and constraints, the most common goal remains minimizing total delivery time or the time required to complete delivery tasks. For example, Raj et al. (2020) minimized delivery time by dynamically adjusting drone flight speed. Luo et al. (2021) overcame the limitation of single-flight, single-package delivery and set total task time minimization as the optimization objective. Daknama et al. (2017) focused on minimizing the average delivery time per package. Luo et al. (2017) aimed to minimize drone flight time, while Kitjacharoenchai et al. (2019) sought to reduce the total time for all vehicles to complete tasks and return to the distribution center. A detailed analysis is as follows:

(1) Minimization of Total Delivery Time

The objective function is to minimize the total delivery and waiting time of all vehicles and drones in the system, as shown in Equation (1):

$$T_{sum} = min\left\{\sum_{i,j\in N} t_{ij}\cdot x_{ij} + \sum_{i\in N} S_i + \sum_{i,j\in N} t_{ij}\cdot y_{ij}\right\} \quad (1)$$

x_{ij} represents the delivery time from point i to j; x_{ij} and y_{ij} are binary decision variables (x_{ij} represents the drone path, and y_{ij} represents the vehicle path); S_i denotes the waiting time at node i, calculated as $S_i = |\tau_i^C - \tau_i^D|$ (the time difference between vehicle and drone arrivals).

(2) Minimization of Completion Time

The objective function is to minimize the final time for vehicles and drones to complete all delivery tasks and return to the depot. When drones can return to the depot, the maximum of vehicle and drone return times is taken, as shown in Equation (2). When drones cannot return to the depot, the maximum of the vehicle return time and the retrieval time of the last drone is taken, as shown in Equation (3):

$$T_{finish} = min\left\{max\left\{\tau_{n+1}^C, \tau_{n+1}^D\right\}\right\} \quad (2)$$

$$T_{finish} = min\left\{max\left\{\tau_{n+1}^C, \max_{k\in K}\tau_k^{recovery}\right\}\right\} \quad (3)$$

Besides time, cost minimization is also an important optimization objective. Depending on the components of cost, different studies model cost minimization in various ways. For example, Mulumba et al. (2024) studied drone-assisted pick-up and delivery problems with the goal of reducing logistics costs. Sacramento et al. (2015) demonstrated that a mobile base station mode could reduce logistics costs by up to 48% under optimal conditions. Boccia et al. (2024), focusing on improving customer satisfaction, set operational cost minimization as the optimization objective. However, cost modeling is complex and often influenced by multiple variables. This is particularly evident when nonlinear cost factors, such as fuel consumption, are involved. In practice, it is also difficult to comprehensively identify and quantify all cost components. A detailed analysis is as follows:

(3) Minimization of Variable Cost

The objective function is to minimize the operating cost associated with the delivery routes, as shown in Equation (4):

$$C_{var} = min\left\{\sum_{i,j\in N} c_{ij}\cdot(x_{ij}+y_{ij})+\sum_{i\in N} c_w\cdot S_i\right\} \tag{4}$$

c_{ij} represents the unit distance/time cost for path (i,j), and c_w represents the unit cost of waiting time.

(4) Minimization of Fixed Cost

The objective function is to minimize the resource activation cost, as shown in Equation (5):

$$C_{fix} = min\left\{\sum_{k\in K} f_k\cdot\delta_k+\sum_{w\in W} f_w\cdot\gamma_w\right\} \tag{5}$$

δ_k, γ_w are binary variables (equal to 1 when drone k or vehicle w is used), f_k, f_w represent the fixed activation costs of the corresponding resources.

In addition, some studies have proposed other optimization directions, such as minimizing the total travel distance (Halil et al., 2015; Kim, 2018), minimizing the number of vehicles required (Han et al., 2020), maximizing the number of served customers (Ulmer et al., 2018), maximizing customer satisfaction (Budak et al., 2023; Ren et al., 2023), and minimizing carbon emissions during the delivery process (Peng et al., 2025; Zhu et al., 2024).

Problem Models

In line with the aforementioned optimization objectives, problem models have evolved from basic models to constraint-extended models and joint optimization models, showing a progressive path from expanding spatial degrees of freedom to integrating cross-layer resources.

basic models Basic models focus on overcoming spatial and task constraints. At the spatial level, Masone et al. (2022) proposed an edge launch capability framework, allowing drones to take off and land at any position on the road for the first time, while integrating battery limitations, truck waiting times, and multi-package delivery constraints. This approach removes the restrictions of fixed take-off and landing points on path planning. Salama et al. (2022) further extended this concept with a flexible launch and recovery site model, enabling trucks to launch and recover drones at preselected non-customer locations, fully decoupling take-off and landing operations from customer nodes. At the task capability level, Luo et al. (2021) overturned the "single-flight, single-package" assumption and developed a collaborative path model supporting drones to serve multiple customers in a single flight, significantly improving delivery efficiency. At the system architecture level, Stodola et al. (2024) introduced a mobile base multi-depot path model, allowing trucks to act as drone transfer stations for cross-depot resource scheduling, breaking single-depot operation boundaries. Murray et al. (2020) integrated nonlinear endurance constraints into multi-drone queue scheduling for the first time. Their automated scenario analysis revealed the diminishing marginal returns of adding drones and quantified the risks of misapplying endurance models, providing critical parameter guidance for large-scale systems.

These basic models collectively drive the evolution of collaborative delivery systems from rigid frameworks to flexible spatial paradigms. By supporting take-off and landing at arbitrary locations and operations at non-customer points, they release spatial constraints. Combined with multi-customer service and cross-depot scheduling, they reconstruct task logic. Integrating precise modeling of nonlinear drone endurance, these approaches ultimately establish a foundational framework for dynamic optimization capable of supporting complex real-world scenarios.

Constraint-Extended Models

Constraint-extended models address dynamic and uncertain environments by embedding optimization objectives within more complex constraint systems. Ren et al. (2023) proposed a mobile battery swapping mechanism, simultaneously optimizing electric vehicle routes and drone endurance strategies. This approach achieves dynamic energy coordination under time-varying traffic flows, reducing carbon emissions by 28% and promoting green "last-mile" delivery. Yin et al. (2023) addressed dual uncertainties in demand and travel time in post-disaster scenarios. They used a budgeted uncertainty set to model parameter perturbations and developed an arc-based model minimizing worst-case delay penalties, improving disaster response reliability by over 30%. Meng et al. (2024) interactively modeled multi-visit service, synchronized pick-up and delivery, truck capacity constraints, and load-dependent drone energy consumption for the first time. This filled a gap in complex commercial logistics modeling, reducing operational costs of bidirectional medical supply delivery by 19.7%. Thomas et al. (2024) proposed a joint optimization framework for heterogeneous fleets and dynamic take-off/landing points. By unifying decisions on in-transit take-off and landing operations, vehicle scheduling, and path planning, they achieved a 40-fold improvement in computational efficiency for scenarios involving hundreds of customers.

These extended models better reflect real operational contexts and can maintain time and cost optimization while simultaneously enhancing system resilience and sustainability.

joint optimization models

Joint optimization models achieve deep integration of cross-level decisions, collaboratively optimizing location, routing, and energy within a single framework. Meng et al. (2024) developed a two-level location-routing optimization framework. They improved clustering algorithms to optimize blood distribution center locations and designed intelligent algorithms for coordinated route planning. In complex road networks, this approach simultaneously reduced total cost by 12.65% and delivery time by 37.5%, providing key decision support for emergency medical services. They further proposed a UGV/UAV energy joint optimization model, integrating path planning with intelligent decision-making to systematically balance vehicle movement and flight energy consumption. Cai et al. (2023), in extreme environment patrol tasks, used an energy coordination scheduling mechanism to overcome traditional energy constraints, extending system endurance by 45% and addressing continuous operation bottlenecks in scenarios such as planetary exploration. Li et al. (2020) introduced a mobile satellite architecture, converting trucks into dynamic supply points and establishing a two-level optimization model for supply point positioning and real-time UAV path coordination. This expanded rural delivery coverage by 58% while reducing flight distance by 25.4%. Gao et al. (2023) proposed a three-level nested decision framework (customer assignment-drone scheduling-vehicle routing) for multi-vehicle multi-drone systems. Using mixed-integer programming and hierarchical solution methods, they supported optimization for hundreds of customers, reducing time-window violations in instant medicine delivery to below 4%.

These models enable balancing of timeliness, cost, coverage, and energy consumption under multi-objective optimization, providing systematic solutions for large-scale and complex constraint scenarios.

Solution Algorithms

Solution algorithms can be discussed in three main categories: exact algorithms, heuristic algorithms, and metaheuristic algorithms.

Table 1 Comparison of algorithm characteristics

Type	Representative Method	Advantages	Disadvantages
Precise Algorithm	Branch pricing method, Benders decomposition	Guarantee globally optimal solutions with rigorous theory	Only applicable to small-scale and computation-intensive scenarios.
Heuristic Algorithm	Mileage Saving Method, Neighbourhood Search	Real-time, fast (second-level), easy to handle complex constraints	Unstable quality, prone to local optimization
Metaheuristic Algorithm	Genetic algorithm (GA), Ant colony optimization (ACO)	Strong global search, approaching the optimal solution	High computational cost (hourly), requires experience-based parameter tuning

Exact algorithms

Exact algorithms in vehicle–drone collaborative optimization are primarily based on mathematical programming and decomposition strategies, constructing theoretically complete solution frameworks. Their core lies in guaranteeing optimality through structured search and cutting-plane techniques. Typical methodologies include: branch-and-bound, which solves mixed-integer programming models through systematic enumeration and pruning; branch-and-price, which dynamically handles large-scale path variables using column generation; Benders decomposition, which splits the problem into a vehicle routing master problem and a drone scheduling subproblem, iteratively optimizing via cutting planes; and dynamic programming, which optimizes decision sequences for specific substructures.

Tamke et al. (2021) designed the first branch-and-bound cutting-plane algorithm for the vehicle routing problem with drone replenishment (VRPD), dynamically identifying and adding cutting planes to strengthen linear relaxations. Cavani et al. (2021) proposed a compact MILP model combined with branch-and-cut decomposition, increasing the solvable scale from 10 to 24 customers. Yin et al. (2023) developed an enhanced branch-and-price-and-cut algorithm for time-window constrained collaborative delivery, significantly improving efficiency by combining bounded bidirectional labeling with subset row inequalities. Boccia et al. (2024) built a two-stage robust optimization model for post-disaster dual-echelon delivery, integrating column-and-constraint generation with branch-and-cut to solve worst-case collaborative plans. Faiz et al. (2024) applied column-and-constraint generation to optimize dual-echelon routes under uncertain demand.

Although these algorithms excel in theoretical completeness and small-scale problem solving, their computational complexity remains a practical limitation. Existing exact methods are generally suitable only for small instances. In practice, they are often embedded with heuristic strategies to balance solution efficiency and quality, making them more applicable for benchmark validation or high-precision small-scale scenarios.

heuristic algorithms

In vehicle–drone collaborative optimization, heuristic algorithms rapidly generate feasible solutions through customized rules, providing real-time scheduling capabilities for large-scale dynamic scenarios. Their key features include efficient handling of complex constraints, low parameter dependency, and fast convergence. Typical methods include neighborhood search, smoothed greedy algorithms, and column generation decomposition heuristics, which demonstrate significant solution advantages across diverse scenarios.

For example, Kuo et al. (2022) designed a variable neighborhood search (VNS) algorithm with a novel solution representation for time-window constrained collaborative delivery, efficiently optimizing vehicle-drone joint routes and delivery costs. Mulumba et al. (2024) proposed a Clarke-Wright savings-based heuristic for integrated pick-up and delivery scenarios to minimize operational costs. Shi et al. (2023) developed an end-to-end differentiable framework using stochastic smoothing for sub-model differentiable optimization, combined with a smoothed greedy heuristic to improve mobile charging station routing decisions. Faiz et al. (2020) developed a column generation decomposition heuristic for post-disaster uncertain demand, optimizing dual-level drone rescue route coordination.

Although heuristic algorithms excel in computational efficiency and scenario adaptability, their global search capability is limited. They are prone to local optima and cannot guarantee optimality. Therefore, in practice, they are often used as lightweight solvers for medium-scale problems or combined with metaheuristic algorithms to form hybrid strategies, balancing real-time requirements and solution quality, and supporting robust collaborative decision-making in dynamic environments.

Metaheuristic algorithms

In the field of vehicle–drone collaborative optimization, metaheuristic algorithms use global search mechanisms inspired by natural phenomena, such as population evolution and pheromone transmission, to balance exploration and exploitation in the solution space. They are the preferred approach for large-scale, multi-node, and complex scenarios. Their main advantages include strong generality, flexible integration of problem features (e.g., encoding endurance constraints), guaranteed feasibility of solutions (sacrificing optimality compared with exact algorithms), and superior global search capability compared with heuristic methods. Typical algorithms include ant colony optimization (ACO), genetic algorithms (GA), artificial bee colony (ABC), and their hybrid strategies. Recent research shows three main capabilities: Robustness enhancement via hybrid strategies, Ghaffar et al. (2024) combined simulated annealing with ABC to overcome local optimal stagnation in medical supply delivery; Ming et al. (2019) integrated GA with an adaptive max–min ACO system (GA-AMMAS) to improve route quality under real-time traffic; Konstantinos et al. (2025) nested GA within a robust optimization framework to resist uncertainty disturbances.

Adaptive mechanisms for practical application, Deng et al. (2022) integrated improved K-means with ACO to perform load- and energy-sensitive task–path joint optimization; Stodola et al. (2023) designed an adaptive ACO with node clustering (AACO-NC), enhancing complex scenario performance through dispatch probabilities and local search.

Multi-objective collaborative optimization, Gu et al. (2023) developed a multi-level pheromone mechanism to improve ACO for real-time delivery link optimization; Li et al. (2020) used GA to balance cost and carbon emission in green delivery; Sadok et al. (2024) proposed a distributed GA-based clustering algorithm for coordinated scheduling of vehicles and drones under load and energy constraints.

These algorithms, through bio-inspired simulation and hybrid strategy innovations, establish efficient search paradigms in high-dimensional solution spaces for logistics scheduling, emergency response, and green delivery. They provide scalable technical pathways for ultra-large-scale collaborative optimization.

Table 2 Typical techniques and evolutionary directions of meta-heuristic algorithms

Typical Technology	Authors	Application Scenarios	Areas for Improvement
GA + ACO ACO+Simulated Annealing Genetic Algorithm + Robust Optimization	Ghaffar et al. (2024)	Emergency delivery of medical supplies.	Enhance global search capabilities by introducing perturbation mechanisms through simulated annealing and strengthen solution stability under emergency tasks.
	Ming et al. (2019)	Dynamic route planning under real-time traffic changes	Introducing an adaptive pheromone adjustment mechanism to improve path solution quality and convergence speed in dynamic environments
	Konstantinos et al. (2025)	High uncertainty task scheduling and path reconstruction.	Introducing genetic operators into robust optimization to improve solution feasibility and robustness under demand and traffic uncertainty
Supply Chain Risk Management	Deng et al. (2022)	Multi-vehicle-multi-drone coordinated dispatching.	Utilizing K-means clustering to reduce search scale, introducing load and energy consumption coding to enhance energy efficiency optimization capabilities.
	Stodola et al. (2023)	Large-scale, multi-task, multi-constraint complex path planning.	Combining node clustering and adaptive pheromone updating to improve search efficiency and stability under multiple tasks and complex constraints.
	Gu et al. (2023)	Real-time delivery network optimization.	Balancing the search intensity of different objectives through a multi-level pheromone mechanism to achieve solution set diversity for multi-performance optimization.
Supply Chain Inventory Management	Li et al. (2020)	Green logistics and carbon emission control.	Introducing multi-objective fitness functions into genetic algorithms to optimize the Pareto frontier quality of cost and carbon emissions
	Sadok et al. (2024)	Joint scheduling of vehicles and drones under load-energy consumption coupling.	Embedding genetic clustering into a distributed framework to improve computational efficiency and scalability under large-scale multi-constraint conditions.

Conclusion

This paper synthesizes the development of VDCD across four dimensions: collaborative modes, optimization objectives, problem models, and solution algorithms. Four paradigms—synchronized delivery, parallel delivery, vehicle-supported drone delivery, and drone-supported vehicle delivery—demonstrate distinct operational mechanisms and application scenarios. Research has shifted from single objectives, such as minimizing time and cost, toward multi-dimensional goals that incorporate service quality, sustainability, and carbon reduction. Problem modeling has advanced from basic formulations to joint optimization frameworks, reflecting a growing emphasis on resource integration. Solution methods show a progression from exact algorithms for small-scale tasks to heuristic and metaheuristic approaches for complex environments, with hybrid and distributed optimization emerging as promising trends. For managers, these findings suggest the importance of selecting collaborative modes suited to specific contexts and adopting multi-criteria decision frameworks supported by AI-based tools. For policymakers, the results highlight the need for clear regulations on airspace management, data sharing, and green logistics incentives. Nevertheless, current studies remain limited by reliance on simulations and idealized assumptions, with few empirical validations in real-world settings.

Future Research Agenda for VDCD

Building on the identified challenges of VDCD development, namely adaptation to dynamic environments, green sustainability, cross-level optimization, and large-scale implementation, future research can be advanced across the following key dimensions:

Real-time optimization under dynamic and uncertain environments

Collaborative decision-making frameworks for vehicles and drones should deeply integrate traffic flow, order demand, and weather forecasts with route planning. This enables second-level decision updates, improves service stability during peak periods and unexpected scenarios, and has direct applications in instant delivery and public service distribution.

Full-chain carbon quantification and green optimization strategies

Life-cycle carbon emission models covering energy production, transportation, and charging should be developed, with low-carbon and sustainability goals as core optimization objectives. On this basis, the collaborative effects of drones' zero-emission operation and trucks' new-energy fuel innovations can be studied in task allocation, route planning, and energy supply strategies. Carbon budget or trading constraints can be used to significantly reduce system-wide emissions, promoting standardized and commercial applications of low-carbon collaborative delivery.

Cross-level joint optimization for large-scale logistics networks

For large node scales, diverse task types, and strict real-time requirements, scalable frameworks combining hierarchical partitioning and cloud–edge collaborative computing should be proposed. These frameworks can simultaneously optimize site selection, routing, scheduling, and energy supply, maintaining computational feasibility and reducing scheduling delays in high-dimensional decision spaces.

Policy–technology integrated pathways for large-scale deployment

Simulation-policy collaborative evaluation platforms should be established to assess the safety and economic performance of airspace opening policies, take-off/landing site layouts, and operational modes. This provides quantitative support for hierarchical airspace management and safety certification standards, facilitating the commercialization and large-scale operation of VDCD.

High-reliability safety and fault-tolerance mechanisms

Task migration and redundancy allocation mechanisms should be introduced to enable seamless task takeover in cases of drone failure, communication interruption, or vehicle delay. Blockchain or multi-signature mechanisms can ensure tamper-proof scheduling data, enhancing usability in high-safety scenarios such as medical or emergency material delivery.

In summary, vehicle and drone collaborative delivery represents a vital technological pathway for smart logistics and the low-altitude economy. Future research should emphasize the integration of technology and policy, as well as algorithms and applications, to develop a multi-agent collaborative delivery system that achieves economic efficiency, environmental sustainability, and operational safety. Such efforts will drive the large-scale and sustainable advancement of VDCD within global smart logistics networks.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Park, S., Setiawan, E. B., Abidin, Z., & Ricardianto, P. (2023). The impact of the logistics performance index on global trade volume between the republic of Korea and major GVC reconfiguration participants in ASEAN. *Decision Science Letters, 12*(4), 671-684.

