

Advances in Management and Intelligent Technologies

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Advances in Management and Intelligent Technologies

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Integrating ESG Indicators into Corporate Financial Reports: Realistic Dilemmas and Countermeasures—A Paradigm Shift in the Accounting Framework

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Abstract: The integration of Environmental, Social, and Governance (ESG) indicators into corporate financial reports is an inevitable trend aligned with the sustainable development theory in corporate accounting. It also serves as a strategic tool for companies to address environmental and social risks and achieve sustainable development. By incorporating ESG indicators, companies can transform non-financial performance into quantifiable references for decision-making, providing stakeholders with a comprehensive value assessment that goes beyond traditional statements. This process offers theoretical support and practical methods for a paradigm shift in accounting. Guided by Information Asymmetry Theory and Signaling Theory, this study analyzes the realistic dilemmas in integrating ESG indicators into corporate financial reports. The findings indicate that the current challenges can be categorized into institutional, market, technical, and corporate levels. Building on these dilemmas, the study clarifies three principles for a renewed accounting framework: systemic relevance, correlation, and dynamism. It further proposes a corresponding accounting framework system comprising four dimensions: an institutional coordination framework, a technical support framework, a market guidance framework, and a corporate management framework. It is hoped that this research will provide theoretical insights for the paradigm shift in corporate accounting. By advancing corporate progress toward sustainable development goals, it aims to offer stakeholders a more comprehensive and accurate basis for evaluating corporate value.

Keywords: ESG Indicators; Corporate Financial Reports; Accounting Framework; Paradigm Shift

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1. Introduction

As societal concern for ecological and environmental changes grows alongside the development of sustainability theory, public attention is increasingly focused on the social responsibilities of enterprises regarding environmental protection. In 1992, the United Nations Environment Programme Finance Initiative introduced the ESG (Environmental, Social, and Governance) system, establishing it as a crucial set of metrics for evaluating how proactively companies fulfill their social responsibilities. With the collaborative advancement of global climate governance, the concepts of environment, social responsibility, and governance have progressively moved from theory to practice, becoming key standards for measuring

corporate sustainability. In recent years, the frequent occurrence of extreme weather events, heightened public focus on social welfare, and prominent corporate governance issues have led stakeholders—including investors, regulators, and consumers—to look beyond mere financial performance. They increasingly seek comprehensive ESG information to assess a company's performance in fulfilling environmental duties, undertaking social responsibilities, and improving internal governance. According to the Global Sustainable Investment Alliance, global sustainable investment surpassed \$35 trillion in 2022, with the proportion of ESG-related investment products continuing to rise. This demonstrates that ESG factors have become a significant variable influencing capital flows and long-term corporate value.

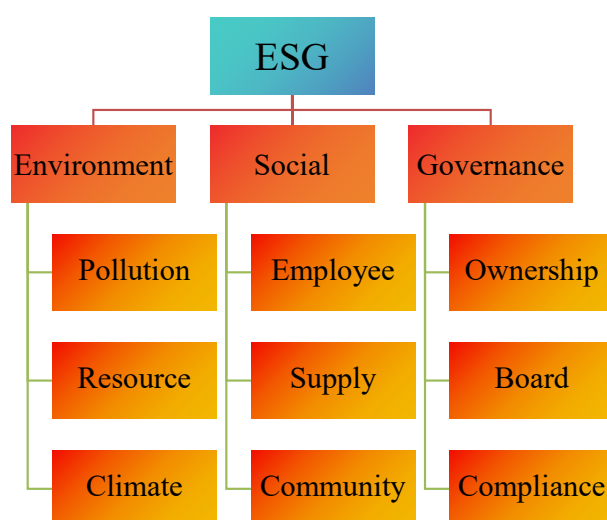
In this context, integrating ESG indicators into corporate financial reporting has emerged as a vital pathway to bridge the connection between a company's financial performance and its sustainability performance. Traditional financial reports primarily focus on financial data such as assets, liabilities, and profits, often failing to comprehensively reflect non-financial information related to ESG. This limitation hampers stakeholders' ability to accurately assess a company's long-term risks and growth potential. However, the integration of ESG metrics with financial reporting is not a simple addition. In practice, it faces a series of challenges, including difficulties in metric measurement, inconsistent data quality, and inadequate adaptability of existing accounting frameworks. Therefore, conducting an in-depth analysis of these dilemmas and exploring solutions from the perspective of a paradigm shift in accounting frameworks holds significant importance. It can not only provide practical guidance for enterprises but also play a crucial role in advancing the sustainable development of Chinese companies and enhancing their international competitiveness.^[10] (Diwan & Binilkumar, 2023).

2. Conceptual Definitions and Theoretical Foundation

2.1 The Concept and Content of ESG

ESG stands for Environmental, Social, and Governance. It is a comprehensive framework used to evaluate a company's performance in the field of sustainable development. Its core lies in measuring a company's impact and fulfillment of responsibilities concerning the environment, society, and internal governance, beyond mere financial performance. Tracing its evolution, the ESG concept originated from the Corporate Social Responsibility (CSR) notion in the 1980s. Over decades of development, it has evolved from a singular advocacy for responsibility into a systematic and measurable comprehensive evaluation standard. Currently, over a thousand institutions globally are utilizing ESG disclosure frameworks established by bodies such as the International Sustainability Standards Board (ISSB) and the Global Reporting Initiative (GRI), promoting the standardization of ESG information disclosure.^[21] (Suresh et al., 2024).

Figure 1: ESG Dimensions and Key Content Framework



From the Concept of ESG, it is evident that its content can be deconstructed into three major dimensions, each encompassing specific focus areas and core indicators.

In the environmental dimension, the primary focus is on the impact of corporate operations on the natural environment and corresponding mitigation measures. Core aspects encompass three main directions: pollution prevention and control, resource

use efficiency, and climate change response.

The social dimension emphasizes the assessment of a company's relationships with its stakeholders and the fulfillment of its social responsibilities. Its core coverage spans three key areas: employee rights and welfare, supply chain responsibility, and community contribution. Regarding employee welfare, this includes compensation and benefits levels, occupational health and safety safeguards, and training and career advancement opportunities. In 2023, China's "Guidelines for Green Development in Outbound Investment and Cooperation" explicitly required enterprises to strengthen environmental and social risk management within their supply chains. In terms of community contribution, indicators include the amount of charitable donations, the number of local jobs supported, and involvement in public infrastructure projects. According to data from the China Charity Alliance, total corporate charitable donations in China exceeded 150 billion yuan in 2023, with over 60% of these donations being ESG-oriented.^[11] (Ellili,2022).

The governance dimension focuses on the standardization and transparency of a company's internal governance structure, covering three main sections: ownership structure, board governance, and compliance and risk management. These three dimensions are interconnected and mutually supportive, collectively forming the comprehensive framework of the ESG evaluation system. This framework also serves as the core basis for corporate ESG information disclosure and indicator measurement.^[16] (Lulaj & Brajković, 2025)

2.2 Foundational Theories

2.2.1 Information Asymmetry Theory

In 1970, while studying the used car market, American economist George A. Akerlof discovered that sellers often possess more accurate information about a vehicle's true condition than buyers. This information asymmetry leads to a "market for lemons" phenomenon, where high-quality cars are driven out of the market by lower-quality ones due to information opacity, eventually leaving only low-quality vehicles available. Akerlof defined this market failure as information asymmetry. Information asymmetry is a common market phenomenon, and its negative consequences primarily manifest as adverse selection and moral hazard. Adverse selection occurs when buyers, due to a lack of transparent information, lower their offer prices to mitigate potential losses. Over time, this leads to inferior products dominating the market—the "lemons" problem. Moral hazard refers to situations where the party with an information advantage engages in irresponsible behavior for personal gain, while the disadvantaged party remains unaware, thus triggering moral hazard.

Under the traditional financial reporting system, companies, as information providers, hold detailed data on their own operations, environmental impacts, and social responsibility performance.^[6] (Choi & Lee, 2024) In contrast, external stakeholders such as investors and regulators are in a position of information disadvantage. This information asymmetry can prevent stakeholders from accurately assessing a company's true ESG performance, thereby affecting their investment decisions and the effectiveness of regulation. Particularly when facing capital market choices, companies might, driven by self-interest, selectively disclose favorable ESG information while concealing or downplaying unfavorable aspects. This leads to external stakeholders being unable to gain a comprehensive understanding of a company's ESG risks. Therefore, integrating ESG indicators into corporate financial reports to enhance information transparency is a crucial pathway to alleviating information asymmetry and improving market efficiency.^[8] (Da, 2025).

2.2.2 Signaling Theory

Signaling Theory is a significant management theory developed on the foundation of information asymmetry, forming, together with theories of market asymmetry, a cornerstone of information economics. The theory was formally introduced by Michael Spence in 1973 in "Job Market Signaling." It explains how the party with an information advantage can mitigate information asymmetry through signaling.

When a company actively discloses ESG information, it is essentially sending positive signals to the capital market, investors, and creditors. These signals indicate that the enterprise is capable of proactively fulfilling environmental responsibilities, social responsibilities, and improving corporate governance.^[23] (Vanina & Dian,2025). F This often implies that the company emphasizes long-term development and possesses sufficient cash flow and robust operational capabilities. Simultaneously, a company's ESG disclosure signals its active commitment to social responsibility and the establishment of a favorable public

relationship with the government. These signals enhance the company's social responsibility image, bolster investor and creditor confidence, and make them more willing to provide capital, potentially at a lower required rate of return. Actively engaging in ESG disclosure can also, to some extent, mitigate the problems of adverse selection and moral hazard arising from information asymmetry, enabling the company to secure needed capital at a lower cost. Therefore, the integration of ESG information into corporate financial reports is, in essence, the transmission of positive corporate signals to investors. By demonstrating the company's positive, steady, and long-term development potential, it aims to obtain financing at a lower cost.

3. Practical Challenges in Integrating ESG Indicators into Corporate Financial Reports

3.1 Institutional Level: Ambiguous ESG Disclosure Standards and Fragmented Regulatory Frameworks

Currently, the ESG information disclosure system lacks unified standards, exhibiting significant fragmentation across different countries and regions, with notable disparities in the disclosure standards established by various institutions. Taking the ESG rating system of MSCI in the United States as an example, its core logic lies in screening material issues within various industries, which serve as the key basis for evaluating corporate ESG performance. In contrast, China's existing ESG-related guidelines place greater emphasis on aligning evaluation criteria with policy orientations, with indicators often designed around national initiatives such as energy conservation, emission reduction targets, and the "dual-carbon" goals. Such discrepancies in standards require enterprises operating in multiple markets to comply with different regulatory requirements, incurring additional compliance costs and increasing their operational burdens.^[17] (Malik & Kashiramka, 2025). More critically, current mainstream accounting standards lack explicit rules for the recognition and measurement of ESG elements. Whether it is the provision method for contingent liabilities arising from climate risks, the capitalization of human capital investments, or the quantitative accounting of biodiversity loss, specific operational guidance is absent. This situation not only grants enterprises considerable subjective discretion in ESG information disclosure, leading to insufficient standardization and consistency in the content disclosed, but may also incentivize regulatory arbitrage. Some companies even deliberately select disclosure frameworks favorable to themselves, categorizing environmental expenses that should be accounted for as regular costs under "non-recurring gains and losses," thereby diluting the actual impact of ESG costs on corporate financial management^[22] (Tian et al., 2025).

Although the International Sustainability Standards Board has been promoting the establishment of globally unified ESG disclosure standards, differences in national priorities regarding climate policies and sensitivities to social issues have created conflicting interests.^[3] (Bogdan et al., 2025) As a result, the finalized standards must undergo localization adjustments to accommodate the actual conditions of different countries. These adjustments, in turn, exacerbate compatibility issues between different standards, creating further obstacles to the advancement of a globally unified disclosure framework.^[12] (Gafni et al., 2024).

3.2 Market Level: Mismatch Between Supply and Demand for ESG Information and Inefficient Pricing Mechanisms

With the increasing adoption of ESG principles, institutional investors' demand for ESG information has shifted from initial compliance screening to a value-discovery phase. They now seek to leverage ESG data to identify corporate long-term growth potential and inform investment decisions. However, from the corporate perspective, current ESG disclosure practices largely remain at the risk-aversion level, primarily aimed at meeting regulatory compliance requirements rather than proactively communicating value to the market. To align with the preferences of ESG rating agencies and improve their ratings, some companies even resort to "greenwashing" tactics, such as exaggerating the proportion of green revenue in total revenue or providing vague or evasive disclosures regarding negative ESG-related incidents. These practices further exacerbate the problem of ESG information asymmetry in the market, interfering with investors' judgment.^[13] (Kilian, 2021)

The root cause of corporate falsification of ESG information lies in the opaque transmission mechanism between ESG performance and financial performance, making it difficult to establish a clear correlation between the two. For example, in the clean energy sector, investment returns typically take a decade or longer to materialize. Current mainstream corporate

valuation models struggle to capture such long-term value accurately, making it challenging to reasonably assess the long-term financial impact of ESG investments. The influence of ESG risks in the supply chain on a company's gross margin involves multiple variables, including changes in customer demand, the severity of regulatory penalties, and fluctuations in market reputation, making it difficult for investors to form stable expectations about this impact. The imperfections in market pricing mechanisms are also directly reflected in the irrational volatility of ESG premiums. During periods of optimistic market sentiment, companies with strong ESG performance may receive valuation premiums that far exceed their fundamentals. However, when the market encounters a "black swan" event, the entire ESG-related sector may face panic selling, leading to significant valuation declines. This inefficient market pricing situation, in turn, discourages companies from voluntarily disclosing high-quality ESG information, ultimately leading to a "lemons problem" of adverse selection, which undermines the long-term healthy development of the ESG market.

3.3 Technical Level: Challenges in ESG Data Collection and Bottlenecks in Value Quantification

ESG data is typically unstructured, which fundamentally conflicts with the rigid requirements of financial reports for quantified information. In terms of specific data types, environmental data, such as carbon emissions, often relies on third-party verification agencies estimating values using specific methodologies. Enterprises themselves find it difficult to achieve precise carbon emission measurements. Social indicators, such as employee satisfaction, are mostly gathered through surveys and contain a significant amount of subjective content. Such data struggles to meet core accounting information quality requirements, such as horizontal comparability and verifiability. Moreover, challenges in quantification also arise in translating ESG value into financial value. Taking carbon reduction benefits as an example, they need to be converted into measurable financial gains through carbon pricing mechanisms. However, significant price differences across regional carbon markets and the uncertainty surrounding carbon policy adjustments undermine the stability of the benchmarks used in calculating carbon reduction benefits, significantly reducing the accuracy and reliability of the results. Social benefits, such as community contributions, often lack mature market pricing mechanisms. Consequently, related disclosures usually remain at the descriptive level, offering detailed explanations of contributions but failing to provide quantitative data support, which falls short of the quantitative information requirements of financial reporting. Governance indicators similarly face technical difficulties in quantification. For example, governance metrics like board independence scores can be quantified using methods such as the entropy weight method or the Analytic Hierarchy Process (AHP). However, establishing a direct and clear correlation between these scores and the effectiveness of corporate financial risk prevention is challenging. The accuracy of such indicator data is difficult to verify. For investors and regulators who are not involved in the long-term day-to-day management of the company, it is particularly hard to effectively demonstrate the actual impact of governance levels on corporate financial health. ^{[4][5]}(Chen & Lai,2025) (Chen & Rodger,2025)

3.4 Corporate Level: Insufficient Adaptation of Internal Management Systems and Weak Motivation for Disclosure

From the perspective of internal corporate operations, a significant gap exists between existing management systems and the need to integrate ESG metrics into financial reports. Currently, the majority of companies globally are small and medium-sized enterprises (SMEs), most of which have not established specialized ESG management departments. ESG tasks are often assigned as additional responsibilities to departments like finance or administration. This lack of dedicated oversight leads to issues such as data omissions and inconsistent standards, as the collection, organization, and alignment of ESG data with financial data lack centralized coordination ^[7] (Chamera, 2025) Taking the collection of environmental cost data as an example, due to production processes, such data may be scattered across departments like production and procurement and not synchronized promptly with the financial system, hampering the efficiency of integrating ESG metrics with financial reports. Furthermore, ESG-related internal system development lags in most companies, lacking clear regulations concerning ESG data quality control and disclosure procedures. Although some enterprises have begun disclosing ESG information, the absence of standardized data verification mechanisms leads to issues with accuracy and completeness in the disclosed ESG data, further undermining the credibility of the integration of ESG information with financial reports. Moreover, corporate ESG disclosures often entail hiring third-party organizations to verify data and upgrade information systems, requiring

additional investment of human and material resources. Given the difficulty in seeing direct economic returns in the short term, this situation leads to a lack of willingness to invest, particularly among SMEs.

4. Guiding Principles for the Accounting Framework for Integrating ESG Indicators into Corporate Financial Reports

The accounting framework for integrating ESG indicators into corporate financial reports should adhere to three overarching principles: systematic integration, relevance, and dynamism.

4.1 Principle of Systematic Integration

The principle of systematic integration requires the comprehensive and in-depth incorporation of ESG elements into the entire financial reporting process, encompassing recognition, measurement, recording, and reporting. This approach avoids fragmented improvements limited to isolated aspects and ensures the organic fusion of ESG information with financial data. During the recognition phase, it is essential to clarify the asset attributes of emerging ESG elements, such as carbon emission rights and human capital, and determine whether they meet the criteria for accounting element recognition. In the measurement stage, scientifically sound models for environmental cost allocation should be developed to appropriately distribute environmental expenditures to relevant products or business activities. Concurrently, investments in governance should be integrated into the goodwill assessment system to fully reflect the contribution of governance quality to corporate value. In the recording process, interface standards between ESG data and the company's existing financial systems must be established to facilitate efficient alignment and synchronized recording of ESG and financial data. In the final reporting stage, non-financial information should be effectively linked with the three primary financial statements—the balance sheet, income statement, and cash flow statement—enabling stakeholders to clearly discern the tangible impact of ESG factors on the company's financial position, operating performance, and cash flows.

4.2 Principle of Relevance

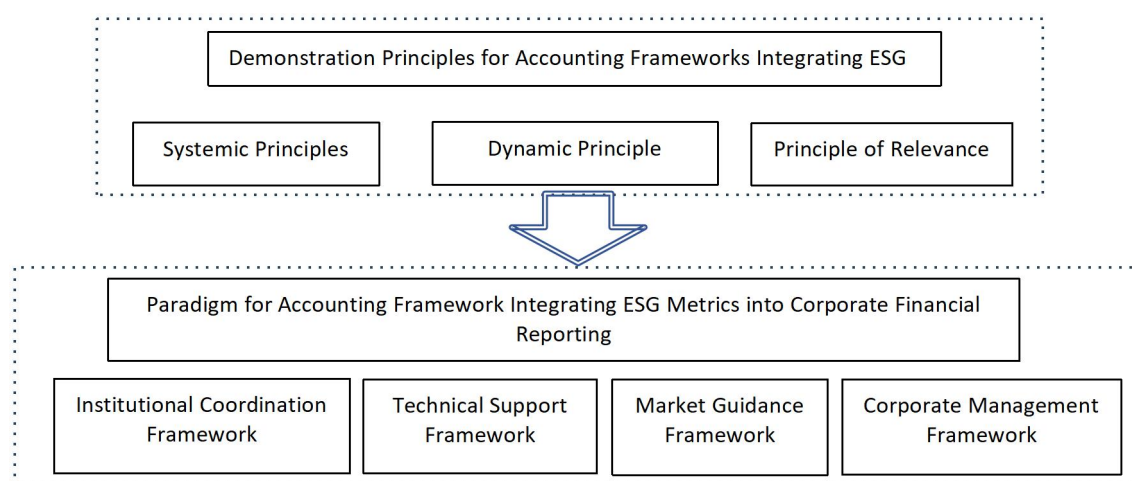
The principle of relevance places high emphasis on aligning ESG information with the decision-making needs of stakeholders, avoiding redundant details that may hinder judgment. On one hand, it requires the selection of core ESG indicators tailored to industry-specific characteristics. For example, high-energy-consumption industries should prioritize disclosing carbon emissions and energy consumption data; the manufacturing sector should focus on supply chain social responsibility indicators; and the financial industry should highlight information related to green finance and ESG risk exposures. This ensures that disclosed content is closely tied to the operational substance of the business and the concerns of stakeholders. On the other hand, it necessitates clarifying the logical connection between ESG information and financial data. Items such as “green revenue” and “environmental costs” should be separately presented in the income statement, while the notes to the financial statements should explain the impact of ESG investments on long-term asset items in the balance sheet. This assists investors in intuitively assessing the transmission relationship between ESG performance and financial outcomes.^[18] (Palas et al., 2025)

4.3 Principle of Dynamism

The principle of dynamism requires that the design of the integration pathway and the disclosure indicators remain responsive to policy changes and technological advancements in the ESG domain. This involves establishing a dynamic adjustment mechanism for ESG indicators, regularly refining the recognition scope and measurement methods for ESG elements in line with updates to international standards, shifts in domestic policy direction, and evolving market demands. In particular, as carbon market mechanisms mature, emerging carbon assets such as carbon allowances and carbon options should be progressively incorporated into the scope of accounting recognition. This ensures that the pathway for integrating ESG indicators into financial reports can be continuously optimized in response to changes in the external environment.^[15] (Li & Lai, 2025).

5. Construction of Accounting Framework for Incorporating ESG Indicators into Enterprise Financial Reports

Figure 2: Accounting Framework Demonstrating the Integration of ESG Indicators into Corporate Financial Reporting



5.1 Institutional Coordination Framework: Resolving Ambiguous Standards and Regulatory Fragmentation

To address the current divergence in ESG standards at the institutional level, the disclosure criteria issued by the International Sustainability Standards Board should serve as the foundational framework, unifying the principles for recognizing ESG elements and their measurement bases. On the other hand, domestic regulatory agencies should formulate localized supplementary guidelines in line with national policy objectives, refining disclosure requirements for specific indicators to avoid the “inadaptability” that may arise from directly applying international standards. Simultaneously, a cross-departmental regulatory coordination mechanism should be established.^[9](Darma et al., 2025) Led by the Ministry of Finance, an “ESG Accounting Disclosure Coordination Group” should be formed in collaboration with departments such as the Ministry of Ecology and Environment, the Ministry of Human Resources and Social Security, and the State-owned Assets Supervision and Administration Commission to standardize regulatory approaches. Clear standards should be defined for integrating environmental data, such as pollutant discharge information from environmental authorities, and social data, such as employee rights records from human resources departments, with ESG information in financial reports. This will prevent companies from incurring multiple compliance costs due to conflicting requirements from various regulatory bodies. Additionally, mechanisms to penalize regulatory arbitrage should be strengthened. Companies that deliberately select disclosure frameworks or manipulate ESG data should be included in the capital market integrity records to increase the cost of non-compliance.^[2] (Bigelli et al., 2023) ^[14] (Lai et al., 2026)

5.2 Technical Support Framework: Overcoming Data Collection and Value Quantification Bottlenecks

To address the challenges of unstructured ESG data and value quantification at the technical level, a multi-source data integration mechanism involving enterprise self-collection, third-party verification, and government data sharing should be established under the leadership of regulatory authorities. In this process, enterprises must develop specialized ESG data ledgers to ensure continuous and complete recording of core data such as carbon emissions and employee satisfaction. At the same time, third-party institutions with ESG verification qualifications, such as accounting firms, should be engaged to professionally verify the authenticity of the ESG data collected by enterprises and issue data quality reports, providing external assurance of data credibility. Furthermore, enterprises should connect with government public data platforms to access official data, including pollution monitoring data from environmental protection departments and employee social security records from human resources departments. This data should be used for cross-validation, further enhancing the verifiability and comparability of ESG data across different enterprises.

In the value quantification phase, corresponding quantification models should be developed based on the characteristics of different ESG dimensions. For the environmental dimension, a carbon price-linked measurement model should be established, using actual transaction prices in regional carbon markets as the baseline accounting benchmark. Dynamic adjustment coefficients should be incorporated to account for expected changes in carbon policies. This approach aims to accurately

calculate the actual benefits generated by corporate carbon reduction efforts and transform them into measurable social value, thereby addressing the issue of excessive qualitative descriptions and insufficient quantitative data in social dimension disclosures. For the governance dimension, a financial impact model for governance effectiveness should be developed. This model would analyze the correlation between governance indicators, such as board independence scores and corporate anti-corruption investments, and financial data, such as the incidence of financial risks and audit adjustment amounts. Regression analysis should be employed to establish a quantitative relationship, thereby clearly demonstrating the actual impact of corporate governance levels on financial health.

5.3 Market Guidance Framework: Balancing Information Supply and Demand and Optimizing Pricing Mechanisms

To improve the efficiency of ESG information supply and demand, relevant regulatory authorities should strengthen the guidance on ESG information needs for institutional investors. For instance, the China Securities Regulatory Commission could require public funds, insurance asset management companies, and other institutions to mandatorily disclose their use of ESG information in investment decision reports, thereby incentivizing enterprises to proactively disclose high-quality information. Concurrently, stock exchanges should be encouraged to establish an “ESG Information Disclosure Quality Rating System,” categorizing enterprises into four tiers—A, B, C, and D—based on the completeness, accuracy, and relevance of their disclosures.^[20] (Soboleva & Zuga, 2022) The rating results should be linked to the eligibility of listed companies for activities such as refinancing and equity incentives, creating positive incentives. On the other hand, the ESG value pricing mechanism should be refined. Securities firms and fund companies should be guided to develop “ESG Long-term Value Valuation Models,” incorporating the return periods of long-term projects like clean energy investments into discount rate adjustment factors to avoid short-term valuation biases.^[24] (Wu & Abeysekera, 2023) Stock exchanges should establish “ESG Sector Indices,” selecting highly-rated enterprises as constituent stocks to attract long-term capital inflows and stabilize irrational fluctuations in ESG premiums. Additionally, relevant departments should collaborate to establish a rapid response mechanism for negative ESG information. When an enterprise experiences a negative ESG event, the stock exchange should promptly require the disclosure of the event’s financial impact to prevent market panic selling and enhance pricing efficiency.

5.4 Corporate Management Framework: Improving Internal Adaptation and Enhancing Disclosure Motivation

Integrating ESG indicators into corporate financial reports will inevitably impact the internal organizational structure and management mechanisms of enterprises. Therefore, in terms of organizational structure, companies should establish a dedicated “ESG Accounting Management Department,” staffed with full-time ESG accounting personnel responsible for integrating ESG data with financial systems and ensuring the recognition and measurement of ESG information. This will prevent ambiguities in responsibility that may arise from part-time management. Simultaneously, ESG performance should be incorporated into management evaluation indicators, linking the quality of ESG disclosures and the effectiveness of ESG cost control with executive compensation to increase management’s emphasis on these areas. (Aluchna et al., 2022)^[1]

In terms of cost allocation, to encourage enterprises to advance the integration of ESG and financial reporting, the government can utilize measures such as tax incentives, fiscal subsidies, and optimized financing. For investments in ESG data collection and system upgrades, enterprises could receive fiscal subsidies of up to 30%. Companies with outstanding ESG performance may benefit from reductions in corporate income tax. Additionally, ESG-specific bonds could be introduced in the capital market, allowing enterprises to use ESG project revenues as a source for debt repayment, thereby lowering financing costs.^[19] (Rossi & Candio, 2023) Furthermore, enterprises should be encouraged to engage in value-added applications of ESG information, using high-quality ESG reports as credit credentials for supply chain cooperation and overseas market expansion. This approach enables companies to derive tangible benefits from disclosure, stimulating proactive disclosure motivation.

6. Conclusion

The integration of ESG indicators into corporate financial reports represents not only an innovation in the accounting field

but also a crucial initiative to advance corporate sustainable development and respond to the global green transition. Although numerous practical challenges currently exist at the institutional, market, technical, and corporate levels, these issues—such as ambiguous standards and fragmented regulation; difficulties in data collection and value quantification bottlenecks; mismatched information supply and demand coupled with inefficient pricing mechanisms; and inadequate internal adaptation and weak disclosure motivation—can be effectively addressed. This can be achieved by establishing systematic, relevant, and dynamic guiding principles for the accounting framework, and constructing specific frameworks across four dimensions: institutional synergy, technical support, market guidance, and corporate management.

Looking ahead, as ESG principles become more deeply ingrained, policy environments continue to optimize, and technological methods keep advancing, the integration of ESG indicators with corporate financial reports will become even more seamless and efficient. This will provide stakeholders, including enterprises, investors, and regulators, with more comprehensive, accurate, and valuable information, thereby contributing to the green, low-carbon, and high-quality development of the economy and society.

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Research on Architecture Design and Optimization of Cloud-Edge Collaborative Emergency Communication System for Low-Latency Response

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Abstract: In terms of the base station destruction, link disconnection and resource contention in the disaster environment of the traditional emergency communication system, there is a clear contradiction between the physical vulnerability of the communication link and its requirements for low-latency response. This paper proposes a cloud-edge collaborative emergency communication architecture to solve this problem. Based on edge collaborative computing and the ability of elastic expansion of the cloud, the architecture creates a communication network with fault self-healing ability by combining task replication scheduling and dynamic resource allocation. The task replication mechanism uses computing resources in exchange for communication efficiency. It can still ensure the continuous execution of tasks when key nodes fail. Dynamic resource allocation is to monitor the load of nodes, the quality of links and the state of energy consumption in real time, so as to achieve the purpose of adaptive distribution of tasks and on-demand scheduling of resources. On this basis, the improved ant colony optimization algorithm is used to complete the rapid deployment of emergency tasks. The efficiency of scheduling and the speed of convergence are improved by improving the pheromone update strategy, the design of heuristic function and the selection of nodes. From the results of theoretical analysis and simulation experiments, under a simulated disaster scenario with three edge node failures (out of a total of 10 edge nodes) and a concurrent task scale of 300-500, the proposed architecture reduces the average task response delay by approximately 40% compared to a baseline cloud-edge collaborative architecture without task replication. Furthermore, the system's task completion reliability reaches over 96% under these conditions, demonstrating significant performance advantages, which can well meet the needs of real-time and stability of communication in emergency situations.