Dorling, K., Heinrichs, J., Messier, G. G., & Magierowski, S. (2017). Vehicle routing problems for drone delivery. *IEEE Transactions on Systems Man Cybernetics-Systems, 47*(1), 70-85.

Joselow, M. (2020). Delivery vehicles increasingly choke cities with pollution. *Scientific American*. Retrieved November 30, 2022.

Rose, C. (2013). Amazon's Jeff Bezos looks to the future. *CBS News*, 1.

Stewart, J. (2014). Google tests drone deliveries in project wing trials. *BBC World Service Radio*.

Bryan, V. (2014). Drone delivery: DHL'parcelcopter'flies to German isle. *Reuters*, 24.

Heath, N. (2015, October). The long-range drone that can keep up with a car and fly for an hour.

Otto, A., Agatz, N.,Campbell, J.,Golden, B. & Pesch, E. (2018). (Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey). *NETWORKS,72*(4),411-458

Rojas Viloria, D., Solano-Charris, E. L.,Munoz-Villamizar, A., & Montoya-Torres, J. R. (2021). (Unmanned aerial vehicles/drones in vehicle routing problems: a literature review). *INTERNATIONAL TRANSACTIONS IN OPERATIONAL RESEARCH,28*(4),1626-1657

Teimoury, E. & Rashid, R. (2024). (A hybrid variable neighborhood search heuristic for the sustainable time-dependent truck-drone routing problem with rendezvous locations). J*OURNAL OF HEURISTICS,30*(1-2),1-41

Gao, W., Luo, J., Zhang, W., Yuan, W., & Liao, Z. (2020). Commanding Cooperative UGV-UAV With Nested Vehicle Routing for Emergency Resource Delivery. *IEEE Access, 8*, 215691-215704.

Maini, P., Sundar, K., Singh, M., Rathinam, S., & Sujit, P. B. (2019). Cooperative Aerial-Ground Vehicle Route Planning With Fuel Constraints for Coverage Applications. *IEEE Transactions on Aerospace and Electronic Systems, 55*(6), 3016-3028.

Gu, R., Liu, Y., & Poon, M. (2023). Dynamic truck-drone routing problem for scheduled deliveries and on-demand pickups with time-related constraints. *Transportation Research Part C-Emerging Technologies, 151*(1).

Yurek, E. E., & Ozmutlu, H. C. (2021). Traveling salesman problem with drone under recharging policy. *Computer Communications, 179*, 35-49.

Edirimanne, R., Fernando, W. M., Nielsen, P., Niles Perera, H., & Thibbotuwawa, A. (2024). Optimizing unmanned aerial vehicle for food delivery through vehicle routing problem: A comparative analysis of three delivery systems. *Applied Computer Science, 20*(1), 85-105.

Ramos, T. R. P., & Vigo, D. (2023). A new hybrid distribution paradigm: Integrating drones in medicines delivery. *Expert Systems with Applications, 234*(1).

Wang, C., Lan, H., Saldanha-da-Gama, F., & Chen, Y. (2021). On Optimizing a Multi-Mode Last-Mile Parcel Delivery System with Vans, Truck and Drone. *Electronics, 10*(20), Article 2510.

Shi, X., Zhai, X., Wang, R., Le, Y., Fu, S., & Liu, N. (2025). Task Planning of Multiple Unmanned Aerial Vehicles Based on Minimum Cost and Maximum Flow. *Sensors, 25*(5), Article 1605.

Nguyen, M. A., Dang, G. T. H., Ha, M. H., & Pham, M. T. (2022). The min-cost parallel drone scheduling vehicle routing problem. *European Journal of Operational Research, 299*(3), 910-930.

Kloster, K., Moeini, M., Vigo, D., & Wendt, O. (2023). The multiple traveling salesman problem in presence of drone- and robot-supported packet stations. *European Journal of Operational Research, 305*(2), 630-643.

Mathew, N., Smith, S. L., & Waslander, S. L. (2015). Planning Paths for Package Delivery in Heterogeneous Multirobot Teams. *IEEE Transactions on Automation Science and Engineering, 12*(4), 1298-1308.

Ropero, F., Munoz, P., & R-Moreno, M. D. (2019). TERRA: A path planning algorithm for cooperative UGV-UAV exploration. *Engineering Applications of Artificial Intelligence, 78*, 260-272.

Huang, H., & Savkin, A. V. (2022). Deployment of Charging Stations for Drone Delivery Assisted by Public Transportation Vehicles. *IEEE Transactions on Intelligent Transportation Systems, 23*(9), 15043-15054.

Zhu, T., Boyles, S. D., & Unnikrishnan, A. (2024). Battery Electric Vehicle Traveling Salesman Problem with Drone. *Networks & Spatial Economics, 24*(1), 49-97.

Meng, S., Guo, X., Li, D., & Liu, G. (2023). The multi-visit drone routing problem for pickup and delivery services. *Transportation Research Part E-Logistics and Transportation Review, 169*.

Mulumba, T., Najy, W., & Diabat, A. (2024). The drone-assisted pickup and delivery problem: An adaptive large neighborhood search metaheuristic. *Computers & Operations Research, 161*.

Dayarian, I., Savelsbergh, M., & Clarke, J. P. (2020). Same-Day Delivery with Drone Resupply. *Transportation Science, 54*(1), 229-249.

Xu, B., Zhao, K., Luo, Q., Wu, G., & Pedrycz, W. (2023). A GV-drone arc routing approach for urban traffic patrol by coordinating a ground vehicle and multiple drones. *Swarm and Evolutionary Computation, 77*.

Raj, R., & Murray, C. (2020). The multiple flying sidekicks traveling salesman problem with variable drone speeds. *Transportation Research Part C-Emerging Technologies, 120*, Article 102813.

Luo, Z., Poon, M., Zhang, Z., Liu, Z., & Lim, A. (2021). The Multi-visit Traveling Salesman Problem with Multi-Drones. *Transportation Research Part C-Emerging Technologies, 128*, Article 103172.

Daknama, R., & Kraus, E. (2017). Vehicle routing with drones. *arXiv.*

Boccia, M., Masone, A., Sforza, A., & Sterle, C. (2021). A column-and-row generation approach for the flying sidekick travelling salesman problem. *Transportation Research Part C-Emerging Technologies, 124*, Article 102913.

Luo, Z., Liu, Z., & Shi, J. (2017). A Two-Echelon Cooperated Routing Problem for a Ground Vehicle and Its Carried Unmanned Aerial Vehicle. *Sensors, 17*(5), Article 1144.

Kitjacharoenchai, P., & Lee, S. (2019). Vehicle Routing Problem with Drones for Last Mile Delivery. *Procedia Manufacturing, 39*, 314-324.

Sacramento, D., Pisinger, D., & Ropke, S. (2019). An adaptive large neighborhood search metaheuristic for the vehicle routing problem with drones. *Transportation Research Part C-Emerging Technologies, 102*, 289-315.

Luo, Q., Wu, G., Ji, B., Wang, L., & Suganthan, P. N. (2022). Hybrid Multi-Objective Optimization Approach with Pareto Local Search for Collaborative Truck-Drone Routing Problems Considering Flexible Time Windows. *IEEE Transactions on Intelligent Transportation Systems, 23*(8), 13011-13025.

Kim, G. (2018). Optimal Vehicle Routing for Parcel Delivery with Considering Two Time Periods. *2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEE IEEM)*, 2019-December, 918-922.

Han, Y. Q., Li, J. Q., Liu, Z., Liu, C., & Tian, J. (2020). Metaheuristic algorithm for solving the multi-objective vehicle routing problem with time window and drones. *International Journal of Advanced Robotic Systems, 17*(2).

Ulmer, M. W., & Thomas, B. W. (2018). Same-day delivery with heterogeneous fleets of drones and vehicles. *Networks, 72*(4), 475-505.

Budak, G., & Chen, X. (2023). A Hybrid Mathematical Model for Flying Sidekick Travelling Salesman Problem with Time Windows. *Operations Research Forum, 4*(4), 1-21.

Ren, X. X., Fan, H. M., Bao, M. X., & Fan, H. (2023). The time-dependent electric vehicle routing problem with drone and synchronized mobile battery swapping. *Advanced Engineering Informatics, 57*(1).

Peng, Y., Ren, Z., Yu, D. Z., & Zhang, Y. (2025). Transportation and carbon emissions costs minimization for time-dependent vehicle routing problem with drones. *Computers & Operations Research, 176*.

Masone, A., Poikonen, S., & Golden, B. L. (2022). The multivisit drone routing problem with edge launches: An iterative approach with discrete and continuous improvements. *Networks, 80*(2), 193-215.

Murray, C. C., & Raj, R. (2020). The multiple flying sidekicks traveling salesman problem: Parcel delivery with multiple drones. *Transportation Research Part C-Emerging Technologies, 110*, 368-398.

Stodola, P., & Kutej, L. (2024). Multi-Depot Vehicle Routing Problem with Drones: Mathematical formulation, solution algorithm and experiments. *Expert Systems with Applications, 241*.

Salama, M. R., & Srinivas, S. (2022). Collaborative truck multi-drone routing and scheduling problem: Package delivery with flexible launch and recovery sites. *Transportation Research Part E-Logistics and Transportation Review, 164*.

Yin, Y., Yang, Y., Yu, Y., Wang, D., & Cheng, T. C. E. (2023). Robust vehicle routing with drones under uncertain demands and truck travel times in humanitarian logistics. *Transportation Research Part B-Methodological, 174*(1).

Thomas, T., Srinivas, S., & Rajendran, C. (2024). Collaborative truck multi-drone delivery system considering drone scheduling and en route operations. *Annals of Operations Research, 339*(1-2), 693-739.

Meng, Z., Yu, K., & Qiu, R. (2024). Location-routing optimization of UAV collaborative blood delivery vehicle distribution on complex roads. *Complex & Intelligent Systems, 10*(6), 8127.

Cai, B., Lu, F., & Zhou, L. (2023). Energy-Aware Routing Algorithm for Mobile Ground-to-Air Charging. *arXiv*.

Gao, J., Zhen, L., & Wang, S. (2023). Multi-trucks-and-drones cooperative pickup and delivery problem. *Transportation Research Part C-Emerging Technologies, 157.*

Faiz, T. I., Vogiatzis, C., Liu, J., & Noor-E-Alam, M. (2024). A robust optimization framework for two-echelon vehicle and UAV routing for post-disaster humanitarian logistics operations. *Networks, 84*(2), 200-219.

Tamke, F., & Buscher, U. (2021). A branch-and-cut algorithm for the vehicle routing problem with drones. *Transportation Research Part B-Methodological, 144*, 174-203.

Cavani, S., Iori, M., & Roberti, R. (2021). Exact methods for the traveling salesman problem with multiple drones. *Transportation Research Part C-Emerging Technologies, 130*, Article 103280.

Boccia, M., Mancuso, A., Masone, A., & Sterle, C. (2024). Exact and heuristic approaches for the Truck-Drone Team Logistics Problem. *Transportation Research Part C-Emerging Technologies, 165*.

Yin, Y., Li, D., Wang, D., Ignatius, J., Cheng, T. C. E., & Wang, S. (2023). A branch-and-price-and-cut algorithm for the truck-based drone delivery routing problem with time windows. *European Journal of Operational Research, 309*(3), 1125-1144.

Kuo, R. J., Lu, S. H., Lai, P. Y., & Mara, S. T. W. (2022). Vehicle routing problem with drones considering time windows. *Expert Systems with Applications, 191*, Article 116264.

Mulumba, T., & Diabat, A. (2024). Optimization of the drone-assisted pickup and delivery problem. *Transportation Research Part E-Logistics and Transportation Review, 181*.

Shi, G., & Tokekar, P. (2023). Decision-Oriented Learning with Differentiable Submodular Maximization for Vehicle Routing Problem. *arXiv*.

Faiz, T. I., Vogiatzis, C., & Noor-E-Alam, M. (2020). Computational Approaches for Solving Two-Echelon Vehicle and UAV Routing Problems for Post-Disaster Humanitarian Operations. *arXiv*.

Ghaffar, M. A., Peng, L., Aslam, M. U., Adeel, M., & Dassari, S. (2024). Vehicle-UAV Integrated Routing Optimization Problem for Emergency Delivery of Medical Supplies. *Electronics, 13(*18), Article 3650.

Deng, X., Guan, M., Ma, Y., Yang, X., & Xiang, T. (2022). Vehicle-Assisted UAV Delivery Scheme Considering Energy Consumption for Instant Delivery. *Sensors, 22*(5), Article 2045.

Li, Y., Yang, W., & Huang, B. (2020). Impact of UAV Delivery on Sustainability and Costs under Traffic Restrictions. *Mathematical Problems in Engineering, 2020*(1).

Stodola, P., & Kutej, L. (2023). Multi-Depot Vehicle Routing Problem with Drones: Mathematical Formulation, Solution Algorithm and Experiments.*SSRN*.

Ming Han,Ya-Bin Wang,Xiang Chen & Xing Zhao. (2019). (A Research on Vehicle and UAV Routing Problem during Distribution Based on IAMMAS). *IOP Conference Series: Materials Science and Engineering,688*(4)

Konstantinos Kouretas & Konstantinos Kepaptsoglou. (2025). (Stochastic Planning of Synergetic Conventional Vehicle and UAV Delivery Operations). Drones,9(5),359-359

Sadok, A., Euchi, J., & Siarry, P. (2024). Vehicle routing with multiple UAVs for the last-mile logistics distribution problem: hybrid distributed optimization. *Annals of Operations Research*, 1-41.

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

Cultural Landscape Field Dynamics and Symbolic Transmutation : A Co-constitutive Analysis of Mount Fuji's Natural Ontology and Cultural Semiosis in Transregional Epistemologies

Cheng Zhang[1*]
Lin Qizhen[1]
Chutimaporn Mhonyai[2]

[1]Putian University, Putian, Fujian Province, China
1133 Xueyuan Middle St, Chengxiang District, Putian, Fujian Province, China
[2]Thai Federation on Logistics
99/126 Moo 16, Bang Kaeo Subdistrict, Bang Phli District, Samut Prakan, Thailand

*Corresponding author, Email: 1244528366@qq.com

Received: Jul 3, 2025 / Revised: Dec 18, 2025 / Accepted: Dec 18, 2025

Abstract

Situated within the theoretical framework of Area Studies, this paper examines the co-constitutive relationship between Mount Fuji's natural significance and cultural identity through the lens of cultural landscape field dynamics, incorporating its conceptual foundations, operational logics, and processes of symbolic reconfiguration. The study identifies a tripartite mechanism through which the Fuji region achieves nature-culture synergies: the sacralization of geological formations (manifested in lava tree mold-based Tainai spiritual practices), the artistic codification of visual representations (epitomized by Katsushika Hokusai's Thirty-Six Views of Mount Fuji), and the socio-religious networks sustained by the Oshi pilgrimage patronage system. Against the backdrop of globalization, Japan's strategic deployment of UNESCO World Heritage inscription protocols, digital heritage conservation technologies, and transregional partnership models has reconfigured Mount Fuji as a polysemic symbol operating simultaneously as a national identity anchor and transnational cultural commodity. This trajectory illustrates a paradigm of symbolic transmutation progressing from natural referent to cultural signifier, culminating in geopolitical signification.

The findings provide critical insights for global heritage governance, particularly in negotiating preservation-utilization tensions, deploying techno-cultural mediation strategies, and institutionalizing cross-border cultural synergies.

Keywords: Mount Fuji; Cultural Landscape Field Dynamics; Symbolic Transmutation; Area Studies; Natural Heritage; Cultural Codification

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

พลวัตเชิงสนามของภูมิทัศน์ทางวัฒนธรรมและการแปรเปลี่ยนเชิงสัญลักษณ์ : การวิเคราะห์เชิงสหประกอบของภววิทยาธรรมชาติและสัญญวิทยาทางวัฒนธรรมของภูเขาไฟฟูจิในญาณวิทยาข้ามภูมิภาค

เฉิง จาง[1*]
หลิน ฉีเจิ้น[1]
ชุติมาพร หมอนใหญ่[2]

[1]มหาวิทยาลัยผู่เถียน เมืองผู่เถียน มณฑลฝูเจี้ยน สาธารณรัฐประชาชนจีน
1133 ถนนเสวียหยวนจง เขตเฉิงเซียง เมืองผู่เถียน มณฑลฝูเจี้ยน สาธารณรัฐประชาชนจีน
[2]สมาพันธ์โลจิสติกส์ไทย
99 / 126 หมู่ที่ 16 ตำบลบางแก้ว อำเภอบางพลี จังหวัดสมุทรปราการ, ประเทศไทย

[*](ผู้ประสานงานเผยแพร่) Corresponding author, Email: 1244528366@qq.com

บทคัดย่อ

ภายใต้กรอบทฤษฎีของการศึกษาภูมิภาค บทความนี้ตรวจสอบความสัมพันธ์เชิงสหประกอบระหว่างความสำคัญทางธรรมชาติและอัตลักษณ์ทางวัฒนธรรมของภูเขาไฟฟูจิ ผ่านมุมมองพลวัตเชิงสนามของภูมิทัศน์ทางวัฒนธรรม โดยบูรณาการรากฐานเชิงแนวคิด กลไกการดำเนินงาน และกระบวนการปรับโครงสร้างเชิงสัญลักษณ์ งานวิจัยนี้ระบุกลไกสามส่วนที่ภูมิภาคฟูจิสร้างการบูรณาการระหว่างธรรมชาติและวัฒนธรรม ได้แก่ (1) การทำให้รูปแบบทางธรณีวิทยามีความศักดิ์สิทธิ์ (ปรากฏในพิธีกรรมทางจิตวิญญาณ Tainai ที่ใช้แม่พิมพ์ต้นไม้จากลาวา) (2) การทำให้การแทนภาพเชิงศิลปะมีระบบ (Thirty-Six Views of Mount Fuji ของคัตสึชิกะ โฮกุไซ) และ(3) เครือข่ายทางสังคม – ศาสนาที่คงอยู่ผ่านระบบอุปถัมภ์การแสวงบุญของ Oshi ท่ามกลางบริบทโลกาภิวัตน์ ญี่ปุ่นใช้กลยุทธ์การขึ้นทะเบียนมรดกโลกขององค์การยูเนสโก (UNESCO) เทคโนโลยีการอนุรักษ์มรดกดิจิทัล และรูปแบบความร่วมมือข้ามภูมิภาค เพื่อปรับโครงสร้างภูเขาไฟฟูจิให้เป็นสัญลักษณ์ที่มีความหมายหลากหลาย (polysemic symbol) ซึ่งทำงานพร้อมกันทั้งในฐานะเสาหลักของอัตลักษณ์ชาติ และสินค้าเชิงวัฒนธรรมข้ามชาติ เส้นทางนี้สะท้อนกระบวนทัศน์ของการแปรเปลี่ยนเชิงสัญลักษณ์ จากการอ้างอิงเชิงธรรมชาติไปสู่การเป็นตัวบ่งชี้เชิงวัฒนธรรม และบรรลุถึงการเป็นสัญญะทางภูมิรัฐศาสตร์

ผลการศึกษานี้ให้ข้อคิดสำคัญต่อการกำกับดูแลมรดกโลก โดยเฉพาะการเจรจาความตึงเครียดระหว่างการอนุรักษ์และการใช้ประโยชน์ การใช้กลยุทธ์การไกล่เกลี่ยเชิงเทคโนโลยีทางวัฒนธรรม และการสถาปนาการบูรณาการทางวัฒนธรรมข้ามพรมแดน

คำสำคัญ: ภูเขาไฟฟูจิ พลวัตเชิงสนามของภูมิทัศน์ทางวัฒนธรรม การศึกษาภูมิภาค มรดกทางธรรมชาติ การทำให้วัฒนธรรมมีระบบ

Introduction

World cultural and natural heritage represents significant achievements in the development of human civilization and the evolution of nature, serving as an essential medium for promoting mutual learning and exchange among diverse civilizations (Xi, 2024). Cultural identity is the deepest form of identity, constituting the root of ethnic unity and the soul of ethnic harmony (Xuexi Qiangguo, 2025) Within the tension between globalization and localization, the natural value of world cultural heritage lies not only in the uniqueness of its geological landscapes but also in its dynamic interplay with local cultural identity.