Keywords: Emergency Communication; Cloud Edge Collaboration; Low Delay Response

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1. Introduction

In the emergency communication scenario, because it is close to the data source and the transmission distance is short, edge computing can be used to reduce the service delay to a certain extent^[1]. However, relying solely on edge nodes has the disadvantages of limited computing resources, small coverage, and poor power supply capacity. When the number of concurrent tasks increases sharply in the early stage of the disaster, it is easy to cause local overload. Relying solely on a centralized cloud center, although it has strong computing and storage capabilities, it is very sensitive to the stability of

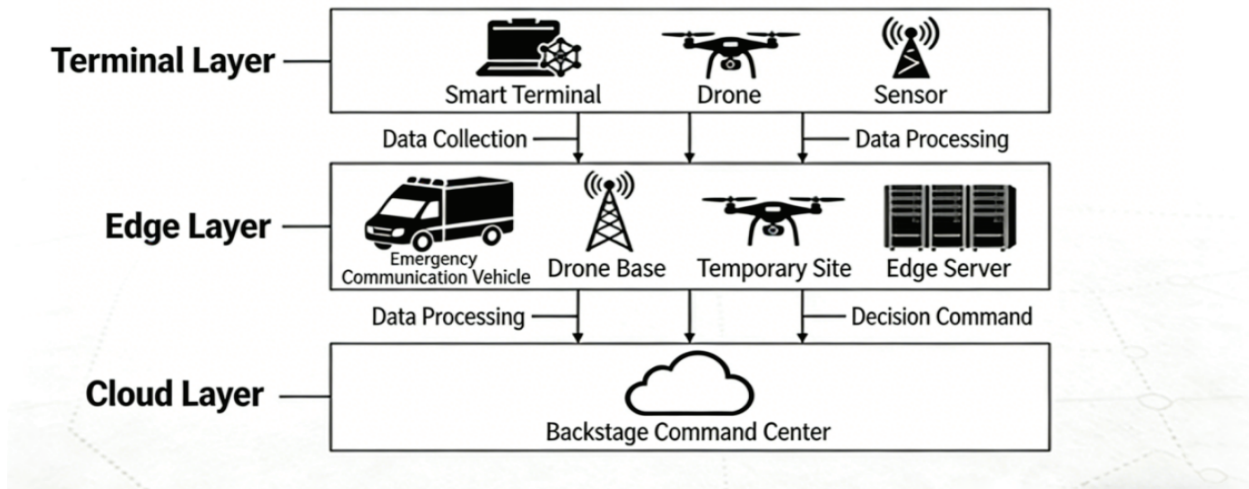
the network link ^[2]. Once the backbone network is interrupted or the base station is damaged, the entire system will be paralyzed. Therefore, edge and cloud have their own advantages, but they cannot independently meet the dual needs of high concurrent access and high reliable continuous service in emergency scenarios. Cloud-side collaboration is the main way to solve this problem ^[3]. This paper takes low-latency response as the design core, designs and optimizes from the cloud-edge collaborative architecture, mainly solves the fault tolerance problem under the conditions of node failure and resource fluctuation, and designs an emergency communication system with adaptive scheduling of task load fluctuation.

2. Emergency Communication System Architecture Design

2.1 Three-tier Collaborative Overall Architecture

According to the main requirements of emergency communication low-latency response, this paper mainly proposes a three-tier collaborative architecture of end, edge and cloud. Each layer has clear responsibilities and cooperates with each other to lay the foundation for low latency from the architecture. The terminal layer completes data acquisition and preliminary processing, and uses a lightweight protocol to achieve local rapid response; the edge layer is the main computing node, which completes tasks such as real-time analysis, task scheduling, and nearby decision-making, which greatly shortens the distance of data transmission. The cloud layer performs global resource co-ordination, complex task processing, model training, etc., and can achieve elastic expansion and task takeover when the edge nodes are overloaded or failed. The three layers rely on dynamic link quality perception and adaptive offloading to achieve coordination, ensuring that tasks are performed with the lowest delay in the most suitable place. In a simulated weak-signal area with a radius of 500 meters where fixed edge node coverage is absent, a simulation experiment deploying a single UAV as an aerial edge node was conducted. The experimental results show that, for 200 delay-sensitive tasks (e.g., real-time video analysis), adding this UAV-assisted edge computing reduces the average task response time by approximately 49.6% (from 1.45 seconds to 0.73 seconds) compared to the scenario relying solely on a cloud center via a long-distance, low-bandwidth backup link. This solves the problem of incomplete coverage of fixed edge nodes and enhances the ability of the architecture to guarantee low latency in extreme environments. which solves the problem of incomplete coverage of fixed edge nodes and enhances the ability of the architecture to guarantee low latency in extreme environments. As shown in Figure 1:

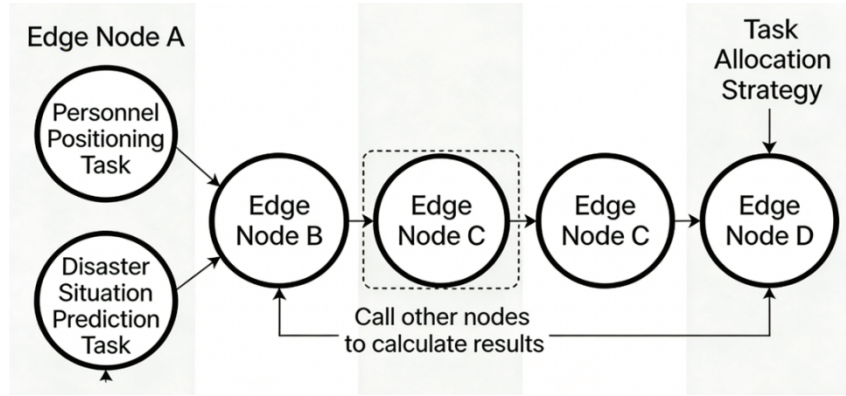
Figure 1: Three-tier collaborative overall architecture



2.2 Task Replication Scheduling Mechanism

In the emergency communication scenario, the dependencies between tasks are more complex ^[4], and the data transmission time is one of the main factors that cause low delay response. In order to overcome this core bottleneck, this architecture mainly uses the task replication scheduling strategy. The basic idea is to exchange computing for communication, that is, to a certain extent, to increase the consumption of computing resources, so as to achieve the purpose of greatly reducing communication delay. As shown in Figure 2.

Figure 2: Task replication scheduling mechanism



In a simulation with 10 edge nodes and 400 randomly generated tasks with complex dependencies, we compared a ‘task replication’ strategy (with a maximum replication factor of 3 for critical tasks) against a ‘no replication’ baseline. The experimental results show that a reasonable task replication strategy can increase the system’s response speed by 1.45 times, i.e., reduce the average task completion delay by approximately 31% (from 820 ms to 566 ms). However, it is necessary to take into account the constraints of resources, and the competition of resources between edge nodes cannot be intensified due to excessive replication, thereby increasing the delay and achieving the balance between ‘low latency’ and ‘resource efficiency’.

2.3 Dynamic Resource Allocation Mechanism

In the emergency communication scenario, the task load has a strong suddenness and a high degree of unpredictability. In the early stage of the disaster, the field data will flow to the system in a very short period of time, and the task load will increase exponentially. If the system uses a fixed resource allocation method and cannot make corresponding adjustments according to the real-time state, it is easy to cause the computing resources of some edge nodes to be depleted instantly and overloaded, and the front-end backhaul link becomes very congested due to a sudden increase in traffic, which leads to a significant increase in task processing delay and has a serious impact on the timeliness of emergency response^[5].

Therefore, this architecture designs a dynamic resource allocation algorithm, which does not rely on static preset strategies to work, it is based on the continuous perception and timely response of the system state. The algorithm uses distributed monitoring components to obtain the main state indicators such as computing resource utilization rate, task queue length, residual energy level, packet loss rate of communication links between nodes, bandwidth occupancy, and round-trip delay of each edge node. Nodes with small computing load, good link quality, and sufficient energy are first sent to high real-time or high-priority tasks. For nodes with load greater than the threshold or unstable links, tasks are pulled to adjacent available nodes to prevent local resource constraints from causing the overall system performance to decline. The algorithm adds a mechanism that relies on short-term load trends to predict, and makes resource reservation and task pre-distribution in advance before the peak load, thereby enhancing the forward-looking and smoothness of scheduling decisions. The system uses the closed-loop control mechanism of resource awareness and scheduling execution to control the response delay within an acceptable range under the emergency situation of large fluctuations in task load, and provides strong resource support for low-latency response. The main design points and quantitative results are shown in table 1:

Table 1. Dynamic resource allocation core elements and effect table

decisive variables	core aim	Specific allocation strategy/mechanism description	Quantitative benefits/description
Core optimization objectives	Minimize task response delay	As the highest priority of resource allocation, all decisions are made around reducing task waiting and processing time.	—
Key factor one	Current load rate of node	Prioritize task allocation to nodes with load rate < 60% to avoid processing bottlenecks caused by high-load nodes.	Achieve load balancing to prevent a single point of overload

decisive variables	core aim	Specific allocation strategy/mechanism description	Quantitative benefits/description
Key factor two	The amount of data to be transmitted	Assign to local or adjacent nodes Assign to local or adjacent nodes to reduce data transmission time.	Reduce network transmission delay
Key factor three	link quality	Delay-sensitive tasks are preferentially allocated to nodes with link packet loss rate <5% to ensure transmission stability.	Ensure high reliability transmission
Key factor four	Node energy consumption state	Avoid assigning to nodes with energy consumption less than 20%, and prevent the node from failing in the middle of the task due to the exhaustion of power consumption.	Improve system robustness and reduce task interruption risk
auxiliary mechanism	Load forecasting and resource reservation	Based on historical data, combined with deep learning methods to predict future task arrival patterns, resource reservation is performed in advance.	The accuracy of resource allocation is increased by more than 35%.
comprehensive effect	Delay control and energy consumption optimization	Through the above strategy combination, the resource utilization efficiency is optimized while ensuring low latency.	The energy consumption of edge nodes is reduced by about 20%.

3. Low-latency Task Scheduling Optimization Algorithm

3.1 Problem Modeling

The task scheduling problem in the emergency communication system is to minimize the task response delay while satisfying the resource constraints and task dependence constraints. In this paper, the problem is modeled as: given the emergency task set , there is a clear dependency between tasks, and the computing node set, including edge nodes and cloud nodes. Each task can be assigned to one or more edge nodes to perform. The goal is to minimize the overall task response delay of the system, taking into account the system energy consumption and resource overhead. The optimization objective is , where f_T represents the average task completion time, f_E represents the total energy consumption of the system, and f_R represents the resource overhead caused by task replication. Constraints include node computing power constraints, communication bandwidth constraints, task dependency constraints, and node energy consumption constraints. This problem is a NP-hard problem. When the task size is larger than 300, the exact optimal solution can not be solved in polynomial time. Designing efficient heuristic algorithms to achieve near-optimal scheduling under low-latency targets becomes the key.

3.2 Task Scheduling Algorithm Based on Improved Ant Colony Optimization

Ant colony optimization algorithm has good adaptability and optimization ability in task scheduling problem by simulating the path optimization behavior of ant foraging ^[6]. However, its standard version has some shortcomings, such as slow convergence speed, easy to fall into local optimum, and low delay demand in emergency scenarios. In this paper, according to the characteristics of emergency communication scenarios, the standard ant colony algorithm is improved, and a task scheduling optimization algorithm for low latency is designed. The core improvement points focus on low latency targets, as follows:

- (1) Pheromone update strategy optimization: In the traditional ant colony algorithm, the pheromone update rules of all paths are consistent, which cannot reflect the priority difference of emergency tasks. In this paper, the task priority factor is introduced, and the tasks are classified according to the emergency priority, such as life rescue-related tasks, as the highest priority. The high priority tasks on the critical path will obtain higher pheromone enhancement coefficients, and guide the subsequent 'ants' to assign high quality edge nodes to high priority tasks to ensure the low delay execution of core tasks.
- (2) Heuristic function design optimization: The expression of heuristic function can be expressed as:

$$\eta(i, j) = \alpha \cdot (1/(\text{load}_{\text{ate}}(j))) + \beta \cdot (1/(\text{transmission}_{\text{delay}}(i, j))) + \gamma \cdot (1/(\text{replication}_{\text{times}}(i)))$$

Where α , β , γ are the weight coefficients, and β is the highest priority to ensure low delay.

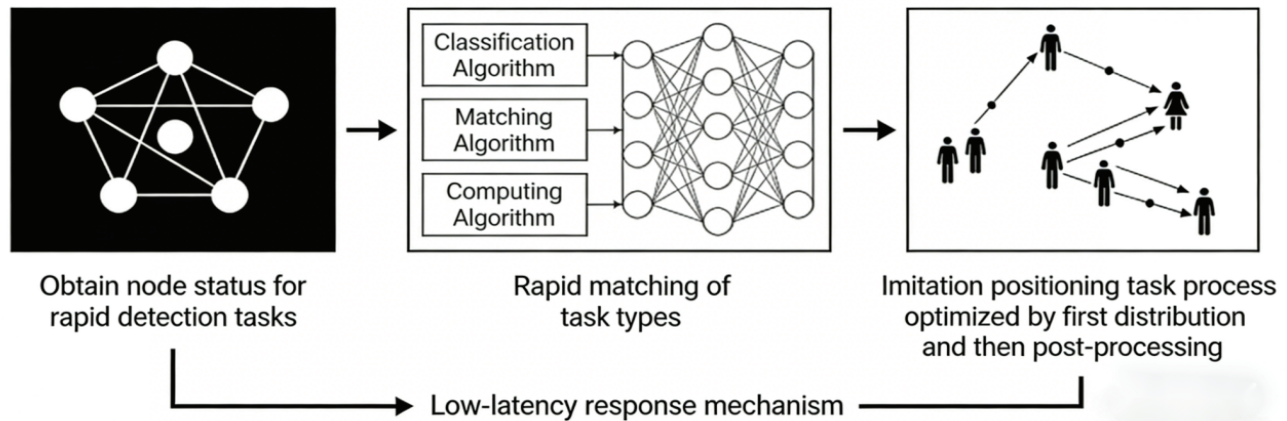
- (3) The improvement of node selection mechanism. The ϵ -greedy algorithm is used to select nodes, which considers both the accuracy of optimization and the speed of convergence. In the first 30% iterations of the algorithm, ϵ is set to be 0.8, and a new

path is randomly explored with high probability to prevent falling into local optimum in the early stage. In the later 70% of the iteration times of the algorithm, the number of iterations is gradually reduced from 0.2, the probability of greedy selection is increased, and the approximate optimal solution is quickly converged to ensure that the scheduling algorithm can quickly respond to the sudden demand of emergency tasks.

3.3 Cold Start Optimization Strategy

In the early stage of the emergency scenario, the system has not accumulated enough historical data such as node load and link quality. The scheduling algorithm will encounter the problem of cold start, which is easy to cause unreasonable task allocation, thereby increasing the response delay, and ensuring that the system can achieve low-latency response at the beginning. The effect is shown in Figure 3:

Figure 3: Cold start optimization strategy of emergency scenario



4. Key Technology Implementation and Efficiency Analysis

4.1 Lightweight Containerized Deployment

This architecture regards the Docker container as the basic unit of application encapsulation and deployment. Compared with the virtual machine, in a comparative test on a standard edge node (4 vCPUs, 8GB RAM), the average startup time for a Docker container running a lightweight emergency data processing application was measured at 350 ms, which is more than 80% faster than a traditional KVM-based virtual machine (which took over 2.1 seconds to boot the same application). Concurrently, the container's idle resource consumption was over 60% lower than that of the virtual machine. This allows for rapid deployment and migration of emergency applications, providing basic support for low-latency response. Container image management uses hierarchical storage to deploy the basic image to each edge node in advance. When the application is updated, only the incremental layer is transmitted, which greatly reduces the overhead of network transmission and thus reduces the delay. At the same time, the container orchestration tool is used to manage and dynamically schedule the edge node containers to ensure the rational allocation of resources.