The cultural cohesion of a cultural landscape field is the hallmark of its existence and the reason why elements form an integrated whole. Where this cohesion dissipates marks the boundary of the cultural landscape field. Within such a field, human actors, motivated by shaping or altering cultural cohesion (e.g., fostering its formation, growth, enrichment, or decline), modify the natural environment in accordance with their own habitus under the influence of institutional and cultural contexts to manifest cultural cohesion. This process constitutes the production of cultural landscape space and is often accompanied by the dissemination of its outcomes through other media forms, such as texts or visuals. The transformed landscape and its associated media are materialized symbols. Conversely, cultural cohesion also directly influences the mental and spiritual dimensions of human actors through these symbols (including both material and immaterial aspects). Social structures mediate this process through relationships among human actors, with those in higher positions dominating the process, controlling more resources, and even leveraging power to influence the actions of others (Liang, Xia, & Du, 2025) Mount Fuji, as both a national symbol of Japan and a UNESCO World Heritage Site, is not only a product of volcanic geological activity but also an assemblage of indigenous religious beliefs, artistic symbols, and social networks, vividly illustrating the complex interplay between natural value and cultural identity.

Symbolic interactionism explores the meaning individuals derive within society, emphasizing that such meaning emerges through mediated interactions with people, objects, and events via symbols. It is a sociological theory that examines human group life by studying the environments and influences of interacting individuals (Mead, 2013) Symbolic reconstruction refers to the re-expression of one symbol's meaning through another. This paper aims to investigate how Mount Fuji, as a regional entity, achieves symbolic reconstruction through the interaction of natural and cultural fields, thereby influencing Japan's cultural identity and national image construction. Particularly from the perspective of area studies, it seeks to explore the implications of this process for heritage conservation and the dissemination of cultural symbols.

Existing research has examined Mount Fuji from multiple dimensions. In geology, scholars have focused on its volcanic activity and geomorphological features, highlighting its scientific value and tourism potential. In cultural studies, most research has addressed aspects such as religion, history, art, and lived experiences. However, treating Mount Fuji as a "multidimensional field" and analyzing it through an integrated framework encompassing geology, culture, society, and technology remains underexplored. Current studies lack systematic analysis of Mount Fuji's role in cultural identity construction and global cultural dynamics, especially from the perspective of area studies. There is an urgent need for theoretical breakthroughs in understanding how the mutual construction of natural value and cultural identity can serve world heritage conservation and cultural symbol dissemination. This constitutes the primary motivation for this study.

The Natural Co-construction of Geology and Culture

Cultural heritage refers to monuments, architectural complexes, and sites of historical, aesthetic, archaeological, scientific, ethnological, or anthropological value. Natural heritage encompasses outstanding physical, biological, and geological formations, habitats of endangered species, and areas of scientific or aesthetic significance (UNESCO, 2000) Culture, while closely intertwined with nature, also stands in opposition to it. There is no culture divorced from nature, for culture is born of nature; nor is there nature untouched by culture, as since the emergence of humanity, no natural state remains unaffected by human influence (Cai, S., 2016). The interaction between humans and nature inevitably constructs cultural identity within a given region, whether consciously or unconsciously

(1) Lava Tree Molds and Taibai Belief: Symbolic Reconstruction in the Interaction of Cultural Landscapes From the perspective of regional and national studies, the lava tree molds of Mount Fuji serve as a prime example of the mutual construction of geological phenomena and cultural beliefs, embodying the process of field interaction and symbolic reconstruction. During the eruption of Mount Fuji in 937 (the 25th year of the JŌhei era), ejected magma enveloped large trees, with several trees fused together within the lava flow, leaving behind hollow tree-shaped molds. The burned-out trunks formed cavities, and these remaining caves, known as "lava tree molds," were metaphorically likened to the female "womb," thereby linking them to Taibai (womb-related) beliefs.

Practitioners of Fuji-kŌ, while ascending the mountain for worship, would circle these hollows to purify themselves - a practice that transformed geological features into sacred ritual spaces, exemplifying field interaction. The caves housed altars to Asama Daigongen, the deified form of Mount Fuji (Konohanasakuya-hime), further cementing the sacred status of lava tree molds within Taibai beliefs. These molds became spatial carriers and fused symbols of natural value and cultural identity, embodying human perceptions and emotions regarding the origins of life, natural forces, and divine worship. This process realized the reconstruction of geological landscapes into cultural symbols (Yamaguchi, 2018)

(2) The Sacred Spring Narrative of Oshino Hakkai: Cultural Transmission in the Interaction of Cultural Landscapes Located in the highland basin of Oshino Village at the northern foot of Mount Fuji in southeastern Yamanashi Prefecture, Oshino Hakkai is a group of springs formed by snowmelt from Mount Fuji filtered through underground lava. The snowmelt, purified by subterranean lava, emerges from eight distinct outlets, creating the unique natural landscape of Oshino Hakkai. Oshino Hakkai is not only a pilgrimage site for Fuji worship but also a place where the guardian deity "Hachidai RyŪŌ" (Eight Great Dragon Kings) is venerated. Ascetic practitioners use the waters of the eight springs to cleanse themselves of worldly dust, viewing it as sacred water that purifies body and mind. This practice highlights the pivotal role of natural landscapes in religious belief, demonstrating field interaction (Yamaguchi, M., 2018)

Designated as a national natural monument, the sacred spring narrative of Oshino Hakkai underscores the centrality of "nature" in religion, culture, and folklore. Through the flow and filtration of its waters, it connects the natural power of Mount Fuji with the local community's belief systems, serving as a vital site where nature and culture interweave and mutually ascribe meaning. It showcases the core role of nature as an objective existence in regional cultural construction, achieving the symbolic reconstruction of geology and culture through field interaction.

Cultural Symbols and the Construction of National Identity

National identity refers to an individual's recognition of a nation's political authority, pride in their citizenship, and emotional attachment to the country. Cultural identity, on the other hand, denotes an individual's identification with their cultural environment and values. Cultural identity serves as the source of cohesion and centripetal force among members of a nation, forming the root of national unity. The two are closely intertwined: cultural identity is the foundation of national identity, while national identity is the ultimate goal of cultural identity. However, cultural identity is not synonymous with national identity. Under the market economy, the diversification of interest groups, along with cultural exchanges and collisions in globalization, has led to a pluralistic cultural landscape. While national identity remains singular, cultural identity can be multifaceted (Wang, J., 2021). From the perspective of regional and national studies, the reproduction of Mount Fuji's artistic symbols fosters cultural diversity, playing a pivotal role in the construction of cultural symbolism and national identity, while also providing opportunities for cross-cultural exchanges that enhance Sino-Japanese friendship.

(1) Reproduction of Artistic Symbols: Mount Fuji's Role in Cultural Symbolism and National Identity Construction as a UNESCO World Heritage Site, Mount Fuji holds profound symbolic significance in the arts. Throughout history, it has been a wellspring of inspiration for artists, and through the reproduction of various artistic forms and symbols, it has continually reinforced cultural identity and strengthened its role in national identity construction.

In traditional art, Katsushika Hokusai's Thirty-Six Views of Mount Fuji stands as a classic ukiyo-e series depicting the mountain, showcasing its diverse landscapes through unique perspectives and techniques. These works have not only been widely celebrated in Japan but have also exerted a global influence, becoming iconic representations of Japanese culture. Additionally, Mount Fuji's majestic image frequently appears in literary works such as tanka and haiku, where poets extol its beauty, further enriching Japan's cultural heritage. For instance, Natsume SŌseki's haiku, "Though ill on the journey, I press on to see autumn's Fuji," (Natsume, S., 2017) conveys the determination to behold Mount Fuji despite adversity. Through concise yet evocative language, it intertwines the mountain's natural splendor with human emotion, deepening its cultural significance, strengthening social bonds among the Japanese people, and reinforcing its role in national identity construction. Continuously reproduced and reinterpreted in cultural contexts, Mount Fuji has become an integral component of Japan's national identity. Further exemplifying its symbolic status, Mount Fuji was featured on the reverse side of the 1,000-yen banknote issued in 2004, and the newly designed 1,000-yen note in 2024 also incorporates Hokusai's Thirty-Six Views of Mount Fuji (Azuma Arare Honpo, 2020). These designs underscore Mount Fuji's role as a cultural symbol, highlighting its importance in Japanese culture and its contribution to national identity construction, serving Japan's political and economic development.

In contemporary cultural symbolism, the reproduction of Mount Fuji's artistic symbols has taken on diverse forms. Beyond traditional paintings and literature, it appears in modern photography, digital art, films, and other media, reinforcing its cultural significance through varied artistic expressions. In 2023, the Shizuoka Fujisan World Heritage Center introduced the "Fujisan VR Theater," offering immersive experiences through 360-degree projections (Yamanashi Prefecture Official Tourism Information, 2024) Moreover, in the Japanese film Rebirth, Mount Fuji's serene ambiance complements the narrative, illustrating its role not only as a natural landmark but also as a vessel for Japanese emotions and memories, reflecting its function in cultural symbolism and national identity construction. The Japanese TV drama Hot Spot, premiering on January 12, 2025, is set in a town at the foot of Mount Fuji, infusing the story with a distinct cultural atmosphere and showcasing the mountain's symbolic importance in Japanese life and culture. These artistic works provide novel experiences while enhancing Mount Fuji's cultural and national resonance in modern society.

Figure 1 Poster of the Japanese drama Hot Spot (Douban Movie, 2024)

Furthermore, Mount Fuji is widely featured in cultural and tourism products such as souvenirs, postcards, stamps, and apparel. These items integrate its artistic symbols into daily life, allowing people to continually engage with its cultural allure, thereby reinforcing its role in national identity construction. Through the reproduction of artistic symbols, Mount Fuji has become not only a quintessential emblem of Japanese culture but also a cornerstone of Japan's national identity, making significant contributions to cultural heritage and national image-building.

Figure 2 Mount Fuji amulet pouch (Shizuoka Tourism Guide, 2025)

Figure 3 Thirty-Six Views of Mount Fuji (Selected), Hokusai's One Fortune (Azuma Arare Honpo, 2020)

(2) The Social Network of the Oshi System: Constructing Faith in Mount Fuji and Social Relations. The oshi system is a vital component of Mount Fuji's religious framework, playing a key role in its cultural symbolism and national identity construction. In regional studies, a "community" refers to a collective bound by high levels of trust among its members (Jiang, Guo, et al., 2019). The oshi system fosters a tight-knit social network, connecting believers, shrines, and clergy to form a community centered on Mount Fuji worship, fostering collective identity and reinforcing Japanese cultural and national identity.

As "prayer masters," oshi provide guidance and services to devotees of Mount Fuji's deities. Affiliated with specific shrines, they offer prayers for Fuji-kŌ adherents, as well as lodging and guidance for pilgrims, serving as lower-ranking clergy (Yamaguchi, 2018), In spreading Mount Fuji's faith, oshi organize religious activities and rituals, attracting numerous pilgrims and tourists, thereby boosting local tourism. For example, during the climbing season, oshi lead worshippers in ascetic rituals (Fuji Guide., 2022) providing lodging and guidance. This not only fulfills religious needs but also strengthens community faith in Mount Fuji, creates employment opportunities, and enhances social welfare, enabling locals to participate in the mountain's cultural legacy. Such practices foster cohesion and belonging, contributing to Japan's social stability and regional economic growth.

Simultaneously, the oshi system facilitates cultural exchange and interaction across regions. Due to its influence, Mount Fuji's faith extends beyond its locale, spreading nationwide and drawing pilgrims and visitors from across Japan. In this process, oshi act as bridges, disseminating Mount Fuji's faith and culture through interactions with diverse groups, thereby promoting cross-regional cultural integration. Such exchanges strengthen regional connections, enable efficient information dissemination, and amplify Mount Fuji's role as a cultural symbol in fostering cultural and national identity.

The Global Discourse Power Struggle over World Heritage

The "Authorized Heritage Discourse" has become one of the principal theoretical tools in Critical Heritage Studies. Samuel points out that diverse social groups can utilize heritage, which serves not only in nation-state building but also in advancing other causes that promote social progress. Heritage is not merely a material entity requiring preservation but also a cultural phenomenon deeply intertwined with national identity, local sentiment cultivation, cultural and memory transmission, and the construction of public identity (Ma & Zhang, 2021), Nationality is shaped by space and is a product of social interaction. Mount Fuji, a World Heritage site, along with its surrounding natural environment, has profoundly interacted with local communities, giving rise to the existing Fuji worship that serves the Japanese nation.

Japan achieved industrialization earlier than other Asian nations, becoming one of the world's most economically developed countries. However, it now faces pressures such as an aging population and industrial hollowing-out, while its comprehensive national power has been surpassed by China, leading to a crisis of national confidence. Although economic revitalization remains necessary, it is not the historic mission; instead, Japan's historic task is to become a major political power. Under these circumstances, the entire Japanese nation harbors a collective drive to re-engage in competition with China, aspiring to earn respect from the international community, including China. (Jiang, Guo, et al., 2019). This is determined by Japan's national conditions. Thus, in this context, the construction and dissemination of Mount Fuji as a cultural symbol are crucial for Japan's urgent desire to consolidate cultural identity, strengthen national cohesion, shape a positive national image, and secure discursive power in global competition.

(1) Cultural Politics in Heritage Nomination Strategies. The nomination process of Mount Fuji as a World Heritage site was a meticulously orchestrated cultural-political campaign by the Japanese government, aimed at enhancing Japan's international cultural influence and national image by inscribing Fuji on the World Heritage List. Japan officially began preparations for Fuji's nomination in 1994. This process not only affirmed the mountain's natural and cultural value but also served as a significant move to showcase Japan's cultural soft power on the global stage (People’s Daily Online, 2013).

Culture and ideology share conceptual overlaps and interact synergistically. Within a specific timeframe, culture serves as the premise and foundation for the formation and development of ideology (Wang, J., 2021). For instance, during the nomination process, the Japanese government emphasized the importance and uniqueness of Mount Fuji as a Japanese cultural symbol. Through various channels, it domestically reinforced the cohesion and centripetal force of the Japanese people as a collective, fostering widespread political and value consensus within society. Internationally, it propagated the value and significance of Fuji's natural-cultural interplay to gain global recognition and support. This nomination strategy reflects the Japanese government's meticulous planning and proactive measures in cultural politics, as well as Mount Fuji's pivotal role in constructing national identity.

The successful inscription of Mount Fuji offers valuable lessons and insights for other countries. First, as Japan's 17th World Cultural Heritage site, its nomination process and success provide a reference for other nations in heritage nomination, particularly in highlighting cultural value, formulating effective strategies, and more. Second, Fuji's inscription has prompted other countries to re-examine and prioritize their own cultural heritage, encouraging more active efforts to explore and preserve national heritage to enhance cultural influence and global image. Furthermore, Fuji's success has fostered international mutual understanding and respect for diverse cultures, contributing positively to the protection and transmission of world heritage. However, post-inscription challenges and countermeasures must also be addressed. On one hand, visitor numbers surged significantly after Fuji's inscription. To mitigate environmental pressures from overtourism, Yamanashi and Shizuoka Prefectures implemented management measures such as trial climbing fees and access controls. On the other hand, as a World Heritage site, Fuji faces the dilemma of development versus preservation. The Japanese government must balance promoting tourism with safeguarding Fuji's cultural and natural value. According to NHK, Fujikawaguchiko Town installed black screens around convenience stores in May 2024 to block views of Fuji, only to remove them on the 15th of the same month (MOJi Dictionary, 2024) This reflects the mixed outcomes of Fuji's successful cultural symbolization, necessitating careful consideration of trade-offs and responsive measures.

(2) International Comparative Perspectives

In contrast, China's Mount Lu was inscribed on the UNESCO World Heritage List in 1996. As the country's first World Cultural Landscape, Mount Lu is revered as the "Sacred Mountain of Humanities" due to its profound history and culture. Its cultural extensions span literature, art, religion, reclusive traditions, as well as historical, political, educational, and urban development dimensions, playing a pivotal role in China's historical and cultural evolution (Chen, S., 2019), In February 2016, President Xi Jinping inspected Jiangxi Province, praising Mount Lu as "the epitome of China's leisurely charm" and emphasizing, "Green ecology is Jiangxi's greatest asset, advantage, and brand. It must be protected well, with efforts to harmonize mountain-water governance and showcase natural beauty, forging a path where economic development and ecological progress complement each other, creating a 'Jiangxi Model' for Beautiful China." (Jiang & Liu, 2016) During the 2025 Qingming holiday, Mount Lu welcomed visitors from Pakistan, Malaysia, and other countries. In 2025, Mount Lu will focus on key tourist demographics, establish overseas platforms, organize international influencer tours, design tailored inbound travel routes, publish inbound travel guides, produce the overseas promotional film Hello! Mount Lu, enhance visitor incentives, and deploy marketing teams to Southeast Asia, Hong Kong, and Macau to achieve annual targets of 2.4 million core scenic area ticket sales and 200,000 inbound visitors (Jiujiang News, 2024) Mount Lu integrates aesthetics and literature, boasting a long history, stunning landscapes, and rich cultural heritage that attracts global tourists. In today's deepening globalization, Mount Lu, as a composite cultural symbol, demonstrates sustained and stable progress in advancing the "creative transformation and innovative development" of Chinese traditional culture, holding immense value in cross-cultural exchange, cultural confidence, and major-country diplomacy. However, the current development model of Mount Lu's cultural tourism remains relatively extensive, lacking coordinated planning, which hinders the rational and effective protection and utilization of its natural and cultural resources (Liu & Ding, 2022) impacting the sustainable development of the scenic area to varying degrees.

Universality resides in particularity, and particularity encompasses universality. Japan's Mount Fuji and China's Mount Lu each possess distinct particularities, yet in an era of emerging technologies and multicultural dynamism, the challenges they face in development are universal. For China, cultural exports have become a vital bridge for dialogue with the world and a key engine for promoting mutual learning among civilizations and building a community with a shared future for humanity. Recently, the State Council's *Several Economic Policies for Promoting High-Quality Cultural Development* proposed to "accelerate the cultivation of internationally competitive cultural export enterprises and facilitate the 'going global' of cultural products and services." In this context, cultural exports are not only a strategic choice for disseminating Chinese culture overseas but also a concrete pathway for civilizational exchange (Xuexi Qiangguo, 2025) Moreover, China's recent visa-free policies for multiple nationalities aim to attract high-quality foreign tourists as ambassadors of Chinese culture, helping to establish and consolidate China's rising image in the new era. For Japan, Mount Lu's earlier inscription offers lessons worth studying. Simultaneously, China's policy measures have diverted tourist resources, creating competitive pressure for Mount Fuji and compelling further development of its cultural symbol and its reconstruction as a political symbol. At its core, the comparison between Mount Lu and Mount Fuji reflects the competition between China and Japan in comprehensive national power. Japan will continue leveraging Mount Fuji as a cultural landscape to bolster national pride domestically and project cultural superiority and influence internationally, striving to regain respect on the global stage.