4.2 Cross-node Data Synchronization

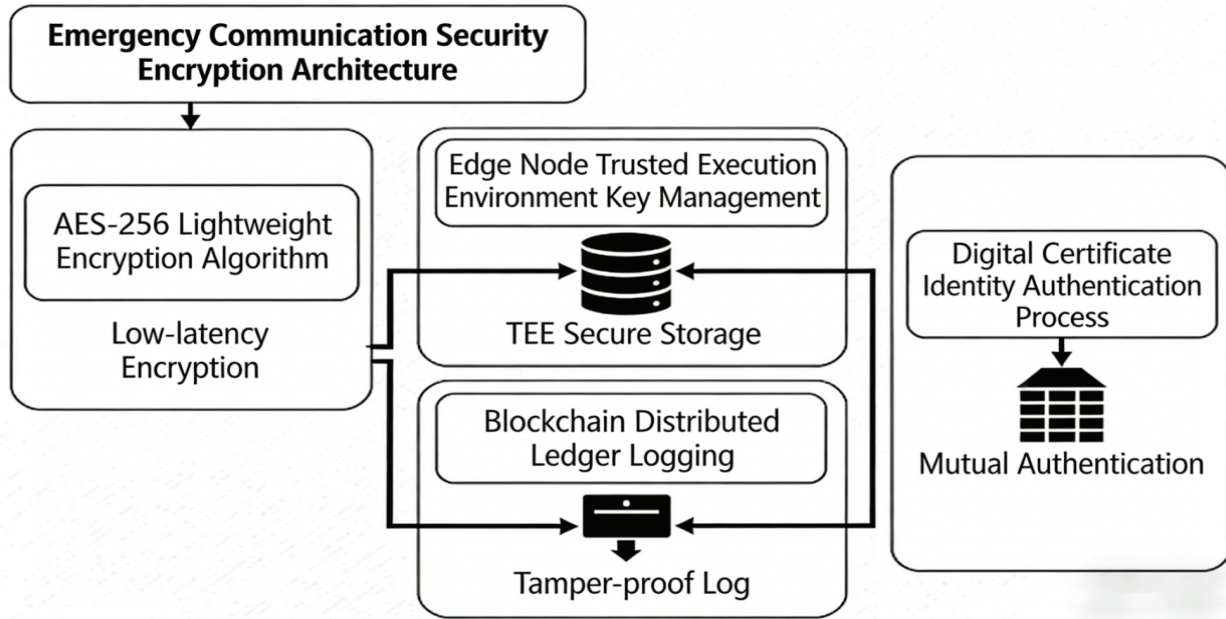
This architecture uses the final consistency model, and uses a distributed message queue (RocketMQ lightweight version) to achieve cross-node data synchronization. The key data uses synchronous replication to ensure that the data is returned after the completion of data writing. Confirmation, non-critical data uses asynchronous replication, does not need to wait for confirmation, and reduces latency overhead. For the problem of network interruption, the node adopts the method of local cache, and the data will be automatically synchronized when the network restarts, so as to prevent the repeated execution of tasks caused by data loss.

4.3 Security and Privacy Protection

Emergency communication includes sensitive data such as the location of rescuers and medical information of the wounded. The security standard is high, but encryption protection will increase the time of data transmission and processing. This architecture uses a lightweight encryption mechanism to minimize latency while ensuring security. The AES-256 lightweight encryption algorithm is used to transmit data and store data. In a benchmark test encrypting 1 MB data blocks (simulating a

typical emergency data packet), the AES-256 algorithm achieved an average encryption/decryption latency of 15 ms. This represents a delay reduction of approximately 25% compared to the widely-used but more computationally intensive RSA-2048 algorithm (which averaged 20 ms for the same operation), while maintaining a comparable level of security. As shown in Figure 4:

Figure 4: Emergency communication security architecture



4.4 Effectiveness Analysis

In order to verify the performance of the architecture, a simulation environment is built based on CloudSim Plus (v6.4.0), and a custom module for task replication and dynamic resource allocation is added. In the experiment, the hardware configuration is : 1 cloud center (32 vCPU, 64 GB RAM) and 10 edge nodes (4 vCPU, 8 GB RAM), the network baseline bandwidth is 100 Mbps, the round-trip delay between the cloud and the edge is 10 ms, the round-trip delay between the edge nodes is 5 ms, and the cloud backup link delay is set to 50 ms in the UAV weak signal simulation. In terms of task model, each simulation randomly generates 500 emergency tasks, and the dependency relationship is represented by a directed acyclic graph. The task size is between 10 MI and 500 MI, and the task arrival obeys a Poisson process with an average of 50 / s to simulate disaster bursts. In the fault scenario, the ‘ node failure ‘ test will randomly select three edge nodes at the 30 th second of the simulation run to make them fail. The comparison baselines include : pure cloud architecture (all tasks are offloaded to the cloud center), pure edge architecture (tasks are only processed locally at the edge), and cloud-edge collaboration without task replication (based on load scheduling but not copying tasks). The evaluation indicators are : average task response delay (the average of 30 runs, given a 95% confidence interval), system reliability (the proportion of tasks completed before the deadline, the deadline is set to 2 times the average completion time under a pure cloud architecture), average node load rate (average CPU utilization of all edge nodes during the simulation), and resource overhead (additional computing time consumed by task replication, measured in CPU seconds).. The comparison objects are three typical schemes: pure cloud architecture, pure edge architecture and cloud edge collaboration architecture without task replication. The performance of cloud edge collaboration with cloud centralized processing, edge independent processing and no task redundancy mechanism under actual emergency conditions is investigated respectively. The evaluation index is mainly considered from three aspects: task response delay, system reliability and resource overhead. Task response delay reflects the degree of satisfaction of the architecture for low latency requirements. System reliability is used to measure the ability of task completion in the case of node failure. Resource overhead is used to measure the computing and communication costs paid by the architecture in order to achieve low latency and high reliability. The above settings are used to compare the comprehensive performance of the architecture in different comparison objects, different task loads,and fault scenarios.

Table 2. Experimental comparison table

Scenario	Evaluation Metric	Proposed Architecture	Cloud-only Architecture	Edge-only Architecture	Cloud-Edge Collaboration without Task Replication
Node Failure (3 edge nodes down)	Average Task Response Delay	Baseline ($\approx 40\%$ reduction) 1060ms \rightarrow 636ms	$\approx 120\%$ higher 1400ms	$\approx 73\%$ higher 1100ms	Baseline 1060ms
	System Reliability (On-time Completion Rate)	$\geq 96\%$	72%	80%	88%
Normal Condition (Fault-free, 200 tasks)	Communication Delay Reduction vs. Cloud-only	$\geq 30\%$	—	—	—
	Computing Resource Overhead (vs. No Replication)	+15% \sim +20%	—	—	—
Large-scale Concurrency (500 tasks)	Average Node Load Rate (Balance)	$\leq 60\%$ (Balanced Load)	$\leq 20\%$ (Centralized Bottleneck)	$> 85\%$ (Local Overload)	70% \sim 90% (Uneven Distribution)
	Task Response Delay (P99)	$\leq 500\text{ms}$	$> 1500\text{ ms}$ (Severe Backlog)	$> 1200\text{ ms}$ (Resource Contention)	$> 900\text{ ms}$ (High Latency)

5. Conclusions and Prospects

Based on the rigid requirements of emergency communication for low-latency response, this paper proposes an emergency communication architecture with end, edge and cloud collaboration. From the perspective of task deployment, computing resources are used to exchange communication efficiency, and dynamic resource allocation is used to achieve real-time matching of node load, link quality and energy consumption status. In the aspect of scheduling optimization, improved ant colony optimization algorithm and cold start strategy are added to ensure that the system can quickly generate a near-optimal scheduling scheme in the early stage of emergency without historical data accumulation. From the perspective of engineering implementation, lightweight containerized encapsulation and cross-node data synchronization technology are used to improve the deployment efficiency of applications and the consistency of multi-copy data, providing support for the actual landing of the architecture. In the future, deep reinforcement learning will continue to be used to improve the adaptability of scheduling strategies, expand the network coverage in extreme environments on the basis of multi-UAV collaboration, and use federal learning to ensure data privacy while achieving multi-node collaborative modeling. Continuously improve the system's intelligent scheduling capabilities and security service levels in complex emergency scenarios.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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How Customer Participation Drives Continuance Intention in Fresh Food E-Commerce: The Mediating Role of Perceived Service Quality and the Moderating Role of Technology Anxiety

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Abstract: This article develops and tests a mechanism-based model of continuance intention in fresh food e-commerce. The model positions customer participation as a multidimensional antecedent, perceived service quality as the mediating mechanism, and technology anxiety as a moderating boundary condition. The study is situated in Guangdong Province, China, where fresh food e-commerce is highly competitive, logistics intensive, and closely linked to repeated household purchasing. Drawing on a process-oriented perspective, the analysis distinguishes four dimensions of customer participation: task cognition, information seeking, effort expenditure, and human-computer interaction. These dimensions are hypothesised to influence continuance intention directly and indirectly through perceived service quality. Technology anxiety is further expected to weaken the positive relationship between participation and perceived service quality, particularly in those pathways that depend on digital information processing. A structured questionnaire was administered to fresh food e-commerce users, and 550 valid responses were analysed using Partial Least Squares Structural Equation Modelling. The measurement model demonstrated acceptable reliability and validity. Structural results show that all four participation dimensions positively influence perceived service quality. Effort expenditure exerts the strongest effect, followed by information seeking and human-computer interaction. Perceived service quality, in turn, positively influences continuance intention, indicating a meaningful mediating role. The direct effects of customer participation on continuance intention remain significant, which suggests partial rather than full mediation. Technology anxiety has a significant direct negative effect on perceived service quality and significantly weakens only the information-seeking pathway. Its moderating effects on task cognition, effort expenditure, and human-computer interaction are not statistically significant. The findings indicate that customer participation in fresh food e-commerce is both valuable and internally differentiated. The results also show that digital psychological constraints do not undermine all participation forms equally. The article extends current work on digital retail continuance by showing that users remain with fresh food e-commerce platforms not simply because the service is convenient, but because their own participation is successfully converted into favourable evaluations of service quality. For practice, the results suggest that platforms should prioritise interface clarity, information transparency, fulfilment reliability, and low-friction support for technology-anxious users rather than merely increasing participation volume.

Keywords: Customer Participation; Perceived Service Quality; Continuance Intention; Technology Anxiety; Fresh Food E-Commerce; Guangdong

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1. Introduction

China's fresh food e-commerce market has moved from an experimental niche to a mainstream retail infrastructure. What began as an efficiency-driven digital response to consumers' demand for convenience now operates as a complex service ecosystem in which product quality, delivery reliability, information transparency, and interface usability jointly shape repeat purchasing. This evolution has important theoretical implications. In fresh food e-commerce, continuance intention cannot be reduced to a generic post-adoption attitude, because the service is experienced under unusually high operational pressure: products are perishable, fulfilment is time-sensitive, product inspection is delayed until after delivery, and service failures are immediately consequential for household consumption. As a result, repeated usage depends on more than price or habit. It depends on how customers evaluate the service process over time.

Recent research on digital platforms has repeatedly shown that continuance intention is strongly affected by service-related evaluations, including satisfaction, perceived value, trust, and perceived service quality (Gao et al., 2023; Kim & Lee, 2023; Utami et al., 2025; Yu et al., 2024). Yet fresh food e-commerce is not merely another online retail format. It introduces high uncertainty around freshness, quantity, substitutions, packaging integrity, and delivery punctuality. In these conditions, customers do not passively receive service. They actively search, compare, interpret, and coordinate. Customer participation is therefore not peripheral to the service encounter. It is part of the service process itself.

This observation matters because most existing studies still treat customer participation in broad or aggregated terms, often under the labels of engagement, interaction, or co-creation. Such approaches are useful for establishing that participation matters, but they are less useful for explaining how specific participation forms create value. In practical settings, task cognition is not the same as information seeking, and neither is equivalent to effort expenditure or human-computer interaction. These dimensions vary in cognitive demands, behavioural intensity, and technological dependence. When they are collapsed into a single construct, the field loses the ability to identify which forms of participation are most likely to generate favourable service evaluations and which are most vulnerable to digital friction (Islam et al., 2023; Rather et al., 2022).

A second limitation concerns the role of perceived service quality. Although service quality is widely recognised as a key predictor of loyalty and continuance in digital services, it is often modelled as an independent predictor rather than as a process mechanism through which upstream customer activities become downstream behavioural persistence (Kim & Yum, 2024; Nguyen et al., 2024). This leaves an important question insufficiently answered: when customers participate more actively in fresh food e-commerce, why does that participation sometimes strengthen retention and sometimes fail to do so? One plausible answer is that participation affects continuance intention only when it is successfully converted into favourable perceptions of service quality.

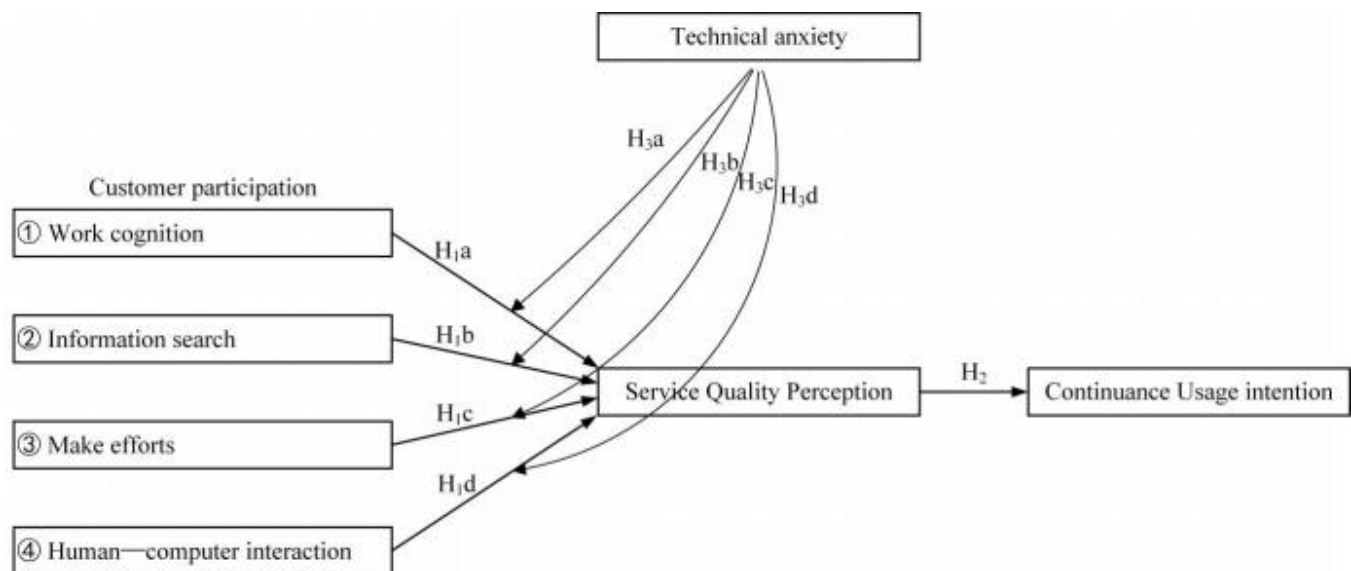
A third limitation lies in the treatment of digital psychological barriers. Technology anxiety is usually examined as a direct inhibitor of adoption, intention, or satisfaction. However, in technology-mediated retail environments, it may be more analytically useful to treat anxiety as a boundary condition that changes the effectiveness of participation. A customer may search extensively for information, compare options carefully, and still emerge with a weak or negative service evaluation if technological complexity, uncertainty, or overload disrupts the interpretive process. This possibility is especially relevant in fresh food e-commerce because service judgements depend heavily on digitally conveyed information about origin, freshness, logistics, and platform reliability (Jiao et al., 2025; Sarker et al., 2025; Tarhini et al., 2021).