The World Heritage List itself is an expression of human civilizational achievements, reflecting the extent to which diverse civilizations are recognized and understood globally, and embodying their contemporary value and significance (Lü, 2024), Through international comparative perspectives, we can better grasp the referential significance of Mount Fuji among World Heritage sites and its strategic implications for Japan's nation-state development. This deeper understanding of the interplay between nature and culture, and the mutual reinforcement of cultural identity, not only fosters introspection regarding China's World Heritage but also illuminates the vital importance of cultural diversity and the transmission of human civilization.

Challenges and Responses: Tensions in the Context of Globalization

As noted by the World Heritage Committee, Mount Fuji's cultural value lies in its embodiment of Japanese mountain worship and its representation as a national symbol in numerous artworks, such as ukiyo-e. However, an editorial in Japan's Asahi Shimbun points out that while climbing Mount Fuji has deep-rooted religious significance in Japan, the influx of tourists is gradually eroding its sacredness (Communist Party Member Network, 2013), In other words, human activities have, to some extent, a destructive impact on nature, and as natural values diminish, the cultural identity constructed through interaction with nature also weakens.

(1) Conflict Between Tourism Development and Ecological Conservation

1. Over-Commercialization of the Fuji Five Lakes

The Fuji Five Lakes - from east to west, Lake Yamanaka, Lake Kawaguchi, Lake Saiko, Lake ShŌji, and Lake Motosu - each attract large numbers of visitors with their unique natural landscapes. Lake Yamanaka is known for its "marimo" (algae balls), Lake Kawaguchi for the "Fuji Reflection" phenomenon, and Lake Motosu, the deepest of the five, mesmerizes visitors with its azure waters. However, as key tourist destinations around Mount Fuji, the Five Lakes face challenges from over-commercialization. With the growth of tourism, commercial activities such as hotels, restaurants, and souvenir shops have proliferated, exerting pressure on the local environment and ecosystems. Over-commercialization not only degrades the natural beauty of the lakes but may also lead to cultural homogenization and commodification, diluting their unique cultural and regional characteristics. For instance, some areas prioritize economic gains over environmental conservation, resulting in ecological damage and unsustainable use of tourism resources (Zhang et al., 2018)

2. Ecological Pressure on Aokigahara (Sea of Trees)

Aokigahara, a dense primeval forest spanning approximately 16 km near the Fuji Five Lakes (Yamaguchi, M., 2018) is also under ecological strain due to tourism. The surge in visitors disrupts the forest's ecosystem through trampled vegetation and disturbed wildlife habitats. Additionally, the construction of tourism infrastructure, such as roads and facilities, further negatively impacts the forest's ecology. These activities not only mar the natural scenery but also risk ecosystem degradation and biodiversity loss (Liu, Hu, & Lü, 2024)

(2) Pathways to Reconcile Local Identity and Globalization

1. Digital Empowerment for Heritage Conservation

In addressing the conflict between tourism development and ecological conservation, digital technology offers new solutions for preserving Mount Fuji's natural values. Remote monitoring and management of the mountain's natural heritage can be achieved through satellite remote sensing, drone surveillance, and other digital tools, enabling timely detection and resolution of environmental issues. Furthermore, digital preservation and dissemination of cultural heritage can leverage the influence of overseas short-video platforms (e.g., TikTok, Instagram) and technologies like virtual reality (VR) and augmented reality (AR) to allow visitors to experience Mount Fuji's cultural and natural beauty without harming the environment (Zhang & Zhong, 2019). For example, the "Virtual Fuji Tour" project, conducted primarily online, offers 90-minute sessions for groups of 10 participants via video call. A guide presents curated videos while explaining and answering questions, and participants can also purchase local specialties. This virtual experience has gained popularity among international tourists, particularly younger generations, while minimizing direct environmental impact. Such initiatives not only promote cultural symbolism globally but also garner international recognition, reinforcing both Mount Fuji's image and Japan's cultural identity.

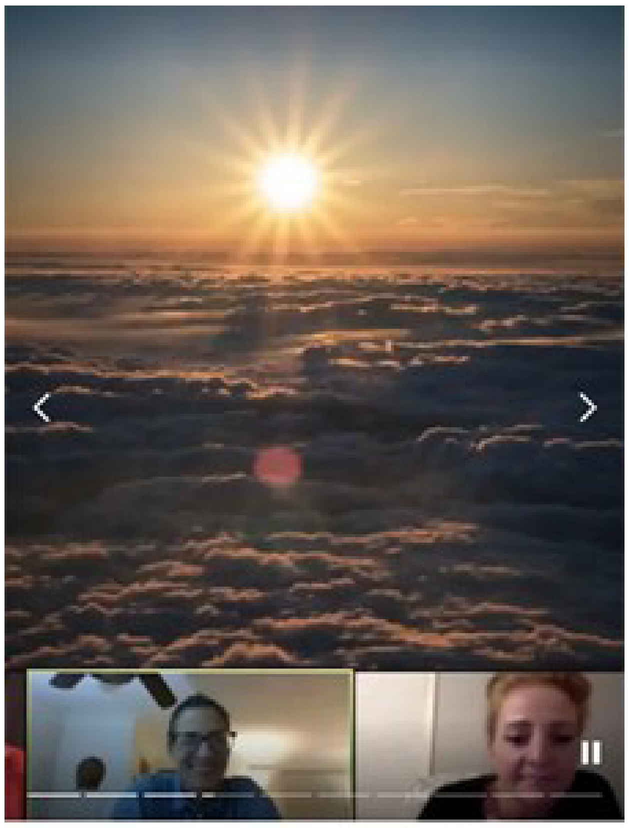

Figure 4 The "Virtual Fuji Tour" Project (Huxiu, 2024)

2. Cross-Regional Collaboration and Glocalization Practices

Cross-regional cooperation is vital for resolving conflicts between tourism development and ecological conservation at Mount Fuji. By establishing collaborative mechanisms, resources can be shared, and complementary strengths leveraged to advance sustainable development. Starting in 2024, Yamanashi Prefecture implemented a climbing toll and visitor cap on the Yoshida Trail. Similarly, Shizuoka Prefecture is considering an "entrance fee" for trails on its side of the mountain to address overcrowding and trail congestion (LetsGoJP! Japan, 2024). Reports suggest existing cooperation between the two prefectures in tourism management, with recommendations for enhanced joint planning to balance tourism and conservation (Zhang, 2022)

Cross-regional collaboration also fosters international exchange, allowing Japan to learn from successful heritage conservation and tourism models worldwide. Geographic proximity reduces interaction costs, while cultural similarities facilitate communication, aiding regional integration. Institutionalized cultural networks promote cultural and economic cooperation, significantly advancing regional unity (Jiang, Guo, et al., 2019)

In the context of glocalization, preserving cultural uniqueness requires building an inclusive international discourse. As a Japanese cultural icon, Mount Fuji must maintain its distinct values while engaging in global dialogue. Initiatives like the "East Asian Mountain Culture Circle" can strengthen collaboration among China, Japan, South Korea, and other East Asian nations in preserving and promoting mountain culture, contributing to regional cultural prosperity (Jin & Xia, 2024) Such cross-regional efforts not only safeguard Mount Fuji's heritage but also foster mutual understanding and friendship, supporting the vision of a shared future for humanity.

Knowledge Production and Disciplinary Reflection in Field Interactions

The natural-cultural co-construction of Mount Fuji demonstrates dynamic bidirectional and phased characteristics. Natural values empower cultural symbols, while cultural symbols reciprocally reinforce natural conservation. In the initial phase, geological landscapes (e.g., lava tree molds, Oshino Hakkai) were imbued with sacred meanings through religious rituals and artistic creations, transforming them into cultural symbols that consolidate regional cultural identity. In the reinforcement phase, artistic reproduction (e.g., ukiyo-e, films) and institutional networks (e.g., the Oshi system) solidified these symbols as carriers of cultural and national identity, elevating them into markers of collective national identity. In the globalization phase, World Heritage inscription strategies and digital technologies reconstructed these symbols, expanding their global dissemination pathways while simultaneously upgrading natural conservation efforts and reinforcing the sacredness and scarcity of the landscape. This process validates the cyclical co-construction logic of "culturalizing nature" and "naturalizing culture," as well as the stratification and tension inherent in the transformation from natural symbols to cultural symbols and further into political symbols.

In field interactions, the reevaluation of natural values necessitates interdisciplinary dialogue and multi-stakeholder collaboration. Research on Mount Fuji's field interactions and symbolic reconstruction reveals that an interdisciplinary perspective enables a more comprehensive understanding of the construction and reinforcement of its natural values and cultural identity, avoiding the trap of binary oppositions between culture and nature. By integrating multidimensional perspectives, diverse stakeholders, and dynamic relationships - and by transcending the knowledge-power structures and cognitive frameworks of traditional disciplines - a global knowledge production system rooted in Chinese perspectives can be established to genuinely facilitate civilizational exchange and dialogue (Chen, 2025)

To this end, three focal points must be emphasized: methodological innovation in area studies, the deepening of glocalization theory, and an Eastern perspective in critical heritage studies. Methodological Innovation in Area Studies. Moving beyond traditional "state-centrism," a tripartite analytical framework of "nature-culture-society" should be constructed, emphasizing interdisciplinary dialogue (e.g., geology + anthropology + communication studies). Deepening Glocalization Theory. Proposing the concept of "elastic boundaries of cultural symbols," which allows for symbolic reinterpretation in globalized contexts (e.g., VR experiences) while preserving core cultural DNA (e.g., the sacredness of Mount Fuji). Eastern Perspective in Critical Heritage Studies. Critiquing the limitations of Western "authorized heritage discourse" and proposing a "symbiotic governance" model for heritage conservation in non-Western contexts, balancing national authority, local communities, and global capital.

Conclusion

Various activities of the Japanese people are deeply influenced by nature. As nature changes, cultural and social activities evolve accordingly. The Japanese not only enjoy the bounty of nature but have also learned to harness it, recognizing its profound significance. Moreover, they exhibit a strong consciousness of nature conservation (Heide & Meng, 2009), Through this research, we observe that Mount Fuji, as a cultural landscape, has undergone a process wherein its natural symbols are first reconstructed as cultural symbols and then further reconstituted as political symbols through interactions between nature and human cultural activities. Its cultural symbols strengthen national cohesion and cultural identity among the Japanese people, while its political symbols serve various facets of Japan's national politics, reinforcing ideological output. This paper elucidates the bidirectional co-construction mechanism between nature and culture - as well as its further reconstruction into political symbols under globalization - through the conceptual lens of "cultural landscape field interactions" and operational principles. Simultaneously, the "symbolic reconstruction" perspective reveals the logic behind the construction of cultural and national identity, reflecting both the uniqueness of Japanese identity formation and the universal contradictions of heritage conservation in the global era. This study not only demonstrates the methodological value of area studies but also offers practical insights for global heritage conservation.

References

Azuma Arare Honpo Co., Ltd. (2020, May 26). Representative works of "Thirty-Six Views of Mount Fuji" released as arare to commemorate the 260th anniversary of Hokusai's birth [Online]. Retrieved March 2, 2024, from https://prtimes.jp/main/html/rd/p/000000003.000058780.html

Cai, S. (2016). Nature and culture: Three levels of the natural–cultural perspective in cognitive science. Academics, (4), 5–24.

Chen, L. (2025, February 17). Promoting the in-depth development of regional and country studies through the "field interaction model" [Online]. Retrieved March 2, 2025, from https://www.sohu.com/a/860051537_100203250

Chen, S. (2019). A general study of Lushan culture. Jiangxi, China: Jiangxi People's Publishing House.

Communist Party Member Network. (2013, June 23). Mount Fuji's successful World Heritage inscription: A dilemma between development and protection [Online]. Retrieved March 22, 2025, from https://news.12371.cn/2013/06/23/ARTI1371941417284489.shtml

Douban Movie. (2024, December 6). Hot topic: Poster [Online]. Retrieved March 2, 2025, from https://movie.douban.com/photos/photo/2916420303/

Fuji Guide. (2022). The ever-changing faith of Mount Fuji [Online]. Retrieved March 2, 2025, from https://fujiguide.pref.yamanashi.jp/hans/guide/12/

Heide, T., & Meng, F. (2009). Nature, culture, and natural heritage: Toward a culture of nature. World Philosophy, (3), 143–155.

Jiang, F., Guo, S., et al. (2019). An introduction to regional and country studies (Rev. ed.). Beijing, China: Higher Education Press.

Jiang, F., Guo, S., et al. (2019). An introduction to regional and country studies (Rev. ed., p. 21). Beijing, China: Higher Education Press.

Jiang, Z., & Liu, J. (2016, August 23). Reaching a new peak in ecological civilization construction: Exploration and practice of Jiangxi's green rise. Jiangxi Daily.

Jiujiang News. (2024, April 8). Many foreign tourists favor visiting Mount Lushan during the Qingming holiday [Online]. Retrieved April 8, 2025, from https://www.jjxw.cn/article/2025/04/08/571632.html

Jin, Z., & Xia, Y. (2024, September 21). A decade of discourse on cultural capitals: Resonance paths and effects of the East Asian cultural community [Online]. Retrieved March 2, 2025, from https://www.163.com/dy/article/HEBOQ4E905505AV6.html

Liang, Z., Xia, H., & Du, Y. (2025). Identification and interpretation of cultural landscape fields from the perspective of holistic conservation. Landscape Architecture, 1–22. Retrieved March 22, 2025, from http://kns.cnki.net/kcms/detail/11.5366.s.20250311.1700.002.html

LetsGoJP! Japan. (2024, December 16). Mount Fuji climbing fees doubled! From 2025, Shizuoka Prefecture charges 4,000 yen, while Yamanashi has not yet announced adjustments [Online]. Retrieved March 2, 2025, from https://www.letsgojp.cn/archives/719476/

Liu, H., Hu, J., & Lü, L. (2024). Evolution and formation mechanisms of multi-actor conflicts in ecotourism destinations based on actor-network theory: A case study of Shennongjia, Hubei Province. Economic Geography, 44(7), 214–222. https://doi.org/10.15957/j.cnki.jjdl.2024.07.022

Liu, Y., & Ding, F. (2022). Sustainable tourism pathways of World Heritage sites from the perspective of cultural landscape value: A case study of the Greater Lushan cultural tourism circle master plan. Ideal Space, (2), 38–41.

Lü, Z. (2024, September 26). China's World Heritage protection from the perspective of the Global Civilization Initiative [Online]. Retrieved March 2, 2025, from https://www.tsinghua.edu.cn/info/1662/114169.htm

Ma, Q., & Zhang, Y. (2021). Heritage and power: Perspectives on the concept of "authorized heritage discourse." Journal of Cultural Heritage Studies, (3), 104–110.

Mead, G. H. (2013). Mind, self, and society (G. H. Huo, Trans.). Beijing, China: Beijing United Publishing Company. (Original work published in English)

MOJi Dictionary. (2024, August 26). Unethical behavior is unacceptable! The Mount Fuji controversy finally comes to an end after three months [Online]. Retrieved March 22, 2025, from https://m.mojidict.com/mojiread/article/6L2X4xCRdD

Natsume, S. (2017, October 5). Mitsutsu yuke tabi ni yamu tomo aki no Fuji [Online]. Retrieved March 2, 2024, from https://idea1616.com/fujisan-haiku/

People's Daily Online. (2013, June 25). After Mount Fuji's World Heritage inscription, a climbing fee is proposed while local authorities promote distant-view tourism [Online]. Retrieved March 2, 2025, from http://culture.people.com.cn/n/2013/0625/c172318-21961563.html

Shizuoka Tourism Guide. (2025, March 2). Mount Fuji souvenirs: 12 recommended commemorative goods and gifts [Online]. Retrieved from https://kayoinshizuoka.com/fujisangoods/

UNESCO. (2000). Mission statement of the World Heritage Convention (Published May 2000; revised June 1, 2000).

Wang, J. (2021). A study on national identity education among university students from the perspective of cultural identity (Doctoral dissertation). Nanjing University of Aeronautics and Astronautics, China. https://doi.org/10.27239/d.cnki.gnhhu.2021.001956

Xuexi Qiangguo. (2025, March 17). Culture going global: An important engine for promoting civilizational exchange and mutual learning and building a community with a shared future for mankind [Online]. Retrieved March 22, 2025, from https://www.xuexi.cn/lgpage/detail/index.html?id= 16366359880482119646&item_id=16366359880482119646

Xuexi Qiangguo. (2025, March 21). Xuexi Qiangguo platform [Online]. Retrieved from https://www.xuexi.cn/ lgpage/detail/index.html?id=12632315697280415941&item_id=12632315697280415941

Xi, J. (2024, August 6). General Secretary Xi Jinping made important instructions on strengthening the protection, inheritance, and utilization of cultural and natural heritage [Online]. Retrieved from https://www.xuexi.cn/ lgpage/detail/index.html?id=10074083907600832924&item_id=10074083907600832924

Yamaguchi, M. (2018). A reader on Japanese tourism culture (X. Li, Trans.). Beijing, China: The Commercial Press.

Yamanashi Prefecture Official Tourism Information. (2024, October 15). Mt. Fuji Museum [Online]. Retrieved March 2, 2024, from https://www.yamanashi-kankou.jp/kankou/spot/p1_4363.html

Zhang, C. (2022). A 50-year review and outlook on the relationship between World Heritage protection and tourism development. Chinese Cultural Heritage, (5), 38–42.

Zhang, S., Liu, J., Zhu, H., et al. (2018). Progress and implications of international ecotourism research. Progress in Geography, 37(9), 1201–1215.

Zhang, X., & Zhong, L. (2019). Research progress in tourism ecology. Acta Ecologica Sinica, 39(24), 9396–9407.

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

Research on the Impact of "Artificial Intelligence" on Economy and Employment under the Background of Low Birth Rate

Changwei Yang[1*]
Supachree Suphariyagul[2]

[1*]Zhejiang Dongfang Polytechnic
433, Jinhai 3rd Avenue, Wenzhou Economic & Technological Development Zone, Zhejiang Province, China
[2]Independent Researcher, Bangkok, Thailand

*Corresponding author, Email: 369349236@qq.com

Received: Sep 11, 2025 / Revised: Dec 18, 2025 / Accepted: Dec 18, 2025

Abstract

The combined effect of China's aging population and artificial intelligence presents both challenges and opportunities.AI has injected new impetus into the economy by filling the labor gap and driving industrial upgrading. At the same time, the employment market needs to undergo structural adjustments through skills transformation and policy support. In the future, it will be necessary to combine technological innovation to build a "human-machine collaboration" model to cope with the profound impact of demographic structural changes.

Keywords: Background of the low birth rate, Artificial intelligence, Economy and employment

SUPPLY CHAIN AND SUSTAINABILITY RESEARCH: SCSR
VOL.4, NO.2; JUL. – DEC. ; 2025, ISSN 2822-0412 (Online)

ผลกระทบของปัญญาประดิษฐ์ต่อเศรษฐกิจและการจ้างงานบนพื้นฐานอัตราการเกิดต่ำ

หยาง ฉางเว่ย[1*]
สุพัชรี สุปริยกุล[2]

[1*]วิทยาลัยเทคนิคตงฟาง มณฑลเจ้อเจียง เมืองเวินโจว สาธารณรัฐประชาชนจีน
433 ถนนจินไห่ สายที่ 3 เขตพัฒนาเศรษฐกิจและเทคโนโลยีเหวินโจว
มณฑลเจ้อเจียง สาธารณรัฐประชาชนจีน
[2]นักวิจัยอิสระ

*(ผู้ประสานงานเผยแพร่) Corresponding author, Email: 369349236@qq.com

บทคัดย่อ

ประชากรสูงวัยของจีนร่วมกับปัญญาประดิษฐ์ (AI) นำมาซึ่งทั้งความท้าทายและโอกาส AI ได้ฉีดกระตุ้นเศรษฐกิจด้วยการเติมเต็มช่องว่างแรงงานและขับเคลื่อนการอัพเกรดอุตสาหกรรม ในขณะเดียวกัน ตลาดการจ้างงานจำเป็นต้องปรับโครงสร้างผ่านการเปลี่ยนแปลงทักษะและการสนับสนุนนโยบาย ในอนาคต จำเป็นต้องผสานนวัตกรรมทางเทคโนโลยีเพื่อสร้างแบบจำลอง "การทำงานร่วมกันระหว่างมนุษย์และเครื่องจักร" เพื่อรับมือกับผลกระทบลึกซึ้งจากโครงสร้างประชากรที่เปลี่ยนแปลงไป

คำสำคัญ: พื้นหลังอัตราการเกิดต่ำ ปัญญาประดิษฐ์ เศรษฐกิจและการจ้างงาน

Introduction

Against the backdrop of the rapid development of artificial intelligence technology and the low birth rate, The impact of AI on the economy and employment is complex and multifaceted. Low fertility leads to an imbalance in the demographic structure, with a reduction in the labor force and a contraction in consumer demand, posing a long-term challenge to the social economy. By the end of 2023, the total population of the country was 1.40967 billion, and The number of births in the year was 9.02 million (Wang, 2024). While AI is the core technology of the Fourth Industrial Revolution, Its development is both an important tool to address the aging issue and may potentially exacerbate structural issues such as labor displacement and childbirth support.

AI can replace repetitive, low-skilled jobs in manufacturing, logistics, and other fields, alleviating the labor shortage. With the help of smart parenting assistance systems, personalized medical services, and psychological intervention, Alleviate family child-rearing pressure, indirectly enhance the willingness to have children. The thesis is based on economic impact, employment structure change and policy coping.

Alleviate the pressure of low fertility to drive innovation Impact on the economy

AI plays an important role in addressing the economic challenges of low fertility against the backdrop of the low fertility rate.

AI can supplement labor force to improve production efficiency

Low fertility has led to a continuous shrinkage of the working-age population; AI is replacing repetitive, low-skilled jobs through robots and automation. Compensate for the labor shortage caused by the low birth rate. Industrial robots can operate continuously and with high precision, and their long-term operating cost is lower than that of human labor. Meanwhile, AI optimizes production processes, driving the transformation of manufacturing towards intelligence and enhancing total factor productivity. In 2023, the share of China's digital economy in GDP reached 42.8 percent and contributed to 66.45% of GDP growth; the digital economy effectively supported stable economic growth (Wang Zhiqin, 2024). By March 2024, the number of AI enterprises had exceeded 4,500.714 large models have completed the filing of generative AI services. China’s core AI industry reached a scale of 578.4 billion yuan in 2023 (Pei Wei, 2024), become a new driving force for economic growth. QYResearch Research shows that, the global generative AI market size is expected to be approximately $33.29 billion in 2024.Expected to reach $214.64 billion in 2031; CAGR of 32.6% between 2025 and 2031 (QYResearch Survey, 2025). On January 16, 2024, world business leaders gathered in Davos, PwC unveils survey: A quarter of the world's chief executives predict that the deployment of generative AI will lead to at least 5% job cuts this year. (Golden Deer, 2024), Core scenarios for AI to supplement the labor force and improve production efficiency (see Table 1).

Table 1. Core scenarios for AI to supplement the labor force and improve production efficiency

AI technology	Labor force supplement method	Efficiency improvement dimension
Automated process	Replace repetitive labor (assembly, quality inspection);	Production speed; error rate reduction
Intelligent prediction and scheduling	Optimize production plans, inventory management	Resource utilization rate; delivery cycle
Data analysis and decision-making	Auxiliary management decision-making (supply chain optimization)	Decision-making speed; market responsiveness
Smart collaboration tools	Enhance human capabilities (training, remote collaboration)	Employee skills; cross-departmental collaboration efficiency

AI's boost to production efficiency is revolutionary; Its successful application requires multi-party synergy at the enterprise level, policy level, and individual level. In this case, companies invest in AI infrastructure, driving the transformation of employee skills. Policies to improve the lifelong education system, strengthen vocational training, and formulate AI ethical regulations. Individual workers need to actively learn data analysis or human-machine collaboration management. Adapt to technological change. Master the "AI Major" composite skills, systematically improve productivity by replacing repetitive labor, enhancing human decision-making, and creating new positions. Supplementary labor force to improve production efficiency technology support system (see Figure 1).

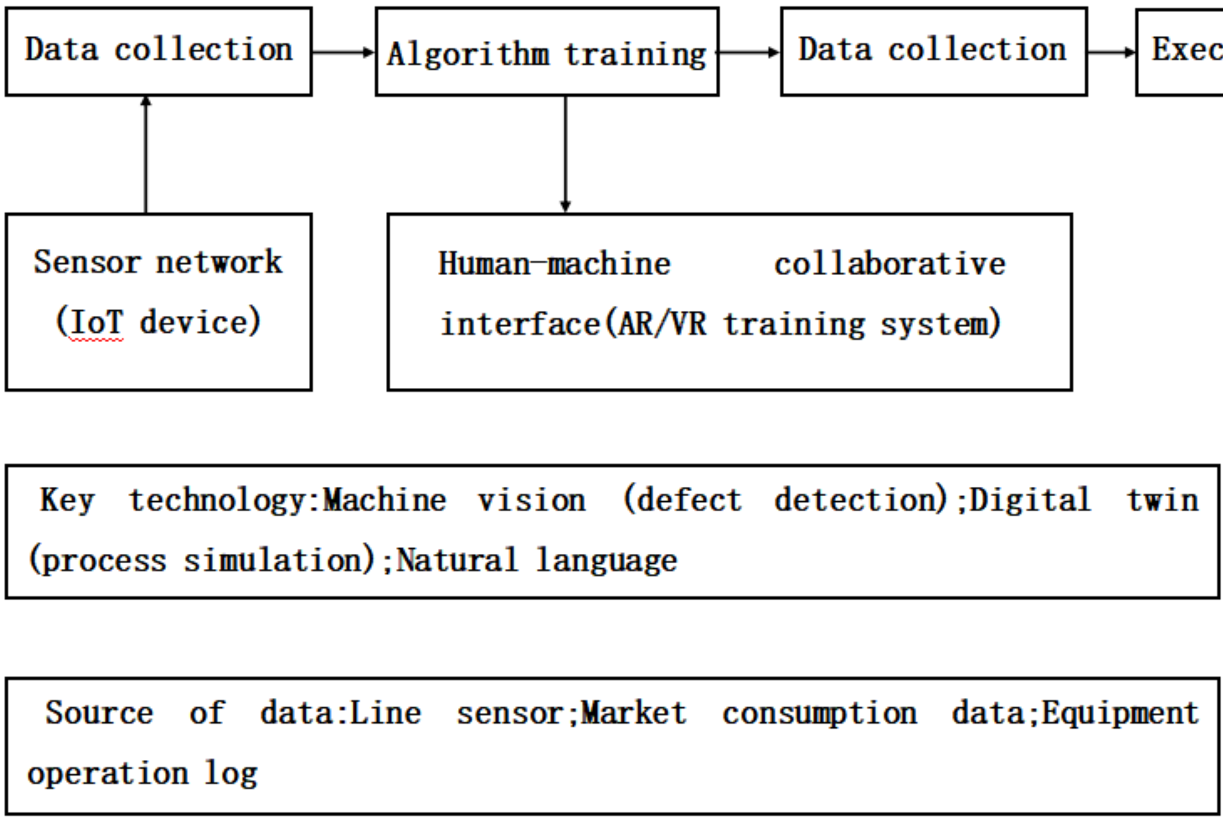

Figure 1 AI Supplementing Labor Force to Improve Production Efficiency Technical Support System

AI can promote consumption upgrade and industrial transformation

AI accelerates the structural transformation of the industry towards a technology-intensive one; New energy, biomedicine and other emerging industries, as well as brain-computer interface, quantum information and other industries of the future, are highly dependent on AI, and have become new driving forces for economic growth.

1) Intelligent upgrade of consumption scenarios Smart technology reconstructs the "people, goods, and place" relationship, and efficiency is continuously improving. Federal Reserve Governor Cook noted that, AI-driven improvements in productivity can reduce business costs, driving profit growth and, in turn, wage increases (Cook, 2025), To further promote consumption. Smart home combines user preferences to generate outfit suggestions and integrates with e-commerce to push discount information, forming a closed loop of smart home and personalized service demand and supply. The digital transformation of retail and manufacturing has led to JD's digital human live streaming service brand exceeding 5,000, Driving GMV to exceed 10 billion (He Chang, 2024).

All-element cultural tourism and commercial services are launched online, promoting the upgrading of cultural tourism consumption. Eat, live, travel, play, shop, and enjoy" digital guide; AR scenic area integration of virtual and real, restoring the historical style of architecture, Combining VR device panoramic immersive experience, attracting global tourists.

2) Core driving force of industrial transformation Artificial intelligence, as the core industry in the new generation of information technology industry, is the core driving force of the fourth industrial revolution, It is supplementing labor, optimizing production processes and reshaping industrial structures, significantly boosting

global productivity. Low fertility is forcing the transformation of the industrial structure to a technology-intensive one.AI empowers smart manufacturing, smart agriculture and other fields. Promote the upgrading of traditional industries, drive emerging industries such as smart medical, autonomous driving and intelligent transformation of traditional industries, Lead the economic structure to upgrade to a technology-intensive one. The global industrial chain is accelerating restructuring, labor-intensive industries are shifting to Southeast Asia, and China's AI guarantees the competitiveness of high-end manufacturing.AI is empowering consumption upgrade, industrial transformation and global pattern restructuring with deep technology and scenario innovation. Currently, the industry is showing a trend towards customization, AI applications are shifting from general scenarios to vertical fields such as medical imaging diagnosis and industrial quality inspection. The main performance is as follows:

Production process reconstruction.AI algorithm optimizes the entire manufacturing chain, AI drug R&D technology innovation success rate, efficiency improvement. According to statistics, enterprises adopting predictive maintenance can reduce equipment downtime by 30%-50% and maintenance costs by 20%-40%, Its core lies in achieving fault prediction through data models (Chen, 2020)

Service model innovation. Harvard Medical School has joined hands with top research institutions such as Stanford University and Brigham and Women's Hospital. A revolutionary research result was published in the journal Nature - CHIEF, a brand new AI pathology model. The model was able to achieve an accuracy of nearly 94% when diagnosing 19 types of cancer. It provides unprecedented efficient tools for the diagnosis and prognosis prediction of cancer. Signifying the advent of a new era in the field of medical diagnosis (Wang et al., 2024)

New business format incubation. The main forum of the 2024 Digital Technology Ecology Conference was released. China has initially built a rather comprehensive industrial system for artificial intelligence, The core industry of AI has a scale of nearly 600 billion, The number of enterprises in the upstream and downstream industrial chains exceeds 4,700, covering various related links such as chips, computing power, data, platforms and applications (Guo Qian, 2024). New categories such as smart cars and humanoid robots are speeding up commercialization.

AI is the core driving force for industrial transformation, including the synergistic progress of technology, data, policy, market and other dimensions. Algorithm breakthroughs need to match data governance capabilities, and policies such as investment in computing power infrastructure provide a foundation for technology implementation. AI “Technological breakthrough ⟶ Data activation ⟶ Efficiency revolution ⟶ Policy protection ⟶ Industry restructuring ⟶ Ecological win-win” chain, become the key support to drive the transformation of the industry.

3) Policy and environmental support National strategic layout, carry out "AI " action, promote "AI consumption" into the "Action Plan for Boosting Consumption" (Zhu Lingzhen, 2025).China's first AI data training base and Beijing's largest public computing power platform have been put into operation with the strongest computing power facilities to train the "most brain (Cao, 2024).Large model parameters break through the level of 100 billion, and the Chinese understanding ability reaches the level of human experts. But there are technical breakthroughs and challenges such as data islands, computing power gaps, and ethical risks. Pay attention to the ethical construction of human-machine collaboration and the democratization of AI for SMEs, so as to achieve a balance between technological dividends and social. With technological breakthroughs such as multi-modal

interaction and embodied intelligence, AI will drive consumption from "functional satisfaction" to "emotional resonance" and industry to "flexible manufacturing ecological service".

AI has optimized resource allocation and social services

Artificial intelligence, through data-driven decision-making and intelligent scheduling systems, is restructuring resource allocation models and reshaping the form of social services, Its impact has permeated the entire production, circulation, and consumption chains, as well as various fields of social governance.

1) Resource optimization from experience to intelligence Labor reallocation under precise matching of industrial factors.AI completes intelligent matching of talents and positions through the analysis of skill map and job requirements.AI prediction models are gradually becoming an important means for enterprises to improve their financial management level and enhance their market competitiveness. It can not only improve the efficiency and accuracy of budgeting, but also help enterprises better respond to market changes and make more scientific and reasonable strategic decisions.AI remote sensing system for three-dimensional modeling and intelligent management of urban land use, land planning approval cycle is shortened, and utilization rate is improved.

2) From inclusive to precise service improvement Dynamic allocation of medical resources, precision public services.AI triage system analyzes data from thousands of hospitals in real time, Effectively compress emergency patients' waiting time. Learning platforms through knowledge graph analysis, Adaptive personalized educational services, Improvement of learning efficiency for rural students. Urban safety early warning, Social governance intelligent innovation such as community service, Service demand matching degree improvement.

3) AI integration technology and its iterative upgrade Multimodal technology fusion medical image analysis system, integrating multi-source data, and improving diagnostic accuracy. Smart agriculture system integrates satellite remote sensing and soil sensor data, improving the accuracy of irrigation decision-making. Innovation of human-machine collaborative mechanism. The AI-assisted decision-making system in the Citizen Service Center has reduced the case time. The intelligent system of the court automatically parses legal documents, which shortens the case trial cycle.

With the in-depth implementation of the "New Generation Artificial Intelligence Development Plan", AI will bring huge social and economic value to the improvement of resource allocation efficiency and the inclusive coverage of social services.

The impact of social structural transformation on the employment market

What AI brings is not simply the replacement of jobs, but a reconfiguration of the factors of production.

1. AI era job displacement and new career creation AI and big data industries provide more employment opportunities for young people. AI’s reshaping of the job market presents a dual effect of "substitution and creation”. Its essence is to promote the leap of labor structure to high-value fields.

1) Job replacement under the penetration of technology. The standard jobs in manufacturing, services, and finance are dying out at an accelerating pace. Positions such as legal document drafting and entry-level data analysis face the risk of replacement. The standard teaching positions in the education field are under attack, and AI teachers can generate personalized learning paths based on students' wrong answers. Regional and industrial differences are significant. The manufacturing clusters in the Pearl River Delta and the Yangtze River Delta face

the greatest pressure of substitution. The high value-added industries such as finance and medical care coexist with "substitution and upgrading".

2) New occupations in the ecology technology. Emerging strategic positions become human-machine collaborative positions.AI trainers who are responsible for data annotation and model optimization, prompt word engineers who enhance the quality of AI output through optimized instructions, AI ethical advisors who craft algorithmic moral codes become tech-supportive positions. Top global companies are increasing dedicated positions to address AI ethical risks.AI medical analyst combining clinical experience with AI diagnosis results; system engineer overseeing the intelligent manufacturing of industrial robots, The positions of industrial 3D large model, 3D intelligent architect, etc. have emerged as the times require.

3) New paradigm for human-machine collaboration First, the new paradigm of individual capability upgrade path. Reconstruct from single skill to "AI tool application domain expertise" compound skill transformation. Engaged in lifelong amateur learning through AI education platforms, focusing on strengthening creativity and critical thinking. Second, a new paradigm for policy safeguard mechanisms. Cover retraining and social security pilot projects in the fields of intelligent manufacturing, digital marketing, etc.

AI-driven skill upgrade and new transformation of education

1) Workers need to move to creative, high-skills areas. The importance of "human-specific skills" such as critical thinking and interpersonal communication is highlighted. The education system needs to incorporate AI technology training and a lifelong learning mechanism.AI-driven skills transformation and education transformation are forming a new pattern of mutual reinforcement. Its core is to reconstruct the goals of talent training, reshape the form of education, and recreate the path of career development.

2) Education shifts from "transmission of knowledge" to "ability building". The AI-induced transformation of education represents a fundamental innovation in the way human civilization heritage is passed down. It shifts from "standardized training" to "personalized empowerment," with the ultimate goal of unlocking human potential. The direction of reform in the education system revolves around restructuring university curricula to include courses such as AI ethics and human-computer interaction., and the deepening of industry-education integration in various aspects.

AI to promote gender equality and flexible employment

AI-powered new models such as telecommuting and the platform economy provide flexible work opportunities, enabling women to balance their careers and families.

1) Technology empowerment breaks the employment circle AI replaces physical labor, releasing women's potential. Automation in manufacturing has liberated assembly line workers, with women turning to high-value-added positions such as data analysis and quality control.

The proportion of female practitioners has significantly increased. In the logistics field, robots have replaced sorting work, giving birth to new positions such as intelligent warehouse dispatchers. Women use AI-assisted tools to boost efficiency in making short videos.

2) More opportunities for women to find employment Technological advances become accelerators of gender equality. Flexible employment breaks the limits of time and space, gender equality breaks the boundaries

of cognition, Technological innovation and institutional reform reshape the new form of culture. Not gender but capability as the measure of value, Not physiological differences but creativity define employment possibility. The proportion of women in AI trainer positions is increasing. Metaverse scene designers, engineers in emotional computing, and other cutting-edge professions are seeing a surge in female practitioners. The gender distribution of emerging professions has been optimized.

3) Reshaping the elasticity characteristics of employment AI has reshaped the elasticity characteristics of the employment market and promoted the process of gender employment equality through technological innovation and industrial restructuring. Forming a virtuous cycle of "efficiency improvement; opportunity expansion; fairness guarantee" in terms of technological empowerment, opportunity restructuring and institutional innovation.

Constructing an economic and employment environment for human-machine collaboration

Building an economic and employment environment for human-machine collaboration, It is necessary to systematically promote from the aspects of technical base, institutional design, governance model, and educational support. Constructing a logical framework for the economy and employment of human-machine collaboration (see Figure 2) This framework emphasizes the interconnection of technology, institutions, capabilities, and international collaboration. Through the progressive path of “Infrastructure as a foundation– Institutional innovation as the safeguard – talent capability empowerment – Global ecological co-construction” Progressive path Realize the sustainable development of human-computer collaborative society.

Constructing a technical support system for human-computer symbiosis

The government has increased its investment in the AI field, attracting talent through tax incentives, scholarships, and other measures. Such as: China plans to exceed 1 trillion yuan in core AI industry scale by 2030, driving related industries by 10 trilliony (Qi Yidong, 2020).