This article addresses these issues by developing an integrated model in which four dimensions of customer participation - task cognition, information seeking, effort expenditure, and human-computer interaction - influence continuance intention through perceived service quality, while technology anxiety operates as a moderator of the participation-service quality relationship. The empirical analysis is based on users of fresh food e-commerce platforms in Guangdong Province, one

of China's most dynamic regional markets in this domain. Guangdong is an analytically strong site because it combines advanced digital infrastructure, dense platform competition, and a consumer base with substantial exposure to app-based fresh food purchasing. The combination of these characteristics makes it possible to study not simply whether users adopt these services, but how they decide to continue using them.

The article makes three contributions. First, it differentiates customer participation into behaviourally distinct dimensions and demonstrates that their effects are not homogeneous. Second, it clarifies the mediating role of perceived service quality in the participation-continuance relationship. Third, it shows that technology anxiety constrains participation selectively rather than universally. These contributions speak directly to contemporary research on digital retail continuance, online service evaluation, and technology-mediated consumer behaviour.

Figure 1. Conceptual framework



2. Literature Review and Hypotheses Development

Customer participation is best understood as the set of customer-contributed cognitive and behavioural inputs that shape the service process. In digital service environments, participation includes not only visible interaction but also information work, task management, procedural effort, and technology-enabled coordination. Contemporary reviews of online customer engagement suggest that participation should be analysed as a differentiated construct because distinct forms of customer input serve distinct functions in value co-creation (Islam et al., 2023; Rather et al., 2022). The current study follows this logic and isolates four dimensions that are especially relevant in fresh food e-commerce.

Task cognition refers to the degree to which customers understand the tasks required to use the platform effectively. In fresh food e-commerce, users often need to interpret product specifications, delivery choices, promotional rules, and service procedures before completing a purchase. Stronger task cognition should improve perceived service quality because customers who understand the system better can judge platform performance more accurately and use available service functions more effectively. Prior studies linking customer participation to service-quality assessments suggest that cognitively prepared customers are more likely to generate positive service evaluations when the platform performs adequately (Wang & Wei, 2011; Wu & Chen, 2017).

Information seeking refers to the active acquisition, comparison, verification, and interpretation of product and service information. This dimension is highly salient in fresh food e-commerce because uncertainty is high and many quality attributes are experienced only after delivery. To reduce uncertainty, customers rely on reviews, descriptions, origin information, traceability cues, promotions, and platform signals. Information seeking can therefore strengthen perceived service quality by allowing users to interpret the platform as transparent, informative, and trustworthy. Research on digital shopping and continuance intention supports this expectation, especially in contexts where uncertainty reduction is central to user retention (Gao et al., 2023; Jiao et al., 2025).

Effort expenditure refers to the behavioural resources customers invest while using the platform, including the time and energy spent comparing alternatives, arranging deliveries, managing discounts, and coordinating orders. In some settings, customer effort may create fatigue, but in highly interactive service systems it can also intensify process involvement and strengthen the customer's sense of control. In fresh food e-commerce, where customers often need to coordinate highly practical choices, effort expenditure may become a critical driver of perceived service quality if the platform rewards effort with accurate information, reliable fulfilment, and smooth transaction management. The likely implication is that effort expenditure will be positively associated with perceived service quality and may even emerge as one of the strongest drivers.

Human-computer interaction refers to the quality of interaction between users and platform interfaces, automated functions, recommendation systems, and digital guidance. In digital retail, interface quality affects how easy it is to browse, compare, decide, and resolve problems. Studies of virtual customer service agents and interface design show that better interaction quality can improve consumer perceptions and behaviour by enhancing social presence, responsiveness, and procedural fluency (Chattaraman et al., 2022; Verhagen et al., 2021). In fresh food e-commerce, repeated app use makes this dimension structurally important because customer retention depends on routinised and low-friction digital interaction.

Perceived service quality is positioned in this study as the central evaluative mechanism that translates participation into continuance intention. In e-commerce settings, service quality has been consistently associated with trust, customer satisfaction, loyalty, and long-term platform usage (Kim & Lee, 2023; Kim & Yum, 2024; Nguyen et al., 2024). In the fresh food context, however, service quality is broader than interface or delivery quality alone. It includes confidence in product condition, timeliness, information completeness, packaging integrity, responsiveness, and the platform's ability to support repeated daily purchasing without undue uncertainty. This broader conception is particularly appropriate when studying retention rather than one-off transactions.

The article adopts a stimulus-organism-response perspective. Customer participation serves as the stimulus because it reflects what users do within the service environment. Perceived service quality serves as the organism because it captures the internal evaluation formed through the service encounter. Continuance intention serves as the response because it reflects the behavioural tendency to continue using the platform. This perspective is useful because it offers a mechanism-based explanation rather than a simple predictor-outcome account, thereby clarifying why participation matters only when it becomes meaningful in evaluative terms (Gao et al., 2023; Utami et al., 2025).

On this basis, the first set of hypotheses concerns the direct relationships between the four dimensions of customer participation and perceived service quality. Customers with stronger task cognition should evaluate service more favourably because they can align platform functions with shopping objectives. Customers who seek information actively should perceive better service when the platform provides useful and credible informational support. Customers who expend effort should judge service more positively when that effort is rewarded with successful execution. Customers who experience better human-computer interaction should likewise generate stronger service-quality evaluations. The overarching expectation is therefore that each participation dimension positively influences perceived service quality.

The next proposition concerns the relationship between perceived service quality and continuance intention. Recent digital-platform studies consistently show that users persist when service quality is perceived as reliable, effective, and credible over time (Dandis et al., 2026; Yu et al., 2024). In fresh food e-commerce, where transactions are frequent and service failures are especially visible, the service-quality judgement should have strong behavioural consequences. A customer who repeatedly perceives the service to be timely, transparent, and dependable is more likely to continue using the platform, recommend it, and integrate it into everyday shopping routines.

The mediating logic follows directly from these assumptions. If customer participation shapes perceived service quality, and perceived service quality shapes continuance intention, then service quality should function as a mechanism that carries part of the effect of participation into post-adoption persistence. This addresses a notable gap in the literature, because studies on customer participation often emphasise direct co-creation effects, whereas service-quality studies often focus on downstream loyalty-related outcomes without adequately modelling the upstream role of participation (Huang & Benyoucef, 2022; Nguyen et al., 2024). The resulting analytical advantage is that the model can explain not only whether participation matters,

but how it matters.

Technology anxiety provides the model's boundary condition. Technology anxiety describes user discomfort, worry, or tension when dealing with digital systems and technologically mediated service processes. Recent work indicates that anxiety can undermine confidence, satisfaction, and continuance intention in digital services by increasing perceived complexity and reducing evaluative certainty (Sarker et al., 2025; Tarhini et al., 2021). In fresh food e-commerce, anxiety is likely to matter because many service judgements rely on interpreting digitally presented signals rather than physically inspecting products before purchase.

The moderating effect of technology anxiety should not be assumed to be identical across all participation forms. Information seeking is likely to be the most vulnerable because it depends heavily on search fluency, interface clarity, information credibility, and users' ability to process platform cues. Task cognition is cognitively demanding, but it may not be equally disrupted once users become familiar with core platform tasks. Effort expenditure may even remain beneficial under anxiety if it is directed toward concrete shopping outcomes rather than abstract technological interpretation. Human-computer interaction may be somewhat weakened by anxiety, but the effect could be modest in mature app environments where common interface patterns are already familiar. This differentiated view leads to separate moderation hypotheses rather than a single global expectation.

H1a: Task cognition positively influences perceived service quality.

H1b: Information seeking positively influences perceived service quality.

H1c: Effort expenditure positively influences perceived service quality.

H1d: Human-computer interaction positively influences perceived service quality.

H2: Perceived service quality positively influences continuance intention.

H3a: Technology anxiety negatively moderates the relationship between task cognition and perceived service quality.

H3b: Technology anxiety negatively moderates the relationship between information seeking and perceived service quality.

H3c: Technology anxiety negatively moderates the relationship between effort expenditure and perceived service quality.

H3d: Technology anxiety negatively moderates the relationship between human-computer interaction and perceived service quality.

3. Research Method

The study used a quantitative cross-sectional design and collected data through a structured questionnaire administered to users of fresh food e-commerce platforms in Guangdong Province, China. Guangdong was selected because it represents one of China's most developed digital retail regions and hosts a dense mix of national-platform branches, regional vertical platforms, and online supermarket services. This makes the province a suitable empirical setting for studying continuance intention under conditions of intense platform competition and mature consumer exposure.

The target population consisted of consumers with actual experience of purchasing fresh food products through e-commerce platforms. To preserve contextual relevance, the screening mechanism excluded respondents who had not used fresh food e-commerce platforms in Guangdong, who purchased less than once per month, who were under the age of 18, or whose completion time suggested inattentive responding. This procedure was designed to minimise contamination from irrelevant or low-quality responses. Of 570 distributed questionnaires, 550 were retained as valid, producing a valid response rate of 96.5 percent.

The sample structure is consistent with the actual user profile of fresh food e-commerce. The sample was balanced by gender, with 48.0 percent male and 52.0 percent female respondents. In age terms, the user base was concentrated in the 25-34 and 35-44 brackets, which together represented 65.1 percent of valid responses. Educational attainment was also relatively high, with bachelor's degree holders forming the largest category and associate-degree holders the second largest. The source study also reports coverage across core Pearl River Delta cities, non-core Pearl River Delta cities, and eastern, western, and northern Guangdong, together with multiple platform categories and usage-frequency groups, thereby supporting contextual diversity within the sample.

All latent variables were measured using five-point Likert-type scales. Customer participation was operationalised through

four reflective dimensions: task cognition, information seeking, effort expenditure, and human-computer interaction. Perceived service quality was specified as the mediating variable, continuance intention as the dependent variable, and technology anxiety as the moderating variable. The instrument drew on prior scale sources reported in the thesis and was adapted to the specific conditions of fresh food e-commerce. The adaptation process ensured that the items referred directly to behaviours such as evaluating freshness-related information, comparing alternatives, expending effort in platform use, and interacting with digitally mediated service functions.

The instrument-development process involved both pre-testing and pilot testing. The pilot stage used 40 users with actual fresh food e-commerce experience to assess content validity, convergent validity, and item comprehensibility. According to the thesis, item-level content validity ratios exceeded the pre-specified threshold, factor loadings were generally acceptable, item-total correlations were adequate, and understandability scores were high. Items were refined where necessary to reduce ambiguity, improve flow, and limit respondent fatigue. This procedure strengthened the measurement instrument before formal large-sample deployment.

Data analysis was conducted in two stages. SPSS 27.0 was used for screening, coding, descriptive analysis, and preliminary diagnostics. SmartPLS 4.1.1 was then used to estimate the measurement model and structural model. The PLS-SEM approach is appropriate for a study that includes multiple latent variables, direct effects, mediation, and moderation. The thesis reports that model estimation was supported by bootstrapping with 5,000 resamples, enabling significance testing for the structural paths. Reliability was assessed using Cronbach's alpha and composite reliability, while convergent and discriminant validity were examined through factor loadings, average variance extracted, the Fornell-Larcker criterion, and HTMT.

Table 1. Respondent profile (N = 550)

Characteristic	Category	N	%
Gender	Male	264	48.0
Gender	Female	286	52.0
Age	18-24	83	15.1
Age	25-34	193	35.1
Age	35-44	165	30.0
Age	45-54	83	15.1
Age	55 and above	26	4.7
Education	High school or below	138	25.1
Education	Associate degree	165	30.0
Education	Bachelor's degree	193	35.1
Education	Master's degree or above	54	9.8

Table 2. Construct reliability

Construct	Cronbach's alpha	Composite reliability
Task cognition	0.876	0.892
Information seeking	0.861	0.899
Effort expenditure	0.872	0.906
Human-computer interaction	0.885	0.916
Perceived service quality	0.877	0.908
Continuance intention	0.873	0.908
Technology anxiety	0.907	0.929

Beyond reliability, the source thesis reports acceptable factor loadings, average variance extracted above the minimum threshold, and satisfactory discriminant validity based on the Fornell-Larcker criterion and HTMT. These diagnostics suggest that the reflective measurement model was suitable for hypothesis testing.

4. Data Analysis Results

The descriptive analysis suggests that the sample provides a credible basis for investigating continuance intention in fresh food e-commerce. The dominance of the 25-44 age group is analytically consistent with the primary user base of app-mediated shopping services. The balanced gender distribution and medium-to-high educational profile further indicate that the sample contains users likely to engage meaningfully with platform information, service choices, and interface functions. This is important because the conceptual model assumes that continuance intention is shaped by active participation rather than passive platform exposure.

The measurement model performed satisfactorily. Cronbach's alpha ranged from 0.861 to 0.907, and composite reliability ranged from 0.892 to 0.929, comfortably exceeding accepted thresholds for internal consistency. According to the thesis, convergent and discriminant validity were also supported through factor loadings, average variance extracted, the Fornell-Larcker criterion, and HTMT. The source study further reports no serious common-method bias and no problematic multicollinearity. These diagnostics collectively indicate that the data were suitable for structural modelling.

Model fit and explanatory-power indicators were acceptable for a consumer-behaviour study of this kind. The SRMR value was 0.041 for both the saturated and estimated models. The structural model explained 40.3 percent of the variance in perceived service quality and 34.2 percent of the variance in continuance intention. These values indicate moderate explanatory power and are substantively meaningful because continuance intention in digital retail is typically influenced by numerous situational, psychological, and operational factors beyond the present model.

The structural results strongly support the argument that customer participation matters for service-quality formation. All four participation dimensions significantly and positively influenced perceived service quality. Effort expenditure produced the strongest effect ($\beta = 0.239$, $p < 0.001$), followed by information seeking ($\beta = 0.165$, $p < 0.001$), human-computer interaction ($\beta = 0.162$, $p < 0.001$), and task cognition ($\beta = 0.122$, $p = 0.003$). These results show that participation in fresh food e-commerce is not merely symbolic. It contributes to the formation of quality evaluations in concrete and measurable ways.

The direct effects on continuance intention were also significant. Information seeking had the largest direct effect on continuance intention ($\beta = 0.209$, $p < 0.001$), followed by effort expenditure ($\beta = 0.192$, $p < 0.001$), task cognition ($\beta = 0.129$, $p = 0.002$), and human-computer interaction ($\beta = 0.112$, $p = 0.007$). Perceived service quality positively influenced continuance intention as well ($\beta = 0.185$, $p < 0.001$). Taken together, these results indicate that continuance intention is shaped both by what customers do on the platform and by how they evaluate the service process that follows from those activities.

The mediation pattern is therefore consistent with partial mediation. Each participation dimension significantly predicted perceived service quality, perceived service quality significantly predicted continuance intention, and the direct effects of participation on continuance intention remained significant. This implies that customer participation influences repeated platform use through two routes. One route is evaluative: participation enhances perceived service quality, which then strengthens continuance intention. The other route is direct: participation itself appears to build familiarity, confidence, procedural competence, or involvement that independently supports repeated usage.

Technology anxiety produced two important results. First, it had a significant direct negative effect on perceived service quality ($\beta = -0.280$, $p < 0.001$), which means that digitally anxious users evaluate service less favourably overall. Second, its moderating effect was selective rather than universal. Only the interaction between technology anxiety and information seeking was significant ($\beta = -0.178$, $p < 0.001$). The interactions with task cognition ($\beta = -0.052$, $p = 0.270$), effort expenditure ($\beta = -0.004$, $p = 0.939$), and human-computer interaction ($\beta = -0.082$, $p = 0.078$) were not significant. This pattern suggests that technology anxiety chiefly disrupts those participation processes that depend on digital information handling and interpretive confidence.