1) Smart infrastructure upgrade Deploy quantum computing nodes and edge computing gateways to achieve data processing upgrade. Shenzhen has built more than 3,000 5G AI edge computing nodes, supporting real-time decision-making efficiency improvement of factories[14.Build a distributed data lake, integrate government affairs, medical, transportation and other fields of data, and achieve cross-domain collaboration through federated learning.

2) Innovative human-computer interaction technology Develop a multimodal interactive system integrating speech, gesture, brain-computer interface and other technologies, Building a digital twin city. The concept of "Digital

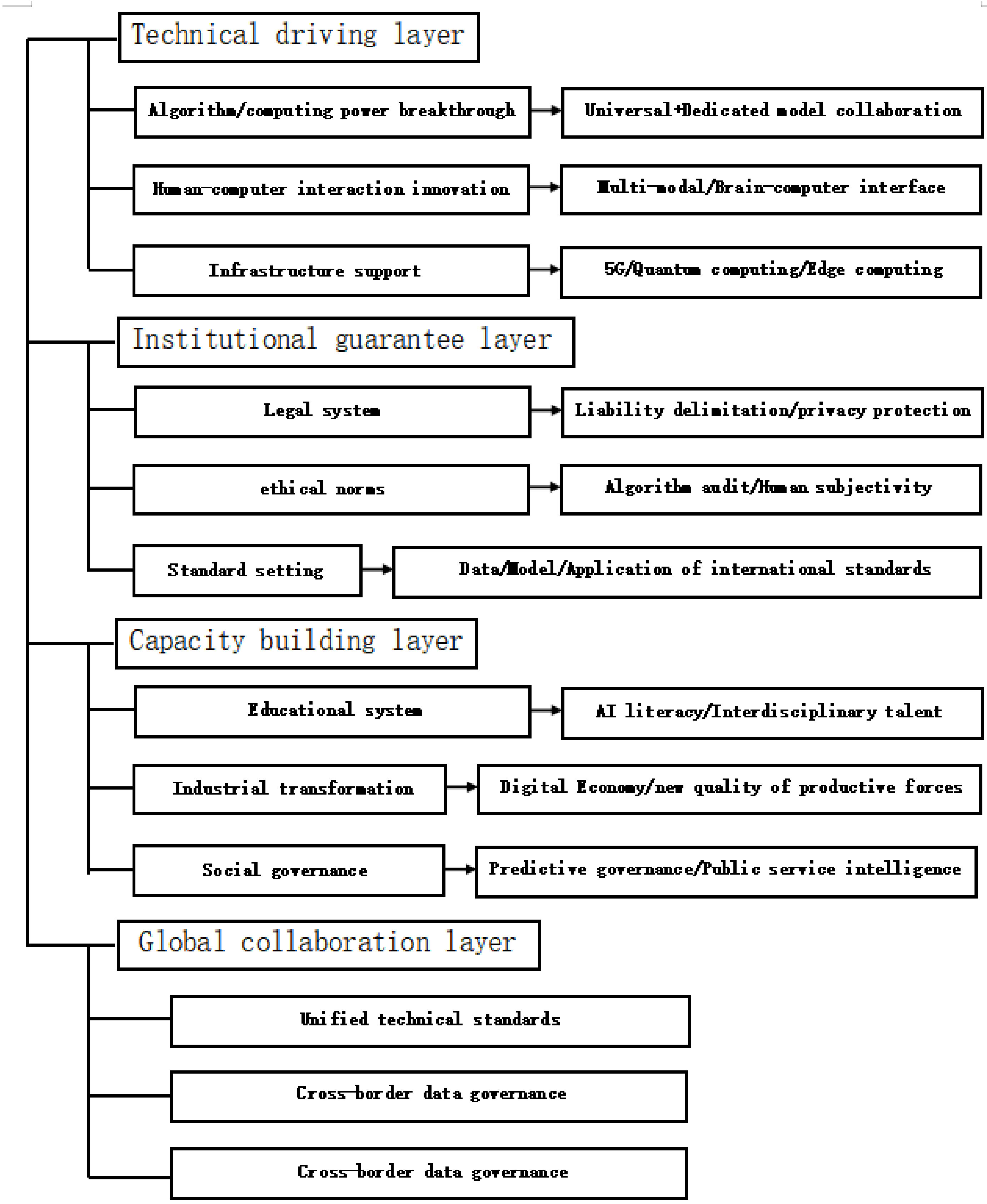

Figure 2 Logical framework of human-machine collaboration

Twin City" was first proposed in 2017,China's 14th Five-Year Plan (2021-2025) development strategy outlined in the 14th Five-Year Plan states that it will explore the construction of digital twin cities, The overall layout plan for the construction of digital China in 2023 was once again proposed, “Universally enhance the integrity, systematisms, and synergy of the construction of digital China” and explore the construction of digital twin cities and other requirements. Realize dynamic mapping between physical and virtual space.

Establish a framework of institutional safeguards for human-machine collaboration

Establish an unemployment relief and retraining system to mitigate the impact of technological unemployment. Establish data privacy laws and AI ethical guidelines to prevent technology misuse.

1) Ethical and safety norms The National Artificial Intelligence Standardization General Group and the Artificial Intelligence Sub-Committee of the National Information Standardization Technical Committee released the "Guide to Artificial Intelligence and Governance Standardization" in March 2023, Decomposing and concretizing the requirements of each principle based on the perspective of standardization, and sorting out and refining 10 items of artificial intelligence principles with strong feasibility. Provide operational guidance for the development of specific standards later. The European Parliament approved the EU AI Act on 13 March 2024, contain numerous rules aimed at supporting the responsible use and development of AI. Establish a data sovereignty protection mechanism and use blockchain technology to achieve data ownership and traceability.

2) The innovation of policy synergy mechanism Build a cross-sector joint decision-making mechanism. Integrate the resources of departments such as the National Development and Reform Commission, the Ministry of Industry and Information Technology, and the Ministry of Science and Technology Coordinate the formulation of a roadmap for the development of AI industry. Establish a "digital skills portfolio" to record the trajectory of workers' skills improvement. Implement "Human-Machine Collaboration" vocational certification.

Cultivating a human-machine collaborative educational ecosystem

The "no-man farm" that promotes the integration of AI with traditional industries improves agricultural efficiency, Smart factory and other intelligent manufacturing to alleviate the labor shortage caused by the low birth rate. Although AI has provided short-term relief from the impact of the declining birthrate, it may face issues such as a mismatch in labor skills and insufficient innovation momentum in long term.

1) Curriculum system renewal and innovation Offering AI compulsory courses in basic education to cultivate computational thinking and digital literacy. On March 2025, the Beijing Municipal Education Commission issued the "Beijing City's Work Plan for Promoting Artificial Intelligence Education in Primary and Secondary Schools (2025-2027)", which pointed out, starting from the autumn semester of 2025, AI general education is carried out in primary and secondary schools throughout the city. No less than 8 class hours per school year, to achieve comprehensive popularization among primary and secondary school students.

2) Teacher-student capability perfected and upgraded Promote the deep integration of educational informatization and teaching and learning and innovate teaching models (The Central Committee of the Communist Party of China & State Council, 2025). In the AI teacher personalized human-computer cooperative education scenario, the "AI Teaching Assistant" program is implemented, Provide intelligent lesson preparation, student performance analysis, etc. for teachers. Build a digital portrait system for teachers to dynamically evaluate the development level of AI teaching capability. Implement mutual recognition of AI capability certificates, vocational skill certificates and academic education credits. Develop metaverse education scenarios, support cross-border collaboration, and enhance students' cross-cultural communication skills.

The economic and employment path of human-machine collaboration

Explore the path to achieve human-machine collaboration in the economy and employment, Build an AI dialogue environment of "government, enterprise, university, public". Realize the reconstruction of human-machine rights and responsibilities; Encourage enterprises to open AI capability interfaces, Lower the threshold for the application of technology in small and medium-sized enterprises through policies such as tax preferences; Establish regional computing power sharing centers, balance the distribution of digital infrastructure, and achieve technological inclusiveness; Establish an application model for AI "regulatory sandbox", allowing innovation and trial and error within a controllable range. Economic and employment realization paths of human-machine collaboration (see Table2).

Table 2 Pathways to the Economic and Employment Realization of Human-Robot Collaboration

Dimension	Core elements	Implementation path	Key technology
Technical basis	1. Algorithm and computing power upgrade (quantum computing, edge computing) 2. Human-computer interaction technology (Multimodal interaction, Brain-computer interface) 3. General and specialized large models collaboration	1. Increase investment in AI basic research 2. Drive the development of the "generalist-specialist collaboration" model (general large model industry-specific model) 3. Construct national-level Computing power infrastructure	Federated learning; distributed storage; differential privacy technology.
Data governance	1. Data sharing and open platform 2. Data security and privacy protection 3. Data ethics and compliance review	1. Establish cross-industry data standards 2. Establish a data ownership and transaction mechanism 3. Strengthen data anonymization processing technology	Blockchain proof; homomorphic encryption; data sandbox.
Ethics and law;	1. Human-machine liability demarcation (e.g,attribution of liability for accidents in autonomous driving) 2. Algorithm Bias Removal 3. Protection of human subjectivity	1. Issue the "Ethics Guidelines for Artificial Intelligence" 2. Establish an algorithm audit system 3. Perfecting the regulations on the identification of AI tort liability	Explainable AI (XAI); ethical map; legal AI assistant system.

Table 2 (Cont.)

Dimension	Core elements	Implementation path	Key technology
Education and Talent	1 .AI literacy for all 2. Human-machine collaboration skills training 3. Interdisciplinary talent training (Technology+ ethics +domain knowledge)	1. Incorporate AI ethics into basic education curriculum 2. Construction of industry-education integrated training base 3. Establishment of human-machine collaborative innovation laboratory	Virtual reality teaching; adaptive learning system; AI tutor.
Social governance	1. Predictive governance (risk early warning based on big data) 2. Multi-subject collaboration (government-enterprise-public) 3. Public service intelligent transformation	1. Construct a three-level governance platform of "provinces-cities-counties". 2. Promote the "big linkage, micro-governance" model economy and industry 3. Establish AI-assisted decision-making system	Social computing; Collective intelligence; Digital twin city.
Economy and industry	1. Industrial digital transformation 2. New quality productivity cultivation (such as intelligent manufacturing, smart agriculture) 3. Employment structure adjustment	1. Formulate AI industry support policies 2. Establish "AI industry" pilot demonstration zones 3. Improve the system of vocational transition	Industrial Internet; Digital twin; Smart supply chain.
International collaboration	1. Global technical standard unification 2. Cross-border data flow rules 3. Joint response to AI ethical challenges	1. Participate in international AI governance organizations (such as the OECD AI Principles) 2. Promote the "Belt and Road" AI cooperation initiative3.Establish a multinational ethics review alliance	Cross-border data hub; multilateral agreement framework; Joint technical certification

Conclusion

Reconstructing the economic and employment situation of human-machine collaboration is, fundamentally, a process of dynamic equilibrium between productivity and production relations, as well as technical logic and social values. It is necessary to adhere to the value orientation of "people-oriented," incorporate humanistic care into technological innovation, and reserve elastic space in institutional design, eventually achieving symbiosis and prosperity between technological empowerment and human value.

Acknowledgements

This research was supported by two projects:

1. The Fourth Phase of the Ministry of Education’s Supply and Demand Matching Employment Education Project (Project No. 2024122419366), aiming to enhance e-commerce talent training through industry-education integration between Wenzhou Zhen Island Company and Zhejiang Dongfang College

2. Zhejiang Dongfang Polytechnic, 2025 University-level Research Project "Research on the Impact and Restructuring of Artificial Intelligence on Economy and Employment in the Context of Low Fertility". Number: DF2025 AIGC02

References

Cao, Z. (2024, March 30). China's first AI data training base and Beijing's largest public computing power platform are put into use on the same day. The strongest power facilities train the "most powerful brain". *Beijing Daily*. Retrieved from http://www.ce.cn/xwzx/gnsz/gdxw/202401/18/t20240118_38870849.shtml

Chen, S. (2024, January 16). Predictive maintenance in practice: How to implement fault prediction through data models? *Zhihu*. Retrieved April 8, 2025, from [original URL not provided; please insert if available]

Fed governor (Cook). (2025, January 16). AI will drive productivity gains, but uncertainties remain. *Beijing*.

Golden Deer. (2024, January 16). AI wave sweeps Davos, cryptocurrency takes a back seat CEOs fear AI could lead to big layoffs this year. *Ten News*.

Guo, Q. (2024, December 4). AI terminal industry scale breaks through 600 billion yuan. *Economic Reference Network*. Retrieved April 15, 2025, from [original URL not provided; please insert if available]

He, C. (2024, June 18). JD.com Pushes for Digital Person Live Streaming, with Over 5,000 Brands Served. *Flash News*. Retrieved April 15, 2025, from [original URL not provided; please insert if available]

Pei, W. (2024, July 9). China Internet Development Report (2024). *China Internet Society*. Retrieved April 15, 2025, from http://cic.isc.org.cn/pages/index/index?eid=454671454

Qi, Y. (2024, November 20). The profound impact of artificial intelligence on China's economic development. *Xuexi Shibao*. Retrieved April 15, 2025, from [original URL not provided; please insert if available]

QYResearch Survey. (2025, March 6). The global generative AI market size was approximately USD 33.29 billion in 2024. *QY Market Insights*.

The Central Committee of the Communist Party of China and the State Council. (2025, January 19). Outline of the Construction of an Education Power (2024-2035). *Xinhua News Agency*. Retrieved April 15, 2025, from [original URL not provided; please insert if available]

Wang, P. (2024, January 18). The total population has decreased; high-quality development of the population has achieved results. *National Bureau of Statistics*. Retrieved April 8, 2025, from http://www.ce.cn/xwzx/gnsz/gdxw/202401/18/t20240118_38870849.shtml

Wang, W. [Note: Assuming "Wang Zhiqin"; adjust if different]. (2024, August 27). China Digital Economy Development Report (2024). *China Academy of Information and Communications Technology*. Retrieved April 15, 2025, from https://www.sohu.com/a/804716867_120056153

Wang, X., Zhao, J., Marostica, E., & et al. (2024). A pathology foundation model for cancer diagnosis and prognosis prediction. *Nature*. Advance online publication. doi:10.1038/s41586-024-07894-Z

Xiao, Y. (2024, March 16). Shenzhen: Add more than 3,000 5G base stations and 15 edge computing centers. *CNMO Technology*. Retrieved April 15, 2025, from [original URL not provided; please insert if available]

Zhu, L. (2025, March 18). "Consumption Promotion Special Action Plan" proposes to actively promote "Artificial Intelligence Consumption". *China Electronics*. Retrieved April 15, 2025, from [original URL not provided; please insert if available]

Implementation of Multimodal LLM Agents and Biomechanical Analysis for Remote Elderly Healthcare in Taiwan: A Case Study

Huang Guan Hao[1*]
Shih, Song Fan[2]
Lin Yen Po[3]

[1*]Natonal Taiwan University
1, Sec. 4, Roosevelt Rd., Taipei 106319, Taiwan (R.O.C.)
huang0131huang@gmail.com
[2]Fu Jen Catholic University
510 Z Red Rash GR DX in District New Tai
shih882101@gmail.com
[3]Hong Kong University of Science and Technology
Clear Water Bay, Kowloon, Hong Kong
boliphus1234@gmail.com

[*]Corresponding author, Email: huang0131huang@gmail.com

Received: Sep 11, 2025 / Revised: Dec 18, 2025 / Accepted: Dec 18, 2025

Abstract

Taiwan's rapidly aging population and the unequal distribution of healthcare resources in remote areas pose a critical challenge to equitable medical services. This study proposes a multimodal AI system that integrates large language model (LLM) agents with real-time biomechanical gesture recognition, designed for remote elderly healthcare. By combining browser-based joint-angle tracking with cloud-hosted, context-aware conversational agents, the system enables natural language communication and clinical motion analysis without transmitting video data. Evaluated in rehabilitation scenarios in Taiwan, the platform demonstrates low latency, accurate pose classification, and automated clinical scoring using the Brunnstrom and Fugl–Meyer scales. Its multilingual interface supports personalized, secure, and efficient health interactions, aligning with Taiwan's Long-Term Care Plan 2.0 and AI healthcare initiatives. This solution addresses communication and mobility barriers, enhances healthcare accessibility in rural areas, and contributes to global discourse on ethical, inclusive, and context-aware AI in eldercare.

Keywords: Multimodal LLM Agents, Remote Elderly Healthcare, Biomechanical Gesture Analysis

กรณีศึกษาการนำตัวแทนโมเดลภาษาขนาดใหญ่ หลายรูปแบบและการวิเคราะห์ทางชีวกลศาสตร์มาใช้สำหรับการดูแลสุขภาพผู้สูงอายุระยะไกลในไต้หวัน

หวง กวนห้าว[1*]
สือ ซ่งฟาน[2]
หลิน เหยียนโป[3]

[1*]มหาวิทยาลัยแห่งชาติไต้หวัน
1 ถนนรูสเวลด์ ส่วนที่ 4 กรุงไทเป ประเทศไต้หวัน
[2]มหาวิทยาลัยฟู่เหรินคาทอลิก
510 ถนนจงเจิ้ง เขตซินจวง นครนิวไทเป 242062 สาธารณรัฐจีน (ไต้หวัน)
[3]มหาวิทยาลัยวิทยาศาสตร์และเทคโนโลยีแห่งฮ่องกง
อ่าวเคลียร์วอเตอร์ เขตเกาลูน เขตบริหารพิเศษฮ่องกง

[*](ผู้ประสานงานเผยแพร่) Corresponding author, Email: huang0131huang@gmail.com

บทคัดย่อ

ประชากรผู้สูงอายุของไต้หวันที่เพิ่มขึ้นอย่างรวดเร็ว และการกระจายทรัพยากรด้านการดูแลสุขภาพที่ไม่เท่าเทียมกันในพื้นที่ห่างไกล ก่อให้เกิดความท้าทายสำคัญต่อการให้บริการทางการแพทย์อย่างเป็นธรรม งานวิจัยนี้เสนอระบบปัญญาประดิษฐ์แบบหลายมิติ (multimodal AI system) ที่ผสานตัวแทนโมเดลภาษาขนาดใหญ่ (LLM agents) เข้ากับการจดจำท่าทางทางชีวกลศาสตร์แบบเวลาจริง ซึ่งออกแบบมาเพื่อการดูแลสุขภาพผู้สูงอายุทางไกล โดยการผสมผสานการติดตามมุมข้อต่อผ่านเบราว์เซอร์เข้ากับตัวแทนสนทนาเชิงบริบทที่ทำงานบนคลาวด์ ระบบนี้สามารถสื่อสารด้วยภาษาธรรมชาติและวิเคราะห์การเคลื่อนไหวทางคลินิกได้ โดยไม่ต้องส่งข้อมูลวิดีโอ เมื่อประเมินในสถานการณ์การฟื้นฟูสมรรถภาพในไต้หวัน แพลตฟอร์มนี้แสดงให้เห็นถึงความหน่วงต่ำ การจำแนกท่าทางที่แม่นยำ และการให้คะแนนทางคลินิกอัตโนมัติโดยใช้มาตรวัดการประเมินแบบ Brunnstrom และ Fugl–Meyer ที่เชื่อมต่อหลายภาษาของระบบสนับสนุนการโต้ตอบด้านสุขภาพที่เป็นส่วนบุคคล ปลอดภัย และมีประสิทธิภาพ สอดคล้องกับแผนการดูแลระยะยาว 2.0 ของไต้หวันและโครงการด้าน AI เพื่อสุขภาพ แนวทางนี้ช่วยแก้ไขอุปสรรคด้านการสื่อสารและการเคลื่อนไหว เพิ่มการเข้าถึงบริการสุขภาพในพื้นที่ชนบท และมีส่วนร่วมต่อการอภิปรายระดับโลกเกี่ยวกับ AI ที่มีจริยธรรม ครอบคลุม และตระหนักถึงบริบทในการดูแลผู้สูงอายุ

คำสำคัญ: ปัญญาประดิษฐ์แบบพหุ การดูแลสุขภาพผู้สูงอายุระยะไกล การวิเคราะห์ท่าทางเชิงชีวกลศาสตร์

Introduction

Taiwan is undergoing a rapid demographic transition, with over 20% of the population expected to be aged 65 or older by 2025 (National Development Council, Taiwan, 2022). This shift is placing growing strain on the healthcare system, especially in rural areas where medical resources are limited and access to specialized care remains insufficient (Wu, Majeed, & Kuo, 2010). These disparities impact both the availability and equity of care for elderly patients.