Overall, the empirical evidence supports the core logic of the model. Customer participation contributes materially to continuance intention, perceived service quality functions as a meaningful transmission mechanism, and technology anxiety selectively constrains the informational pathway rather than the entire participation-service quality relationship. The strongest positive influence on perceived service quality comes from effort expenditure, while the clearest negative boundary effect of technology anxiety appears in the information-seeking route.

Table 3. Model fit and explanatory power

Indicator	Value	Interpretation
SRMR (saturated model)	0.041	Acceptable fit
SRMR (estimated model)	0.041	Acceptable fit
R-squared: perceived service quality	0.403	Moderate explanatory power
R-squared: continuance intention	0.342	Moderate explanatory power

Table 4. Structural path estimates

Path	Beta	t-value	p-value	Result
Task cognition → perceived service quality	0.122	3.006	0.003	Supported
Information seeking → perceived service quality	0.165	4.022	0.000	Supported
Effort expenditure → perceived service quality	0.239	5.482	0.000	Supported
Human-computer interaction → perceived service quality	0.162	4.055	0.000	Supported
Perceived service quality → continuance intention	0.185	3.530	0.000	Supported
Task cognition → continuance intention	0.129	3.077	0.002	Supported
Information seeking → continuance intention	0.209	4.579	0.000	Supported
Effort expenditure → continuance intention	0.192	3.958	0.000	Supported
Human-computer interaction → continuance intention	0.112	2.688	0.007	Supported
Technology anxiety → perceived service quality	-0.280	6.385	0.000	Supported

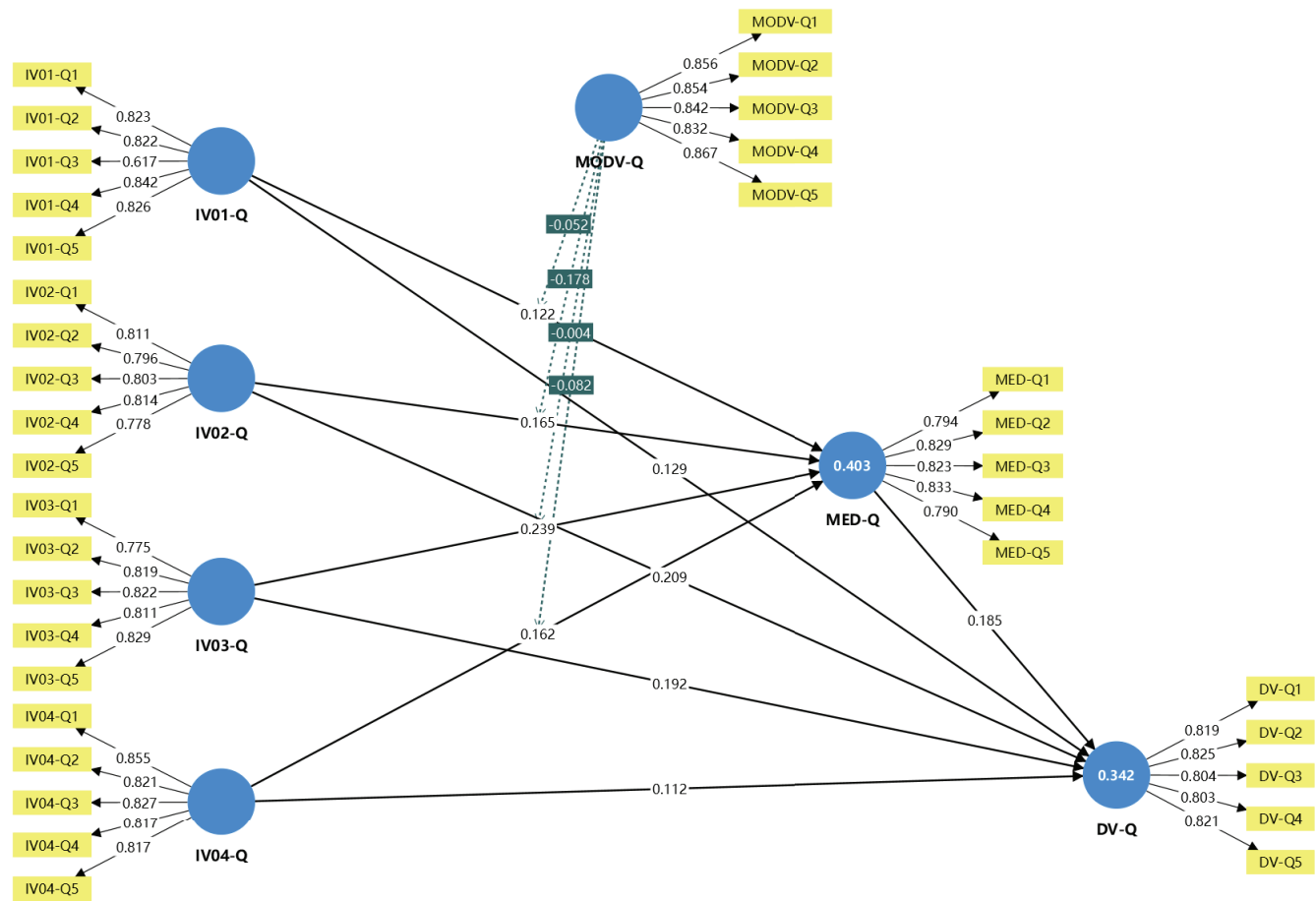
Table 5. Moderating effects of technology anxiety

Interaction path	Beta	p-value	Result
Technology anxiety × task cognition → perceived service quality	-0.052	0.270	Not supported
Technology anxiety × information seeking → perceived service quality	-0.178	0.000	Supported
Technology anxiety × effort expenditure → perceived service quality	-0.004	0.939	Not supported
Technology anxiety × human-computer interaction → perceived service quality	-0.082	0.078	Not supported

Table 6. Mediation interpretation through perceived service quality

Antecedent	Direct path to continuance intention	Path to perceived service quality	Indirect route via service quality	Interpretation
Task cognition	Significant	Significant	Present	Partial mediation
Information seeking	Significant	Significant	Present	Partial mediation
Effort expenditure	Significant	Significant	Present	Partial mediation
Human-computer interaction	Significant	Significant	Present	Partial mediation

Figure 2. Estimated structural model



5. Discussion

The most immediate theoretical implication of the results is that customer participation in fresh food e-commerce is internally differentiated. The four participation dimensions all matter, but they do not matter equally. Effort expenditure emerged as the strongest driver of perceived service quality. This is not a trivial finding. It indicates that value creation in fresh food e-commerce is closely tied to practical, process-oriented engagement. Customers who invest effort in comparing products, arranging delivery windows, and optimising purchase choices are not simply doing extra work for the platform. When the platform performs well, their effort becomes part of the mechanism through which high service quality is perceived.

This result is especially plausible in fresh food e-commerce because service production is partly co-managed by the customer. The customer determines delivery time relevance, product substitution tolerance, price-quality trade-offs, and acceptable levels of uncertainty regarding freshness and fulfilment. In such a setting, effort expenditure represents not friction alone but also procedural involvement. The stronger effect of effort expenditure therefore suggests that service quality in fresh food e-commerce is judged not only on what the platform provides, but on how well the platform allows users to turn their effort into reliable outcomes. This insight aligns with recent work emphasising operational coordination and service-value creation in fresh e-commerce (Imanuddin et al., 2025; Ren et al., 2025).

Information seeking also played a substantial role, both directly and indirectly. Yet it was the only pathway significantly weakened by technology anxiety. This is perhaps the article's most distinctive contribution. Information seeking depends on customers' ability to search, interpret, compare, and trust digital information. In fresh food e-commerce, these tasks are particularly demanding because users must infer quality from proxies rather than direct inspection. When users are technologically anxious, the information environment may become cognitively costly rather than reassuring. Search becomes overload, comparison becomes confusion, and recommendation systems become sources of mistrust rather than support. The finding therefore refines the role of technology anxiety by showing that anxiety undermines not participation in general, but specific forms of participation that depend on digital interpretive work.

The absence of significant moderation for task cognition, effort expenditure, and human-computer interaction is equally informative. The result for task cognition suggests that once customers grasp the basic platform tasks, residual anxiety may not be sufficient to reduce the value of that understanding. The result for effort expenditure suggests that practical effort remains beneficial even for anxious users, perhaps because effort is directed toward visible shopping outcomes. The result for human-computer interaction may indicate that interface design on mature fresh food e-commerce platforms has become sufficiently standardised that anxiety no longer creates systematically divergent evaluations, at least not strongly enough to reach statistical significance in this sample.

Perceived service quality emerged as a meaningful but partial mediator. This matters because it helps reconcile two literatures that often develop in parallel. Customer-participation studies tend to emphasise co-creation and involvement, whereas service-quality studies focus on downstream attitudinal and behavioural outcomes. The present findings show that both perspectives are needed. Customer participation affects continuance intention partly because it changes how customers judge service quality and partly because it builds a direct behavioural orientation toward continued use. In practical terms, this means that repeated usage arises from both evaluative confidence and participatory embeddedness.

The significance of the direct effects is also noteworthy. Information seeking had the strongest direct effect on continuance intention, even though effort expenditure had the strongest effect on perceived service quality. This divergence suggests that not all participation dimensions influence post-adoption behaviour through the same mechanism. Information seeking may directly strengthen continuance intention because it increases customer knowledge, familiarity, and decision confidence, even beyond its effect on service-quality evaluation. Effort expenditure, by contrast, appears especially important for transforming the service process into a positive quality judgement. The coexistence of these differentiated routes strengthens the argument for analysing customer participation dimensionally rather than holistically.

Another important implication concerns the role of service quality in high-frequency online retail. In many digital-platform models, continuance intention is explained through generic post-adoption constructs such as satisfaction or perceived usefulness. The current findings suggest that, in fresh food e-commerce, perceived service quality remains central because the service is recurrent, operationally demanding, and exposed to tangible failure points. Customers are unlikely to continue using platforms that fail on delivery, quality consistency, or information credibility even if the overall concept is convenient. Service quality therefore acts as the bridge between participation and retention precisely because it captures the customer's accumulated judgement of whether the platform can be trusted in routine household provisioning.

The Guangdong context sharpens these conclusions rather than limiting them conceptually. In a region characterised by mature platform competition and relatively advanced infrastructure, the retention problem is no longer whether consumers know these services exist. It is whether they continue to judge them as dependable enough to integrate into everyday life. That makes Guangdong an analytically strong setting for uncovering the behavioural logic of continuance intention. If the model works under such competitive and technologically mature conditions, it captures an important part of the retention challenge that fresh food e-commerce platforms face more broadly.

6. Theoretical Implications

The article contributes to theory in three principal ways. First, it advances customer-participation research by providing empirical evidence that participation is multidimensional in a substantively consequential sense. The dimensions differ not only conceptually but also in explanatory strength. Second, it reinforces a mechanism-based understanding of continuance intention by demonstrating that perceived service quality mediates the effect of customer participation on repeated platform use. Third, it refines the role of technology anxiety by showing that anxiety operates selectively. Rather than weakening all participation-service quality pathways, it significantly constrains the information-seeking route only.

These contributions matter because they move the literature away from overly general claims that participation is uniformly beneficial and that technology anxiety is uniformly harmful. The present findings support a more precise interpretation: participation creates value when the platform converts customer effort and information work into favourable quality judgements, and technology anxiety interferes with this conversion mainly where customers must process and trust digitally conveyed information.

7. Managerial Implications

For managers, the first implication is that participation should be designed rather than merely encouraged. Since effort expenditure had the strongest positive effect on perceived service quality, platforms should improve those stages in which customers actively coordinate the transaction. Delivery-slot selection, product comparison, order adjustment, substitution management, and after-sales handling should be as smooth and transparent as possible. The more clearly customer effort is rewarded with reliable execution, the more likely it is to generate positive service-quality evaluations.

Second, the negative moderation effect of technology anxiety on the information-seeking pathway indicates that platform information architecture is a retention issue, not just a usability issue. Platforms should reduce informational friction by improving product-page clarity, traceability visibility, review organisation, search accuracy, and recommendation transparency. Technology-anxious customers are especially likely to disengage when search and comparison feel cognitively costly or opaque. Simplified navigation, explanation cues, and stronger information credibility signals may therefore yield disproportionate benefits for retention.

Third, the direct negative effect of technology anxiety on perceived service quality suggests a need for user segmentation. Platforms should recognise that customers differ not only by spending level or purchase frequency but also by digital comfort. More supportive pathways for anxious users - such as guided purchasing flows, stable reordering options, visible human support, and fewer unexplained interface interventions - can improve service-quality perception without requiring major changes in product assortment or pricing. In high-frequency categories like fresh food, these seemingly modest interface and service-design choices can accumulate into substantial retention advantages.

8. Conclusion, Limitations, and Future Research

This article examined continuance intention in fresh food e-commerce by integrating customer participation, perceived service quality, and technology anxiety into a single framework. Using survey data from 550 platform users in Guangdong Province and PLS-SEM analysis, the study found that all four participation dimensions positively influence perceived service quality and that perceived service quality positively influences continuance intention. Effort expenditure emerged as the strongest driver of perceived service quality, while technology anxiety significantly weakened only the information-seeking pathway. The evidence therefore shows that customer participation matters, but it matters through differentiated and conditional pathways.

The study has several limitations. The design is cross-sectional and based on self-reported data, which limits causal inference despite the diagnostic procedures reported in the thesis. The empirical setting is restricted to Guangdong Province, which improves contextual precision but may reduce transferability to less mature or differently structured markets. In addition, the model focuses on a targeted set of variables and therefore does not incorporate other potentially relevant constructs such as trust, privacy concern, platform dependence, perceived value, or algorithmic transparency. Future research could address these limitations through longitudinal designs, transaction-data integration, multi-group comparisons, and richer digital-psychology models. Cross-platform and cross-regional replication would also help clarify the conditions under which the present findings generalise beyond the Guangdong fresh food e-commerce context.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Research on the Practical Path of Generative AI Empowering Teaching Reform of Probability and Mathematical Statistics in Chinese Tertiary Education

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Abstract: Probability and Mathematical Statistics is a fundamental public mathematics course widely offered to science, engineering, and economics–management students in Chinese universities.^[1] Driven by global educational digitalization and national initiatives of emerging engineering and emerging liberal arts, traditional teaching has been constrained by overemphasis on abstract theories, insufficient practical instruction, limited personalized support, and oversimplified assessment systems. These shortcomings severely hinder the cultivation of data literacy and statistical reasoning abilities required by contemporary talent development. As an advanced technological tool, generative artificial intelligence presents great potential for innovating instructional design and improving learning effectiveness in higher mathematics education. Based on authoritative data from the Ministry of Education of China, national teaching surveys, and institutional teaching practices, this study identifies core challenges in current probability and statistics education, analyzes the transformative value of generative AI for teaching improvement, and proposes a systematic reform framework covering curriculum optimization, pedagogical innovation, practical training enhancement, and diversified assessment construction. This paper also clarifies ethical boundaries and practical principles for the responsible integration of generative AI. The conclusions and pathways are intended to provide reliable, evidence-based references for advancing the high-quality development of probability and statistics teaching in Chinese tertiary education.

Keywords: Generative AI; Probability and Mathematical Statistics; Teaching Reform; Blended Learning; Educational Digitalization; Tertiary Education

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1. Introduction

1.1 Research Background and Importance

In the era of big data and artificial intelligence, statistical thinking, data analysis capability, and stochastic modeling competence have become essential for high-level professional talents. Probability and Mathematical Statistics, which studies the statistical laws of random phenomena, is characterized by both theoretical rigor and extensive practical applicability, thus playing a fundamental and instrumental role in undergraduate education. According to the Report on the Construction of Public Mathematics Courses in Chinese Universities (2025) issued by the Steering Committee for Mathematics Teaching in Higher Education, the annual enrollment of probability and statistics courses exceeds 5 million students, making it one of the

most influential foundational mathematics courses in China.