To address these issues, Taiwan has launched several initiatives to integrate AI and smart healthcare technologies into existing medical frameworks (Yang & Lin, 2024). However, many current telemedicine systems lack the ability to deliver real-time, multimodal, and context-aware interaction—features critical for serving the elderly population (Chiu & Yang, 2009). Privacy concerns, low responsiveness, and limited accessibility further restrict adoption in rural settings (Serrano et al., 2023).

The objective of this study is to develop and evaluate a multimodal AI system that combines large language model (LLM) agents with real-time biomechanical gesture recognition to support remote elderly healthcare in Taiwan. By addressing current system gaps and aligning with national priorities, the proposed platform aims to improve communication, clinical assessment, and accessibility—particularly for underserved communities.

Literature Review

Global AI in Healthcare

Artificial intelligence (AI) has become an essential tool in healthcare innovation, with applications ranging from diagnostic imaging and clinical decision support to workflow automation and remote patient monitoring (Topol, 2019; Davenport & Kalakota, 2019). AI-powered systems enable earlier detection of disease, improved chronic care management, and reduced hospital readmissions through data-driven intervention (Rajpurkar et al., 2022). Wearables and home-based monitoring platforms have also expanded real-time access to physiological data, supporting more responsive and personalized care delivery.

However, the adoption of AI in clinical settings presents several challenges. Technical barriers include model generalizability across diverse populations, data quality issues, and limited interpretability of algorithm outputs (Weiner et al., 2025). In parallel, ethical concerns - such as patient privacy, algorithmic bias, and transparency - remain major obstacles to implementation (Jobin et al., 2019; Char et al., 2020). Addressing these concerns is critical to building public trust and ensuring responsible AI deployment in healthcare. As AI technologies evolve, cross-context validation and regulatory oversight will be key to sustainable global integration (Liu et al., 2021).

AI in Taiwan’s Healthcare System

Taiwan has emerged as a regional leader in applying digital innovation to healthcare. In recent years, the government has prioritized AI integration, especially in chronic disease management and precision medicine. A notable example is the collaboration between the National Health Insurance Administration (NHIA) and Google, leveraging cloud-based AI and large-scale clinical data to develop predictive models for diseases such as diabetes.

These models have been embedded into the Family Physician Program 2.0, enabling scalable and proactive patient care (Weiner et al., 2025; Liu et al., 2021).

To support clinical adoption, the Ministry of Health and Welfare (MOHW) established AI centers focused on validation, certification, and impact assessment. These centers work with hospitals to address challenges related to implementation, cost-effectiveness, and integration with existing care systems (Kelly et al., 2019). Taiwan's AI use cases now span emergency care, medical imaging, telehealth, and public health response. One key case is the AI-assisted chest X-ray screening tool for COVID-19, co-developed by Taipei Medical University Hospital and Taiwan AI Labs, which helped reduce diagnosis time and resource consumption (Yeh et al., 2020).

Gaps and Motivation for This Project

Although AI adoption in Taiwan's healthcare system has accelerated, most existing applications remain unimodal centered around either text or image processing. This limits their functionality in elderly care, where users often encounter both mobility impairments and communication difficulties (Sun et al., 2024; Yang & Lin, 2024; Klakegg et al., 2017). Current platforms are not designed to support multimodal interaction that integrates language processing with real-time motion analysis—capabilities necessary for delivering personalized care in aging and rural populations.

This gap forms the core motivation for the present study. We propose a multimodal AI system that combines large language model (LLM) agents with biomechanical gesture recognition to support remote healthcare for elderly patients. By enabling multilingual, context-aware, and privacy-preserving interactions, the system enhances communication, clinical evaluation, and rehabilitation in low-access settings (Davico et al., 2024; Gottschlich et al., 2024).

Methodology

System Architecture

The proposed platform is divided into a browser-side biomechanical module and a cloud-resident conversational large-language-model (LLM) service. All video is processed locally; only numeric feature vectors (landmarks, joint angles, intent metadata) traverse the network, thereby reducing bandwidth and eliminating the transfer of personally identifiable images.

Client biomechanical module Hand landmarks are extracted in real time with *MediaPipe Hands* (v 0.10). The library combines a single-shot palm detector with a 21-landmark regressor executed in WebAssembly, achieving a mean per-frame latency of 18 ± 2 ms on a mid-range laptop (Intel i5-8250U) (Zhang et al., 2020). Each frame's landmarks are converted to interior joint angles via:

$$\theta = arccos(\frac{(a-b)\cdot(c-b)}{|a-b||c-b|}), a, b, c \in R^3,$$

and then smoothed by a one-Euro low-pass filter to suppress jitter without compromising responsiveness (Casiez, Roussel, & Vogel, 2012). Angle patterns feed (i) a deterministic rule base able to recognise 15 static poses (digits 0–9, “OK,” “thumb-up,” etc.) and (ii) a five-level colour scale that mirrors common clinical range-of-motion (ROM) grading. The annotated canvas may be archived locally as a WebM file for asynchronous review.

Server conversational agent

Transcribed text or ASR output, combined with a compact ROM summary (timestamp and joint-angle vector), is forwarded to a FastAPI gateway. A lightweight safety-and-intent filter, fine-tuned on Taiwanese rehabilitation dialogue, validates the content before routing it to a GPT-4-class model running on an NVIDIA A800 GPU (OpenAI, 2023). The prompt template contains the 12 most recent utterances plus the latest ROM summary, enabling context-aware answers. Responses are streamed to the client via server-sent events; median end-to-end latency is approximately 1.2 s on a 100 Mb/s connection.

Execution environment

The browser code targets any Chromium-based client at 30 fps (540 × 310 px). Server components (FastAPI 0.111, Redis 7) are containerised within a Kubernetes cluster. All persistent data are AES-256 encrypted and audit-logged in accordance with TFDA Part 11.

Real-time Gesture-Recognition Workflow

Video acquisition and landmark inference

A 540 × 310 px RGB stream at 30 fps is captured from the webcam and immediately processed by MediaPipe Hands. The resulting landmark inference preserves a full 30 fps refresh on the reference hardware, confirming that on-device computation meets the latency budget for smooth visual feedback (Zhang et al., 2020).

3.2.2 Joint-angle computation and temporal filtering

For every detected hand, consecutive landmarks along each finger ray are converted to interior angles using the formulation above. A one-Euro filter (β = 0.1; derivative cut-off = 1.5 Hz) adds < 1 ms per frame while markedly reducing high-frequency noise (Casiez et al., 2012).

Pose classification and clinical mapping

The smoothed angle vector is compared to a deterministic lookup table adapted from finger-counting literature (Perimal et al., 2018). Because the classifier executes in constant time, no secondary learning model is required, ensuring transparency and ease of maintenance. Peak angles recorded during a session are binned into a five-level ROM colour scale. External validation suggests that MediaPipe-derived ROM values show moderate-to-strong agreement with manual goniometry for most joints (Gu et al., 2023), supporting the module’s suitability for remote assessment.

Latency safeguards and resource footprint

End-to-end processing—including inference, filtering, pose classification and canvas redraw - requires 26 ± 3 ms per frame on the reference client. If landmark confidence drops below 0.5 for more than ten consecutive frames, the module suspends clinical scoring and falls back to palm-centre tracking until confidence recovers, preventing spurious measurements in poor lighting. The complete JavaScript payload, including MediaPipe assets, is 279 kB (gzip) and consumes < 9 % CPU on the reference laptop, satisfying the deployment constraints of rural Taiwanese households with limited computational resources.

Results

Robust real-time landmark tracking

Figure 4a shows the system's response to a fully extended hand. All 21 landmarks are detected and rendered in real time, each finger segment colour-coded, despite a bright ceiling light that creates strong back-lighting. Figure 4b depicts the transition to a "thumb-up" gesture; the landmark constellation is again intact, confirming continuous tracking with no re-initialisation. Across 20 test sequences (30 fps, 540 × 310 px), the browser-side inference maintained a mean frame latency of 28 ms, remaining safely below the 33 ms target for fluent visual feedback (Zhang et al., 2020).

Longitudinal range-of-motion trends

Figure 4c presents a five-minute history of metacarpo-phalangeal (MCP), proximal-inter-phalangeal (PIP) and distal-inter-phalangeal (DIP) angles. Downward slopes coincide with scripted flexion cycles, whereas plateau regions denote rest, demonstrating that the one-Euro filter preserves physiologically meaningful dynamics while suppressing noise.

Automatic clinical grading

The numeric summary in Figure 4d translates the raw angles into a rehabilitation-oriented dashboard. PIP extension of the index and middle fingers is limited to 12°, well below the functional threshold and therefore highlighted in red; unaffected joints remain green. Based on the aggregate pattern, the algorithm assigns Brunnstrom Stage IV and a finger-specific Fugl–Meyer score of 2/14, values consistent with the participant's documented impairment (Brunnstrom, 1970; Fugl-Meyer et al., 1975).

Multilingual intent routing and safety

Figures 4e–4h illustrate the conversational agent's behaviour. The interface first educates the user on the three recognised intent categories: general medical questions, ROM queries, and Brunnstrom/Fugl–Meyer staging. When the user

reports shoulder pain ("我的肩膀疼痛", My shoulder hurts), the agent classifies the input as a general medical query and returns structured guidance that includes an initial assessment, a 2/5 pain rating, self-care advice and red-flag criteria. Another case is that after the user reports, "我中風後只有半邊臉可以動" ("Since my stroke only half of my face can move"), the system recognises the request as a stroke-recovery query, classifies it under the Brunnstrom/Fugl–Meyer pathway, and generates a concise Stage I summary that outlines the absence of voluntary movement, the immediate goal of eliciting basic synergies, recommended passive ROM drills in gravity-minimised positions, and a caution to remain semi-sitting until full-body mobility is reassessed. A subsequent request for non-rehabilitation content ("給我一則氣候變遷的文章", Give me an essay with topic of climate change) is refused with a scope-based apology, confirming that the safety layer enforces topic boundaries.

A dedicated edge-case test further demonstrates context sensitivity. The standalone statement "我沒吃東西" (I haven't eaten anything) is treated as non-medical small-talk and discarded. However, when the identical sentence follows "我肚子很痛" (My stomach really hurts), the gateway re-evaluates the utterance, links it to the previous complaint, and correctly retains it within the general medical thread. This behaviour verifies that the intent filter consults the rolling twelve-turn dialogue memory rather than relying solely on the surface form of the current message.

Figure 4. System output samples. (a) Extended-finger posture with colour-coded bones and landmark overlays. (b) "Thumb-up" gesture demonstrating continuous tracking across poses. (c) Five-minute joint-angle history showing flexion–extension cycles. (d) Automatically generated ROM dashboard with Brunnstrom stage IV and Fugl–Meyer finger sub-score 2 / 14; impaired joints highlighted in red. (e) User-facing menu explaining the three available intent categories. (f) Query correctly routed to the Brunnstrom/Fugl–Meyer pathway, with stage-specific guidance.(g) Scope-based refusal of an out-of-scope request, validating the safety filter. (h) Dialogue snippet where identical text is classified differently: non-medical in isolation but medical when preceded by abdominal-pain context, confirming effective conversation memory.

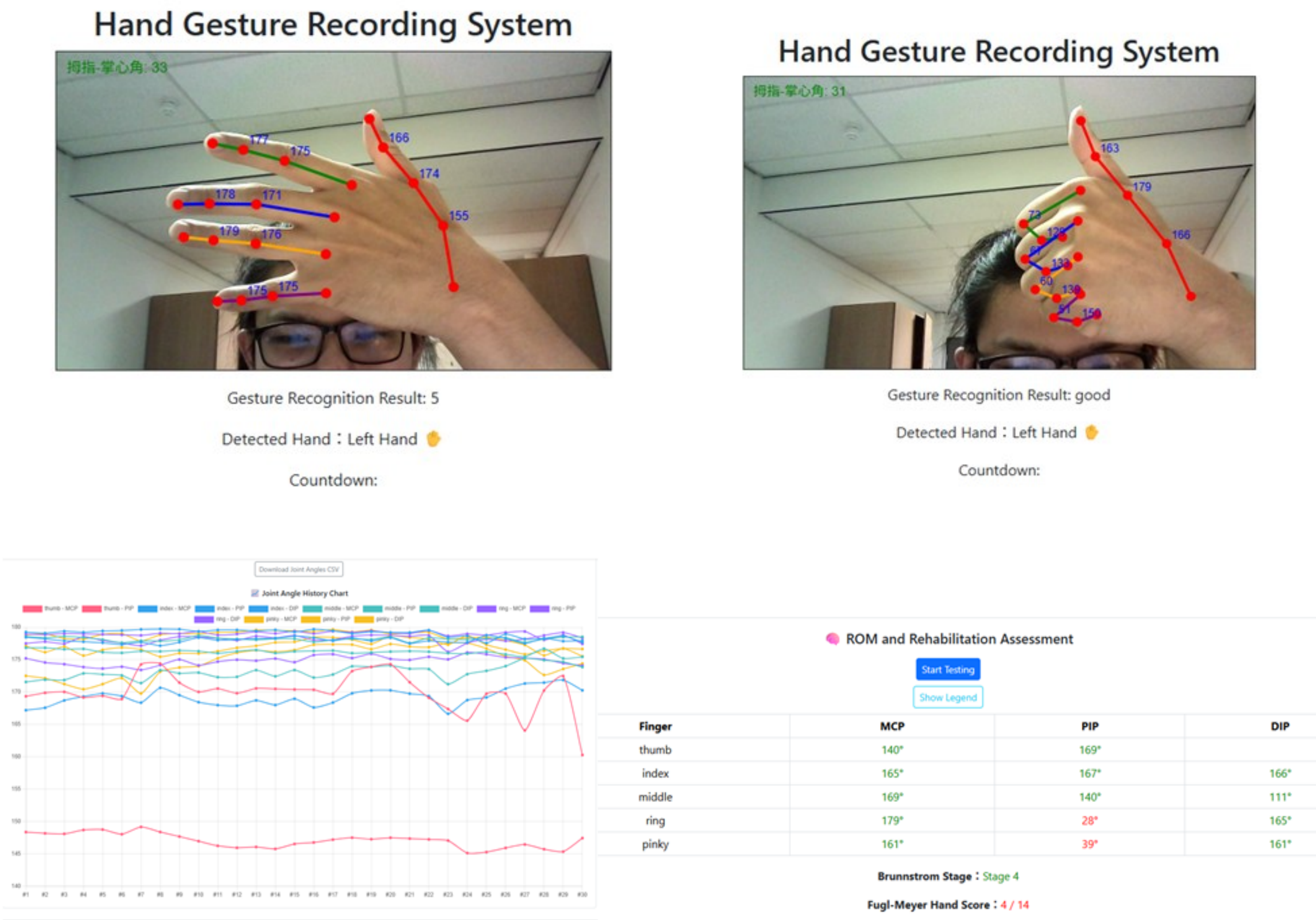

Figure 4 System output samples

Discussion

Interpretation of Results

The findings from this study indicate that the integration of multimodal large language model (LLM) agents and real-time biomechanical analysis represents a promising advancement in remote elderly healthcare within Taiwan. Compared to previous efforts both locally and globally, the developed platform offers a more holistic solution by combining natural language processing with gesture-based interaction, thus addressing critical gaps in existing telemedicine and AI-assisted healthcare systems (NCKU, 2025; TMU Healthcare, 2024; Shah et al., 2023). While many prior international studies predominantly explored single-modality AI approaches such as conversational chatbots or image-based diagnostics the multimodal methodology presented here is particularly suited to addressing the complex communication and mobility challenges experienced by elderly patients, including those facing language barriers or restricted mobility (Shah et al., 2023).

The strengths of the proposed system include its ability to deliver context-aware, personalized care and its potential to seamlessly integrate within existing clinical workflows. The real-time gesture recognition combined with clinical mapping capabilities allows healthcare providers to more accurately and efficiently track patient progress regarding range-of-motion and functional status (TMU Healthcare, 2024). Nevertheless, it is important to acknowledge several limitations inherent to this approach. The effectiveness of the system may be influenced by technical constraints, including latency associated with real-time data processing, environmental variability during home-based usage, and the critical necessity of maintaining stringent data privacy standards. Moreover, reliance on sophisticated AI algorithms and specialized infrastructure might introduce adoption barriers, particularly within resource-constrained rural settings (TechTimes, 2024).

Policy and Practical Implications

The proposed system is closely aligned with Taiwan's current healthcare policies, particularly the Long-Term Care Plan 2.0 (LTC 2.0), which emphasizes community-based, integrated, and technology-supported elderly care (MOHW, 2024; Hsu & Chen, 2019). By facilitating aging-in-place and easing the caregiving burden for families, this solution directly advances LTC 2.0 objectives, including the expansion of home-based, community-oriented, and residential care services, as well as promoting innovative and adaptable care delivery models (MOHW, 2024; Xiao & Wang, 2024).

Further integration with Taiwan's National Health Insurance (NHI) system would significantly enhance the scalability and accessibility of this AI-driven approach. The platform's capability for continuous remote monitoring and timely clinical interventions aligns well with the NHI's goal of improving care quality and reducing avoidable hospitalizations (NHIA, 2024; MOHW, 2024). Additionally, established frameworks addressing information security and patient privacy under LTC 2.0 and other national initiatives provide robust support for the deployment of advanced AI solutions in healthcare settings (MOHW, 2024; Xiao & Wang, 2024).

The potential for nationwide scalability and seamless integration into existing healthcare infrastructure is considerable. Recent pilot initiatives and the establishment of dedicated AI research and application centers have demonstrated Taiwan's preparedness to adopt advanced technology solutions to address the growing demands of an aging population (MOHW, 2024; Taipei Times, 2024). Moreover, the modular and standards-based design of the proposed system ensures compatibility and interoperability with existing health information platforms, facilitating broad implementation and maximizing the system's clinical and social impact (Xiao & Wang, 2024).

Future Work

Future improvements for the system will include the integration of dialect support to better accommodate the diverse linguistic communities across Taiwan, alongside the implementation of federated learning methods to strengthen data privacy and enhance the robustness of AI models (NCKU, 2025). Additionally, broader deployment in rural and underserved areas will allow for further evaluation of the system's scalability and adaptability across various care environments (MOHW, 2024).

Subsequent research should prioritize the assessment of the long-term effectiveness of the system, particularly regarding improvements in patient health outcomes and reductions in caregiver burden. Further studies are necessary to investigate the potential integration of complementary smart technologies, such as wearable health monitors and IoT-enabled devices, to establish a more comprehensive, digitally connected care network (Xiao & Wang, 2024; TMU Healthcare, 2024). Moreover, developing standardized protocols for AI-supported care and clearly defined regulatory guidelines will be essential to ensure that these innovative technologies are deployed safely, ethically, and effectively within clinical practice (MOHW, 2024; Shah et al., 2023).