Nevertheless, long-standing deficiencies persist in instructional practice. First, conceptual abstraction leads to learning difficulties. The 2025 Undergraduate Teaching Quality Annual Report of the University of Science and Technology of China shows that 62.3% of students consider the course overly abstract and difficult to master. Second, instructional methods remain largely lecture-dominated. A bibliometric review in *Educational Progress* (2023) indicates that traditional direct instruction accounts for 73.5% of class time.^[4] Third, practical training is inadequate. A survey conducted by the National Emerging Engineering Education Expert Group (2024) reveals that only 31.7% of universities provide systematic training in Python, R, or other statistical software. Fourth, assessment relies excessively on final examinations, resulting in incomplete and biased evaluation of student ability.

Against this backdrop, China has accelerated its national educational digitalization strategy, building the world's largest online tertiary education resource system. The National Educational Digitalization Strategy Action Implementation Report (2025) notes that the Smart Education of China platform hosts 145,000 high-quality university courses, with 68.7% of tertiary education institutions adopting AI-assisted teaching.^[2] Generative AI's capabilities in content generation, intelligent tutoring, simulation visualization, and personalized resource recommendation offer effective solutions to traditional instructional bottlenecks,^[7] which prompts this study to explore systematic pathways for generative AI to empower the teaching reform of Probability and Mathematical Statistics.

1.2 Research Objectives

This study identifies core challenges in current Probability and Mathematical Statistics teaching in Chinese tertiary education, analyzes generative AI's transformative value in optimizing teaching and improving learning effectiveness, and proposes a systematic, operable reform framework. Specifically, it explores integrating generative AI into curriculum restructuring, pedagogical innovation, practical training enhancement, and assessment optimization, while clarifying ethical boundaries and practical principles of AI integration. Ultimately, it aims to provide evidence-based references for advancing the high-quality development of the course and cultivating talents with strong data literacy and statistical reasoning abilities.

1.3 Data Source Description

This study uses authoritative data from China's Ministry of Education, national teaching surveys, and key university teaching practices. Specific sources include the 2025 Report on the Construction of Public Mathematics Courses in Chinese Universities, the National Educational Digitalization Strategy Action Implementation Report (2025), teaching quality reports from institutions like the University of Science and Technology of China, Nankai University, and Wuhan University, as well as relevant academic journals and surveys. These sources ensure the research's authority and reliability by providing accurate data on course enrollment, student learning difficulties, teaching methods, practical training conditions, and AI application effects.

2. Practical Value of Generative AI in Probability and Statistics Education

2.1 Reducing Cognitive Load for Abstract Concepts

Core concepts such as probability distributions, hypothesis testing, and confidence intervals are inherently abstract, making them difficult to convey through conventional blackboard derivation. Generative AI enables dynamic simulation, visual experimentation, and contextualized case illustration to lower the learning threshold. Nankai University's 2024 Intelligent Teaching Pilot Report shows AI-assisted visualization of the central limit theorem and stochastic processes improved students' conceptual comprehension efficiency by 47%.

2.2 Enabling Precise and Personalized Instruction

The 2025 Annual Operation Report of the Smart Education of China Platform notes that 64.5% of Chinese universities have deployed intelligent teaching systems. By analyzing learning behavior data, generative AI identifies knowledge gaps, delivers tailored exercises, and provides adaptive tutoring, addressing the limitations of one-size-fits-all classroom teaching and helping students target their weaknesses.

2.3 Enriching Localized and Contextualized Teaching Resources

The 2025 National MOOC Development Report shows China has 97,000 MOOCs, ranking first globally.^[3] Generative AI

supports the rapid production of case libraries, experimental datasets, code templates, and analytical materials, enabling instructors to develop localized resources aligned with industrial needs and national development contexts, with targeted cases for different majors to strengthen the link between theory and practice.

2.4 Improving Classroom Engagement and Interaction Efficiency

Wuhan University's 2024 Smart Teaching Construction Report shows integrating AI teaching assistants increased student classroom participation from 38% to 82% and tripled interactive frequency. By automating repetitive tasks like questioning and grading, generative AI allows instructors to focus on higher-order instruction and reasoning guidance, transforming students from passive knowledge recipients to active participants.

3. Major Challenges in Current Probability and Statistics Teaching

3.1 Overemphasis on Theoretical Derivation at the Expense of Application

Mainstream textbooks prioritize formulaic deduction and theorem proving, with limited connection to real-world scenarios, big data analytics, or industrial applications. A 2026 national survey in China University Teaching indicates 71.2% of students struggle to apply knowledge to practical problems, undermining their learning motivation and practical ability.^[5]

3.2 Dominance of Traditional Pedagogy and Weak Student Initiative

The 2024 National Observation Report on Mathematics Classroom Teaching in Local Universities shows lecturing occupies over 70% of class time, with insufficient inquiry-based, interactive, or cooperative learning activities. This leaves students passive, depriving them of opportunities for independent thinking and discussion, which hinders the cultivation of innovative thinking and problem-solving abilities.

3.3 Insufficient Practical Training and Software Proficiency

The 2024 National Survey on Experimental Teaching of Basic University Courses reveals that only 29.4% of local universities have virtual simulation platforms for probability and statistics. Many courses still rely on manual calculation, leaving students unprepared for data-intensive professional environments—despite proficiency in statistical software like Python and R being essential for modern talents.

3.4 Simplified Assessment and Lack of Process-Based Evaluation

Zhengzhou University's 2024 Curriculum Assessment Reform Survey notes final written examinations often account for over 70% of the overall grade, with insufficient attention to homework, practical projects, data analysis reports, or in-class participation. This simplified method focuses solely on final outcomes, ignoring the learning process and students' comprehensive ability improvement.

4. Practical Paths for Generative AI to Empower Teaching Reform

4.1 Curriculum Restructuring: A Three-Dimensional Framework of “Theory + AI + Application”

Guided by the Ministry of Education's 101 Plan for Mathematics Majors (2024), the course curriculum is restructured into a “Theory + AI + Application” three-dimensional framework, integrating theoretical knowledge, technical tools, and practical applications.

First, streamline theoretical content by reducing complicated proofs and focusing on conceptual understanding and methodological application, using generative AI for visualized interpretation and dynamic simulation of core theories. Second, integrate computational tools: generative AI automatically generates Python scripts, data processing templates, and statistical simulation programs to enhance students' practical data analysis abilities. Third, incorporate localized professional cases—household consumption and regional economic data for economics/management majors, industrial quality inspection and meteorological prediction for science/engineering, and social surveys and rural revitalization data for humanities/social sciences—tailored by generative AI to boost curriculum relevance.

4.2 Pedagogical Innovation: Whole-Process Blended Learning

Generative AI enables a whole-process blended learning model covering pre-class, in-class, and post-class, breaking traditional classroom limitations and integrating online and offline teaching.^[8]

Pre-class: AI provides preview materials, concept maps, and diagnostic exercises, with automated grading and learning

analytics to help instructors identify key and difficult points (Lanzhou University of Technology, 2024, reported a 65% improvement in pre-class targeting accuracy). In-class: AI generates dynamic simulations, real-time quizzes, and inquiry-based tasks to boost participation from approximately 40% to over 80%.^[6] Post-class: AI offers round-the-clock intelligent Q&A, targeted assignments, and error feedback, with a 2025 Guangdong report recording a 60% improvement in students' after-class problem-solving efficiency.

4.3 Practical Training Enhancement: A Three-Tier Practical System

Generative AI supports a three-tier practical training system, progressing from basic operation to innovative exploration to comprehensively enhance students' practical ability and innovative thinking.^[9]

Basic operation: AI-generated tutorials and standardized datasets for data cleaning, statistical plotting, and hypothesis testing, helping students master statistical software basics. Comprehensive projects: Contextualized tasks (e.g., consumption structure analysis, urban air quality assessment) requiring complete statistical reports, with AI providing templates and data support. Innovative exploration: Integration with competitions like the National College Students Mathematical Modeling Contest and Challenge Cup, with AI offering case analysis and technical guidance to strengthen data modeling and innovation.

4.4 Assessment Optimization: A Diversified Process-Based Evaluation System

Generative AI supports a three-dimensional evaluation system combining process, outcome, and competency evaluation to comprehensively, objectively, and fairly assess students' comprehensive literacy.

Process evaluation (40%): AI automatically records and quantifies previews, homework, classroom performance, and experimental tasks, emphasizing the learning process. Outcome evaluation (30%): Mid-term and final examinations use AI-generated test papers and automated grading, ensuring scientificity and fairness. Competency evaluation (30%): AI assists in evaluating practical projects, data analysis reports, and group presentations, providing objective references.

5. Precautions for Integrating Generative AI into Teaching

5.1 Uphold the Instructor as the Primary Guide

Generative AI is only an auxiliary tool and must not replace instructors in knowledge construction, logical reasoning, or value guidance. The "people-oriented and teacher-led" principle must be strictly observed (Ministry of Education, 2025), with instructors leading curriculum design, teaching organization, and student guidance, while using AI to handle repetitive tasks and improve efficiency.

5.2 Strengthen Data Ethics and Academic Integrity

Universities should formulate clear AI usage norms, define boundaries for assignments and reports, prevent AI-generated plagiarism, and cultivate students' integrity. Instructors should guide students to use AI as a learning tool (not an assignment shortcut) and foster independent thinking and innovation.

5.3 Enhance Instructors' Digital Literacy and Integration Competence

Per the 2025 National Report on University Teachers' Digital Literacy, universities should strengthen systematic training to improve instructors' ability to integrate AI into curriculum design and instruction. Instructors need to master AI's basic functions and design AI-assisted teaching activities tailored to the course's characteristics.

5.4 Avoid Technological Formalism

Instruction should prioritize conceptual understanding, logical thinking, and applied ability over technological spectacle. AI deployment should be realistic, targeted, and scalable to institutional conditions, focusing on practical teaching needs rather than blind technological novelty.

Conclusion

Against China's educational digitalization strategy, generative AI provides robust technical support for Probability and Mathematical Statistics teaching reform. Restructuring the curriculum, innovating pedagogical models, strengthening practical training, and optimizing assessment effectively alleviates long-standing issues like over-abstraction, weak application, insufficient personalization, and simplistic evaluation.

The Smart Education of China platform has over 178 million users (2025), laying a solid foundation for AI-enhanced

mathematics teaching. Moving forward, universities should deepen the integration of AI and mathematics education, refine implementation pathways, and leverage technology to serve talent development—cultivating high-quality innovative professionals with strong data literacy and statistical competence to support the construction of a strong educational nation.

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Reference

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Renewing Introductory Management Courses in Higher Vocational Colleges through Blended Teaching: The Roles of Digital Literacy and Learning Engagement

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Abstract: This paper examines how blended teaching can renew introductory management courses in higher vocational colleges through two closely related pathways: the development of digital literacy and the strengthening of learning engagement. Rather than treating blended teaching as a simple combination of online and face-to-face instruction, the paper understands it as a pedagogical redesign that reorganises preparation, classroom activity, feedback, and assessment. Drawing on scholarship from blended learning, vocational pedagogy, digital literacy, student engagement, and management education, the analysis identifies four persistent constraints in current practice: weak links between theory and workplace situations, uneven student digital readiness, superficial participation, and assessment systems that over-reward short-term recall. The paper argues that digital literacy matters because students in blended environments must search, evaluate, communicate, and complete tasks through digital tools with growing independence. Learning engagement matters because flexible access and platform use produce little educational value unless students participate behaviourally, invest cognitively, and remain emotionally connected to the course. On this basis, the paper proposes six practical pathways for course renewal: reorganising content around managerial tasks, designing a three-stage learning loop, embedding meaningful digital tasks, strengthening engagement through interaction and assessment, developing teachers' digital-pedagogical capability, and improving institutional support. The study offers a practice-oriented framework for colleges seeking to move foundational management teaching towards more applied, participatory, and digitally informed learning.

Keywords: Blended Teaching; Introductory Management Courses; Higher Vocational Colleges; Digital Literacy; Learning Engagement; Teaching Reform

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1. Introduction

1.1 Research Background and Importance

Blended learning is no longer understood merely as a temporary mixture of online and classroom sessions; it is increasingly discussed as a deliberate redesign of time, interaction, feedback, and assessment^[1-3]. In management education, this matters because course goals extend beyond conceptual recall. Students are expected to interpret organisational situations, coordinate with others, communicate professionally, and make judgements under practical constraints^[4-7]. For higher vocational colleges, the challenge is even sharper. Introductory management courses sit at the foundation of many business-related programmes,

yet they are often delivered through lecture-heavy routines that privilege definitions, principles, and end-of-term tests. Such arrangements may transmit terminology, but they do not easily build applied understanding or workplace readiness.

At the same time, the digitalisation of work has altered what counts as basic managerial competence. Students need not only disciplinary knowledge but also the capacity to search for information, evaluate digital sources, communicate through platforms, and complete technology-mediated tasks. Business and management education therefore cannot treat digital literacy as an external add-on^[5,8-11]. Nor can flexible online access alone guarantee better learning. Research on student engagement consistently shows that meaningful learning depends on participation, persistence, cognitive investment, and a sense of relevance^[12-15]. Against this background, blended teaching becomes significant not because it uses more technology, but because it can connect course design, digital capability building, and sustained engagement in a more coherent manner.

1.2 Research Objectives

This article aims to clarify how blended teaching can renew introductory management courses in higher vocational colleges through two connected mechanisms: the development of digital literacy and the strengthening of learning engagement. Rather than reporting new survey data, the paper offers a conceptual and practice-oriented analysis grounded in scholarship on blended learning, management education, digital literacy, student engagement, and vocational pedagogy^[4,5,8,13,16]. It seeks to answer three questions. First, why are introductory management courses especially suitable for blended redesign in higher vocational settings? Second, through what mechanisms do digital literacy and learning engagement influence the effectiveness of course implementation? Third, what practical pathways can institutions and instructors adopt to turn blended teaching from a technical arrangement into a meaningful pedagogical reform?

1.3 Analytical Basis and Scope

The discussion focuses on introductory management courses typically offered in business, marketing, logistics, tourism, and service-related programmes. These courses usually introduce planning, organising, leading, coordination, communication, supervision, and basic decision-making. The paper does not treat all forms of blended teaching as equivalent. Following existing research, blended teaching here refers to the purposeful integration of online resources, in-class activity, digital communication, and formative assessment into a single learning design^[2,3,17,18]. The analysis also adopts a vocational perspective, meaning that course value is judged not only by exam scores but by the extent to which students can connect concepts to work situations, participate in collaborative tasks, and develop durable learning habits^[6,7,25].

2. Why Introductory Management Courses Need Blended Redesign

2.1 The Competency Profile of Vocational Management Education

Basic management courses in higher vocational colleges are often treated as theoretical foundations, yet their educational function is wider than conceptual introduction. Students must learn to interpret routine organisational problems, allocate simple resources, coordinate roles, communicate across tasks, and respond to uncertainty in service or operational settings. These are not competencies that emerge from memorising principles alone. They require repeated exposure to scenarios, opportunities for reflection, and structured interaction with peers and instructors^[4,6,7]. For this reason, vocational management education benefits from learning designs that combine explanation with application, individual study with collaborative work, and knowledge input with timely feedback.