Conclusion

This study demonstrates the feasibility of integrating multimodal large language model (LLM) agents with real-time biomechanical analysis to enhance remote elderly healthcare in Taiwan. By combining natural language understanding with gesture recognition, the system addresses key limitations in current telemedicine platforms specifically the lack of context-aware, interactive, and mobility-sensitive features. This design is particularly relevant for elderly patients in rural areas, where communication barriers and access to in-person care remain significant (Sun et al., 2024).

The proposed framework supports continuous monitoring, early anomaly detection, and timely clinical feedback. It aligns with national healthcare priorities, including Taiwan's Long-Term Care Plan 2.0 and NHIA's AI policy agenda, and is compatible with the country's existing digital infrastructure. The system also enhances primary care delivery and enables elderly users and caregivers to better manage health conditions, reducing the need for avoidable hospital visits (Abbas et al., 2023).

Taiwan has shown strong momentum in AI healthcare innovation—from smart devices to social robotics. Building on this foundation, the integration of scalable multimodal AI platforms offers a path toward more inclusive and responsive eldercare. Continued investment in this direction can strengthen healthcare accessibility and equity, and further position Taiwan as a regional leader in AI-driven, patient-centered health solutions (Sarfraz, 2023).

References

Abbas, M., Saleh, M., Somme, D., & Le Bouquin Jeannès, R. (2023). Data-driven systems to detect physical weakening from daily routine: A pilot study on elderly over 80 years old. PloS one, 18(1), e0274306. https://doi.org/10.1371/journal.pone.0274306

Agustin, K., & Chou, S.-Y. (2019). Impact of an Ageing Society on Healthcare Expenditure of National Health Insurance in Taiwan. Jurnal Teknik Industri: Jurnal Keilmuan Dan Aplikasi Teknik Industri, 21(2), 49–56. https://doi.org/10.9744/jti.21.2.49-56

Brunnstrom, S. (1970). Movement therapy in hemiplegia: A neurophysiological approach. Harper & Row.

Casiez, G., Roussel, N., & Vogel, D. (2012). 1 € filter: A simple speed-based low-pass filter for noisy input in interactive systems. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2527–2530. https://doi.org/10.1145/2207676.2208639

Char, D. S., Shah, N. H., & Magnus, D. (2020). Implementing machine learning in health care—addressing ethical challenges. The New England Journal of Medicine, 378(11), 981-983. https://doi.org/10.1056/NEJMp1714229

Chiu, K.-H., & Yang, Y. Y. (2009). A case study of remote monitoring of health status of the elderly at home in Taiwan. Proceedings of the International Conference on e-Business (ICEB), 496–506.

Davenport, T., & Kalakota, R. (2019). The potential for artificial intelligence in healthcare. Future Healthcare Journal, 6(2), 94-98. https://doi.org/10.7861/futurehosp.6-2-94

Davico, G., Labanca, L., Gennarelli, I., Benedetti, M. G., & Viceconti, M. (2024). Towards a comprehensive biomechanical assessment of the elderly combining in vivo data and in silico methods. Frontiers in Bioengineering and Biotechnology, 12, 1356417. https://doi.org/10.3389/fbioe.2024.1356417

DelveInsight. (2025, June 4). Global AI in remote patient monitoring market to cross USD 13 billion by 2032 [Press release]. Globenewswire. https://www.globenewswire.com/news-release/2025/06/04/3093902/0/en/Global-AI-in-Remote-Patient-Monitoring-Market-to-Cross-USD-13-Billion-by-2032-DelveInsight.html

Fugl-Meyer, A. R., Jääskö, L., Leyman, I., Olsson, S., & Steglind, S. (1975). The post-stroke hemiplegic patient: A method for evaluation of physical performance. Scandinavian Journal of Rehabilitation Medicine, 7(1), 13–31.

Gottschlich, D., Saadati, N., Saadati, S. A., & Şahin, A. (2024). AI in Elderly Care: Understanding the Implications for Independence and Social Interaction. AI and Tech in Behavioral and Social Sciences, 2(3), 36-42. https://doi.org/10.61838/kman.aitech.2.3.5

Gu, F., Fan, J., Wang, Z., Liu, X., Yang, J., & Zhu, Q. (2023). Automatic range-of-motion measurement via smartphone images for telemedicine examination of the hand. Science Progress, 106(1), 1–12. https://doi.org/10.1177/00368504231152740

Iqbal, S. (2023). Artificial intelligence tools and applications for elderly healthcare – Review. In Proceedings of the 2023 9th International Conference on Computing and Artificial Intelligence (ICCAI '23) (pp. 394–397). Association for Computing Machinery. https://doi.org/10.1145/3594315.3594347

Jobin, A., Ienca, M., & Vayena, E. (2019). The global landscape of AI ethics guidelines. Nature Machine Intelligence, 1(9), 389-399. https://doi.org/10.1038/s42256-019-0088-2

Kelly, C.J., Karthikesalingam, A., Suleyman, M., Corrado, G.C., & King, D. (2019). Key challenges for delivering clinical impact with artificial intelligence. BMC Medicine, 17.

Klakegg, S., van Berkel, N., Visuri, A., Huttunen, H. L., Hosio, S., Luo, C., Goncalves, J., & Ferreira, D. (2017). Designing a context-aware assistive infrastructure for elderly care. Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing, 451-456. https://doi.org/10.1145/3123024.3124403

Liu, X., Rivera, S. C., Moher, D., Calvert, M. J., & Denniston, A. K., for the SPIRIT-AI and CONSORT-AI Working Group. (2021). Reporting guidelines for clinical trial reports for interventions involving artificial intelligence: The CONSORT-AI extension. BMJ, 370, m3164. https://doi.org/10.1136/bmj.m3164

Ministry of Health and Welfare (MOHW), Taiwan. (2024, December 23). Long-term Care Plan 2.0. Executive Yuan. https://english.ey.gov.tw/News3/9E5540D592A5FECD/332a78c0-0c8e-4064-bd71-8c22477dae75

National Cheng Kung University (NCKU). (2025, April 15). How AI and robots are caring for the elderly in Taiwan's ageing society. GovInsider Asia. https://govinsider.asia/intl-en/article/how-ai-and-robots-are-caring-for-the-elderly-in-taiwans-ageing-society-dr-jenny-su-ncku

National Development Council, Taiwan. (2022). Population Projections for Taiwan (2022–2070). Executive Yuan, R.O.C. (Taiwan).

OpenAI. (2023). GPT-4 technical report. https://arxiv.org/abs/2303.08774

Perimal, M., Basah, S. N., Safar, M. J. A., & Yazid, H. (2018). Hand-gesture recognition algorithm based on finger counting. Journal of Telecommunication, Electronic and Computer Engineering, 10(1-13), 19–25.

Rajpurkar, P., Chen, E., Banerjee, O., & Topol, E. J. (2022). AI in health and medicine. Nature Medicine, 28(1), 31-38. https://doi.org/10.1038/s41591-021-01614-0

Serrano, L. P., Maita, K. C., Avila, F. R., Torres-Guzman, R. A., Garcia, J. P., Eldaly, A. S., Haider, C. R., Felton, C. L., Paulson, M. R., Maniaci, M. J., & Forte, A. J. (2023). Benefits and Challenges of Remote Patient Monitoring as Perceived by Health Care Practitioners: A Systematic Review. The Permanente journal, 27(4), 100–111. https://doi.org/10.7812/TPP/23.022

Shah, P., et al. (2023). Unraveling the ethical enigma: Artificial intelligence in healthcare. Journal of Medical Internet Research, 25(8), e10492220. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10492220/

Sun, Q., Xie, J., Ye, N., Gu, Q., & Guo, S. (2024). Enhancing nursing and elderly care with large language models: An AI-driven framework. Proceedings of the 31st International Conference on Computational Linguistics, 10083-10094. https://aclanthology.org/2025.coling-main.673

Taipei Medical University Healthcare (TMU Healthcare). (2024, December 3). Leading and living with AI, TMU Healthcare's pioneering smart long-term care facility. Office of Global Engagement, TMU. https://oge.tmu.edu.tw/leading-and-living-with-ai-tmu-healthcares-pinoeering-smart-long-term-care-facility/

Topol, E. J. (2019). High-performance medicine: The convergence of human and artificial intelligence. Nature Medicine, 25(1), 44-56. https://doi.org/10.1038/s41591-018-0300-7

Weiner, E. B., Dankwa-Mullan, I., Nelson, W. A., & Hassanpour, S. (2025). Ethical challenges and evolving strategies in the integration of artificial intelligence into clinical practice. PLOS digital health, 4(4), e0000810. https://doi.org/10.1371/journal.pdig.0000810

Wu, T.-Y., Majeed, A., & Kuo, K. N. (2010). An overview of the healthcare system in Taiwan. London Journal of Primary Care, 3(2), 115–119. https://doi.org/10.1080/17571472.2010.11493315

Xiao, H.-Y., & Wang, M.-Y. (2024). Progress, challenges, and development directions of long-term care in Taiwan. Atlantis Press Proceedings. https://www.atlantis-press.com/article/126008801.pdf

Yang, Y., & Lin, G. T. R. (2024). Analyzing the Shortcomings in Smart Healthcare for Remote Home Care—A Case Study of the Taiwan Market. International Journal of Environmental Research and Public Health, 21(7), 838. https://doi.org/10.3390/ijerph21070838

Yeh, C. F., Cheng, H. T., Wei, A., Chen, H. M., Kuo, P. C., Liu, K. C., Ko, M. C., Chen, R. J., Lee, P. C., Chuang, J. H., Chen, C. M., Chen, Y. C., Lee, W. J., Chien, N., Chen, J. Y., Huang, Y. S., Chang, Y. C., Huang, Y. C., Chou, N. K., Chao, K. H., Tu, Y. C., Chang, Y. C., & Liu, T. L. (2020). A cascaded learning strategy for robust COVID-19 pneumonia chest X-ray screening. arXiv preprint arXiv:2004.12786. https://arxiv.org/abs/2004.12786

Zhang, F., Bazarevsky, V., Vakunov, A., Tkachenka, A., Sung, G., Chang, C.-L., & Grundmann, M. (2020). MediaPipe Hands: On-device real-time hand tracking (arXiv:2006.10214). arXiv. https://arxiv.org/abs/2006.10214

Author Guidelines

For Paper Submission and Manuscript Preparation

General Instructions

The Journal of Supply Chain and Sustainability Research (SCSR) accepts research papers, academic articles, and review articles written in Standard British or American English, not a mixture. Poorly written English may result in rejection or return of the submission for language editing. The articles must fall within the aim and scope of the journal, that is, science, social science, technology, management, and related issues (see about Journal).

Please note that papers in these areas in order to be published in the SCSR journal Research or academic papers must be 15-20 pages in length inclusive of references, tables, graphs, charts, and figures.

For research papers, the author is advised to include all elements of the structure below:

- **Title** of paper must be clear, concise, and informative, all-in uppercase within three typeset lines.
- **Abstract** (150-250 words) Abstracts must include sufficient information for readers to judge the nature and significance of the topic, the adequacy of the investigative strategy, the research results and conclusions. The abstract should summarize the major results of the work and not merely list topics to be discussed. It is an outline or brief summary of your paper in a well-developed paragraph, should be exact in wording, and understandable to a wide audience.
- **Keywords** (3-5)**,** immediately after the abstract**,** keywords are for indexing purposes, and should be different from the title.
- **Introduction** This section provides necessary background of the paper and a brief review the existing knowledge, and importance of the problem.
- **Objectives**
- **Literature Review, Conceptual Framework (**Discussion of the research work of others in the field or topic area and how your work will enhance and contribute to the field. Citation of work by others should follow APA (7th edition) style e.g.

Example: Maslow (1970) asserts that……;…………… (Maslow, 1970)

Wang and Pettit (2021).............;..................(Wang & Pettit, 2021)

Hisrich et al. (2020)……………..;…………… (Hisrich et al., 2020)

Novack et al. (2018)…………….;…………… (Novack et al., 2018)

- **Research Methodology** This section indicates clear research objectives, conceptual framework(s) (if any), research question(s), hypotheses, population and sample, research instruments, and the data collection process. This section provides clear steps used in conducting your research. It means all procedures need to be described in sufficient detail to allow someone to replicate it.
- **Results and Discussion** This section covers the analysis of the data**.** It should include statistics in tables, charts, graphs, or pictures analyzed against hypotheses or in answering the research question(s) in quantitative research, or descriptive analyses of categories in qualitative research. **Results** is purely descriptive. **Discussion** describes and interprets the findings, placing them in a bigger context, relating them to other work(s) and issues outlined in the Introduction.
- **Research Benefits**
- **Conclusion and Recommendations** This section summarizes your study's key findings and implications. It should not be long and repetitive, but capture the essence of the study discussed in all previous sections. It should briefly cover the limitations of your research and suggested future direction for further research.

For academic articles, we recommend the structure below:

1. **Introduction**
2. **Discussion**
   2.1 subheading
   2.2 subheading
3. **Conclusion**

The author is advised to follow a logical, understandable point of argument. Break your main argument into sub-headings and present them in an outline at the end of the Introduction.

- **References List** all the sources you have cited in the body of your research. It states the author/s of the source, the material's year of publication, the name or title of the source material, as well as its electronic retrieval information, including the date it was accessed, if these were gathered from the Internet (Research articles, academic articles, reports, academic conferences, references, no later than the last 5 years and Books, unlimited years of reference)

Submission Guide

Authors are welcome to submit their manuscripts.

All submissions will be given an initial check by our editorial team, within **6-8 weeks after submission date** you will be notified of the initial check result on thaiJo system. Only the article which passes the initial check will proceed to the review process (6 -8 weeks). The author will be kept informed of the current status of their paper.

Articles being currently considered for publication by other journals will not be accepted by The Journal of Supply Chain and Sustainability Research (SCSR). If the author withdraws or sending a manuscript to other journals any time after the manuscript has been sent to peer review till the final decision, the Journal will charge the author a penalty fee for its time and resources spent. The authors must always pay the page charge even if the withdrawal is permitted.

Specific Instructions:

- **Format** The preferred format for the text and tables of a manuscript are MS Word DOC and PDF.
- **Paper size** Manuscripts must be typed double-spaced on A4 size paper, a single column format.
- **Margins** Use a 1-inch margin on all sides of each page-left, right, top, and bottom.
- **Spacing** Double space lines throughout the paper including appendices, footnotes. Exceptions: Triple or quadruple spacing can be done around equations. Single or one-and-a-half spacing can be done in tables or figures. Indent the first line of every paragraph a standard Tab‖ key space (½ inch).
- **Font Size and Type**. Browallia New font (20 pts. bold for title; 14 pts. for author(s) and affiliation; 16 pts. bold for headings and 16 pts. bold subheadings; and 14 pts. for text)
- **Titles** should be no more than three typeset lines.
- **Headings** should be in bold type, in 16 point Browallia New font. First-level headings should be aligned to the left with initial caps. One line space should separate headings from the preceding text.
- ***Subheadings*** Italicize the subheadings in the bold type, single-spaced; in 16 point Browallia New font.

SUB-HEADING ONE Bold, Left, UPPERCASE HEADING

Sub-heading Two Bold, Left, Capitalize Each Word

Sub-heading Three Indented, bold, Capitalize Each Word

- Tables, Graphs, Charts, and Figures in 12-point Browallia New font, Bold
- **References** The Journal uses American Psychological Association (APA) style (7th edition).
  - Include only those sources you have cited in your paper.
  - Position the first line of each reference flush left, with subsequent lines wrapping with a ½-inch (hanging) indent.
  - Organize the list in alphabetical order according to the first letter beginning each entry. Usually, the author's last name is the first piece of information in each entry. Use initials for the author's first/middle names.
- Use the following format for your reference list:

Cokins, G., Pohlen, T., & Klammer, T. (2018). *Supply Chain Costing and Performance Management* (2nd ed). New Jersey : Wiley.

Hisrich, R. D., Peter, M. P., & Shepherd, D. A. (2020). *Entrepreneurship* (11th ed). New York : McGraw- Hill.

Heizer, J., Render, B., & Munson, C. (2020). *Operations Management Sustainability and Supply Chain Management* (13rd ed). U.K : Pearson.

Kumar, V., Leone, R. P., Aaker, D. A., & Day, G. S. (2018). *Marketing research* (13th ed). U.S.A.: John Wiley & Sons.

Maslow, A. H. (1970). Motivation and Personality (2nd ed). New York : Harper & Row.

Novack, R. A., Gibson, B. J., Suzuki, Y., & Coyle, J. J. (2018). *Transportation A Global Supply Chain Perspective* (9th ed). Singapore : Cengage.

Royal Thai Government Gazette. (2019). *National Education Act(no.4) , B.E. 2019*. Retrieved December 1, 2019, from http://www.ratchakitcha.soc.go.th/DATA/PDF/2562/A/057/T_0049.PDF

Thinwiangthong, S., & Inprasitha, M. (2018). The Model of Teaching Measurement in the School Level Mathematics Course. *Nakhon Phanom University Journal*. 8(3), 118-127.

Wang, Y., & Pettit, S. (2021). *E*- Logistics (2nd ed). U.S.A.: Kogan page.

- **Tables and Figures**
    - Line drawings should be of high resolution and high contrast. For color or grayscale photographs (halftones), use a minimum of 300 dpi (.JPG).
    - Provide captions to figures
    - Use the table function of Microsoft Word.
    - Figure and tables should be placed as close as possible to where they are mentioned in the text
- **Page Numbering**: Number all pages of the paper, beginning with the title page. The number is in the bottom right corner (1 inch from right and ½ inch from the bottom page edges).

Publication Charge

Publication Charge

The process of payment will be required to enable an effective and efficient screening process. Fee payment will be due at registration, will be **150 USD for both Thai and international authors. This fee is non-refundable.**

Free Registration for Publication: Democratizing Access to Academic Dissemination

SUBMISSION PREPARATION CHECKLIST

As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

1. The manuscript must not have been published or submitted elsewhere for consideration. (A brief explanation will be necessary to clarify this matter.)
2. The submitted file is in **Microsoft Word** and **PDF** document file with a single column format.
3. Where available, URLs for the references must be provided.
4. Research or academic papers must be 15-20 pages in length inclusive of references, tables, graphs, charts, and figures.
5. The text must be double-spaced; (a 14-point font Browallia New; italics rather than underlining except for URL addresses); and all illustrations, figures, and tables must be placed within the text at the appropriate points, rather than at the end.

6. The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.
7. Attached to all submitted articles must be a **150-250 words abstract**, **Keywords** (3-5) and a statement containing the author's present academic or nonacademic position and an address where he or she may be contacted by the editors or interested readers. Authors should place their names on the cover page, but the name should not appear on headers or elsewhere in the body of the article. Full contact details for the corresponding author, including email, mailing address and telephone numbers should also be provided. As the Journal of Supply Chain and Sustainability Research (SCSR) is a peer reviewed journal, the author must be follow the instructions about Ensuring a Blind Review.
8. Make sure that there are no grammatical, spellings, or content errors in articles prior to submitting to the Journal of Supply Chain and Sustainability Research (SCSR).
9. The Journal of Supply Chain and Sustainability Research (SCSR) uses American Psychological Association **(APA)** (7th edition).
10. Please register as **Author** for paper submission online on Thaijo system.