Blended teaching is particularly suited to this competency profile. Pre-class digital materials can introduce core concepts in manageable units, while classroom time can be reserved for case analysis, role play, discussion, and problem solving. After class, students can revisit resources, submit short reflections, and receive formative feedback through learning platforms. This sequencing helps move introductory courses away from one-directional lecturing and towards constructive alignment between learning outcomes, learning activities, and assessment^[2,7,17]. Evidence from higher education also suggests that blended environments are most effective when course design, student support, and assessment structures are aligned rather than assembled piecemeal^[19-21].

2.2 The Limits of Lecture-Dominated Delivery

Lecture-centred teaching remains common because it is efficient for covering content, especially in large classes. Yet in introductory management courses it often produces several recurring problems. First, abstract concepts are detached from

work situations. Students can repeat terms such as span of control, motivation, leadership style, or organisational structure, but they struggle to see how these ideas operate in everyday supervisory or service contexts. Second, teacher talk dominates while student reasoning remains thin. Third, assessment often rewards short-term recall more than interpretation or application^[4,7,21].

Management education scholars have long argued that digital and blended delivery should not simply reproduce transmission teaching in a new medium^[2,4,16]. When online components are used only to upload slides or record lectures, the most pressing pedagogical problem remains untouched. By contrast, studies in management education show that digital tools can broaden participation, support reflection, and extend learning beyond the classroom when they are tied to clear task design and communication structures^[5,22]. The issue, then, is not whether technology is present, but whether the course asks students to read, discuss, compare, decide, and produce in ways that approximate managerial work.

2.3 Why Digital Literacy and Engagement Matter Most

Two conditions determine whether blended teaching improves learning in practice. The first is digital literacy. Students in blended courses must navigate learning platforms, locate resources, judge information quality, communicate online, and sometimes produce multimodal work. Digital literacy therefore includes technical operation, cognitive judgement, and social communication rather than mere device use^[8-11]. Without this capability, flexibility can quickly turn into confusion, fragmentation, and passive dependence on teachers.

The second condition is learning engagement. Engagement includes behavioural participation, cognitive investment, and emotional connection to the learning process^[12,13]. Students may have access to excellent online materials, but access alone does not guarantee sustained attention or meaningful effort. Research on educational technology repeatedly shows that engagement is the link between instructional design and learning outcomes^[14,15]. In introductory management courses, where students often enter with uneven academic preparation and limited confidence in theoretical study, engagement becomes especially decisive. Blended teaching works when it lowers entry barriers, increases relevance, and keeps students actively involved over time.

3. A Mechanism Framework for Blended Teaching Reform

3.1 Blended Teaching as an Integrated Pedagogical System

Blended teaching is sometimes reduced to a ratio between online and face-to-face hours. That view is too narrow. A more useful understanding is to treat blended teaching as an integrated pedagogical system that redistributes learning tasks across time, space, and media^[1-3]. In this system, online components are not appendices; they prepare, extend, or deepen classroom work. Face-to-face sessions are not reserved for repeating content that students could read alone; they are used for interaction, clarification, judgement, and practice. The quality of blended teaching thus depends on sequencing, coherence, and feedback rather than on technological density^[17,18,23].

For introductory management courses, this means that concept explanation, case interpretation, peer collaboration, reflective writing, and assessment must be designed as a connected whole. A short video on planning or motivation, for example, only becomes valuable when it leads into discussion questions, application tasks, or classroom scenarios. Likewise, digital quizzes matter not because they automate marking, but because they provide fast diagnosis and inform subsequent teaching. The reform of blended teaching is therefore a matter of course architecture.

3.2 Digital Literacy Development as an Enabling Pathway

Digital literacy is the first enabling pathway in this framework. In blended introductory management courses, students repeatedly work with online platforms, digital resources, collaborative documents, discussion boards, video materials, and simple data-based tasks. When such activities are designed well, students gradually develop the ability to search, compare, judge, organise, and communicate information more independently^[8-11]. This capability reduces their reliance on teacher explanation for every step and allows them to participate more productively in pre-class preparation and post-class consolidation.

The key point is that digital literacy should be cultivated through disciplinary tasks, not taught as a separate technical module. A student learns more from comparing two online case reports, checking the credibility of managerial advice, and preparing

a brief digital presentation than from passively receiving instructions about platform buttons. In vocational management education, digital literacy can also include everyday workplace practices such as drafting collaborative schedules, summarising customer feedback, or interpreting simple operational data. Once students become more competent in these practices, the blended environment becomes easier to navigate and less cognitively wasteful.

3.3 Learning Engagement as a Sustaining Pathway

Engagement forms the second pathway. When blended teaching is structured around relevance, interaction, and timely response, students are more likely to participate consistently. Behavioural engagement grows when tasks are clear, manageable, and visible. Cognitive engagement deepens when students are asked to compare alternatives, justify decisions, and connect concepts to concrete cases. Emotional engagement strengthens when they experience progress, recognition, and a sense that the course speaks to real work situations ^[12-15].

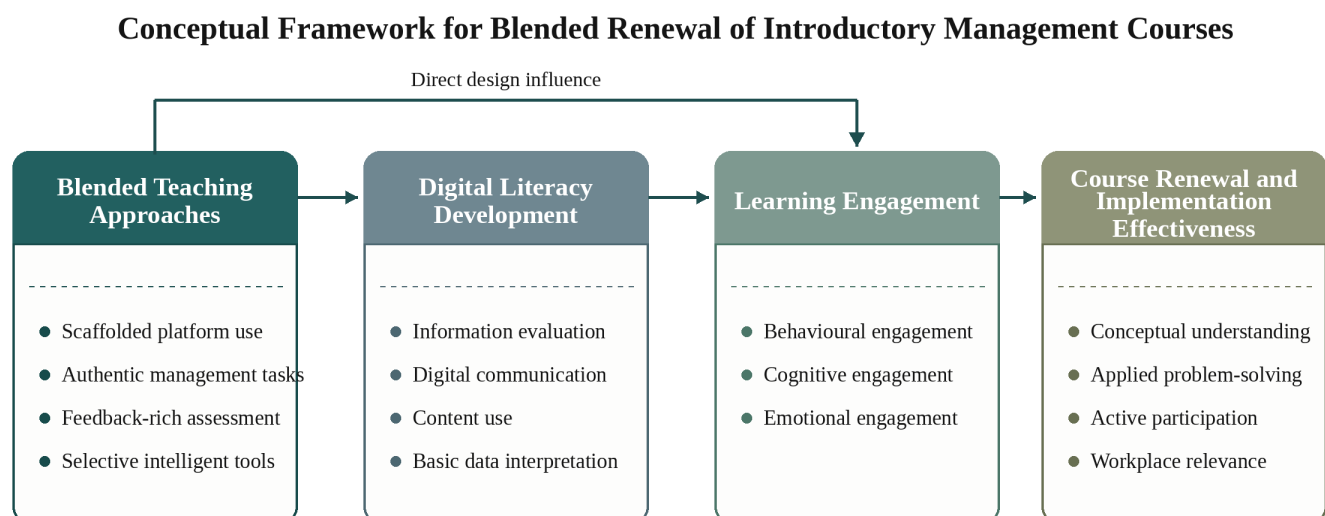
In introductory management courses, engagement can be fragile because abstract content often feels distant from students' everyday experience. Blended teaching can address this by expanding the range of interaction. Short preparatory questions, in-class polling, collaborative case notes, peer comments, and reflective posts can draw more students into the learning process than a single lecture-discussion pattern. Importantly, engagement is not created by novelty alone. It depends on whether students see a reason to invest effort and whether the course gives them structured opportunities to do so.

3.4 The Link Between Digital Literacy and Engagement

Digital literacy and engagement should not be treated as isolated variables. They reinforce one another. Students who can navigate digital platforms confidently are more likely to prepare before class, participate online, and sustain effort after class. At the same time, engaged students practise digital tasks more often and gradually expand their competence through use ^[9,14,19,24]. In other words, digital literacy lowers participation barriers, while engagement turns digital opportunity into actual learning behaviour.

This linkage is especially important in higher vocational settings. Students often differ in prior academic habits, self-management, and familiarity with formal learning technologies. If blended courses assume a level of digital readiness that students do not yet possess, engagement may decline. If courses simplify all digital work to avoid difficulty, students lose an important chance to build relevant capability. Effective blended teaching therefore calibrates challenge: it introduces digital tasks progressively, provides support where necessary, and connects those tasks to visible learning purposes. The overall mechanism proposed in this paper is summarised in Figure 1.

Figure 1: Conceptual framework linking blended teaching, digital literacy development, learning engagement, and course renewal.



Digital literacy is positioned as an enabling capability; engagement is treated as the immediate learning mechanism.

4. Persistent Constraints in Current Course Implementation

4.1 Weak Connection Between Theory and Workplace Situations

A recurring weakness in introductory management teaching is the gap between textbook concepts and the realities of vocational practice. Students may understand formal definitions but fail to apply them to customer service, frontline supervision, team scheduling, or small-scale operational problems. This weakens both retention and motivation. When concepts remain decontextualised, students often see management courses as descriptive or exam-oriented rather than useful for future work ^[4,6,25].

Blended teaching can narrow this gap, but only if digital resources are built around practical situations. Uploading reading materials alone does not create relevance. Courses need short cases, scenario prompts, workplace videos, and discussion tasks that translate principles into decisions and actions.

4.2 Uneven Digital Readiness and Self-Management

A second constraint is the uneven digital readiness of students. Access to devices does not necessarily mean students know how to evaluate online information, manage platform-based learning, or collaborate effectively in digital environments ^[8-11]. Some students are comfortable with entertainment-oriented digital use but uncertain when asked to search academically, synthesise information, or manage deadlines independently. This problem becomes more visible in blended teaching because learning extends beyond the teacher's immediate supervision.

Self-regulation is closely tied to this issue. Research comparing online and blended learners suggests that planning, monitoring, and study management are important for success in technology-mediated learning ^[24]. In higher vocational colleges, where students often balance multiple pressures and may have uneven study habits, blended course design must include explicit support rather than assuming autonomous learning will emerge spontaneously.

4.3 Superficial Participation and Weak Peer Collaboration

A third difficulty is that participation is often visible but shallow. Students may log in, download files, or attend class without investing much thought. In some cases, online discussion turns into short, repetitive responses written only to satisfy attendance rules. In others, group work is unevenly distributed, with a few students carrying most of the task. These patterns reduce the educational value of blended teaching and can create resistance among both students and instructors ^[14,15,18].

For management education, this is a serious issue because collaboration itself is part of the learning outcome. If blended teaching does not improve the quality of peer interaction, it misses one of its main advantages. Students should not simply coexist on a platform; they need structured reasons to exchange views, negotiate decisions, and respond to one another's work.

4.4 Assessment Structures That Over-Reward Recall

The fourth constraint lies in assessment. Many introductory courses still rely heavily on final examinations. This approach is simple to administer, but it captures only a narrow portion of what management education is supposed to develop. Students can often pass by memorising terms and reproducing standard answers, while weaker performance in discussion, application, collaboration, or reflection remains invisible ^[7,21]. Such assessment also discourages sustained engagement because students learn that regular participation has limited value unless it directly affects grades.

In blended settings, this mismatch becomes more obvious. If a course includes pre-class work, online discussion, case analysis, and collaborative tasks, then assessment should recognise those forms of learning. Otherwise, students will treat them as optional or symbolic. A rebalanced system of formative and summative assessment is therefore essential to the credibility of blended reform.

5. Practical Pathways for Course Renewal

5.1 Reorganising Content Around Managerial Tasks

The first pathway is curricular reorganisation. Instead of arranging the course only around textbook chapters, instructors can cluster content around common managerial tasks: setting work goals, allocating responsibilities, coordinating teams, handling service problems, motivating staff, and monitoring performance. Foundational concepts remain important, but they are

introduced as tools for understanding and solving situations rather than as isolated definitions ^[4,7].

This task orientation is particularly appropriate for higher vocational education because it respects the applied logic of the sector ^[6]. It also gives blended teaching a clearer purpose. Pre-class resources can introduce necessary concepts; classroom time can be used for scenario analysis; post-class tasks can ask students to transfer the idea to new settings. In this way, digital materials support rather than fragment learning.

5.2 Designing a Three-Stage Learning Loop

The second pathway is to design a stable pre-class, in-class, and post-class learning loop. Before class, students can work with short videos, concise readings, vocabulary explanations, or simple diagnostic quizzes. The aim is not to complete the whole lesson online, but to reduce passive listening later by ensuring that students arrive with a preliminary grasp of the topic. During class, emphasis should shift to clarification, debate, case analysis, role simulation, and group decision-making. After class, students can submit brief reflections, respond to feedback, revise misconceptions, or complete applied mini-tasks.

This three-stage loop supports both digital literacy and engagement. Students use digital tools with a clear learning purpose, while teachers gain more room for interaction in class. The loop also makes progress visible. Students can see what preparation is expected, what is done collectively, and how learning continues after class. Coherence of this kind is more valuable than adding multiple tools without a clear sequence ^[2,3,17].

5.3 Embedding Digital Tasks That Build Literacy

The third pathway is to embed digital tasks that cultivate literacy within disciplinary learning. For example, students may be asked to compare the credibility of two management websites, summarise a short workplace case using collaborative software, prepare a digital briefing on service improvement, or interpret basic operational data presented in dashboard form. These tasks strengthen information judgement, communication, and platform use while keeping attention on management problems ^[8-11].

The design principle here is moderation. Not every lesson needs a new application or complex platform. Overly technical tasks may distract from learning goals and frustrate students with weaker readiness ^[18]. What matters is repeated practice with a limited set of meaningful digital actions that gradually become part of the students' learning repertoire.

5.4 Strengthening Engagement Through Interaction and Assessment

The fourth pathway is to make engagement observable, supported, and consequential. Observable engagement means that students' preparation, participation, collaboration, and reflection leave traces that instructors can see. Supported engagement means that tasks are scaffolded and feedback is timely. Consequential engagement means that these learning processes count within the assessment structure ^[12-15].

In practical terms, this may involve participation rubrics, short response notes, peer feedback sheets, case discussion records, group presentations, and reflective journals. Low-stakes but regular assessment can help students stay involved without turning every activity into a high-pressure event. In introductory management courses, this approach is particularly useful because it rewards gradual development and reduces the temptation to postpone learning until the final examination. It also aligns better with the communicative and collaborative nature of management work ^[7].

5.5 Developing Teachers' Digital-Pedagogical Capability

The fifth pathway concerns teachers. Blended reform does not succeed simply because a platform is available. Instructors need the capacity to redesign learning tasks, sequence activities, moderate online interaction, read student learning traces, and give feedback efficiently ^[5,17,16]. In management education, teachers also need to connect digital design with the practical rhythm of case-based and discussion-oriented teaching.

Professional development should therefore move beyond basic platform training. It should help teachers make decisions about workload, task difficulty, assessment balance, and the relationship between online and classroom components. This is especially important in higher vocational colleges, where teaching often involves diverse student backgrounds and strong expectations for applicability. Teacher capability is not a peripheral issue; it is one of the conditions that determines whether blended teaching remains superficial or becomes transformative.

5.6 Building Institutional Support and Quality Assurance

The final pathway is institutional. Even well-designed courses are weakened when platforms are unstable, devices are unequal, or teachers work without resource support. Colleges need reliable learning management systems, accessible digital resource banks, manageable class sizes where possible, and shared standards for formative assessment. They also need realistic expectations about workload. Poorly planned blended reform can increase administrative burden without improving learning^[17,18].

Quality assurance should pay attention to more than platform usage statistics. Useful indicators include the coherence of course design, student participation patterns, feedback timeliness, the relevance of learning tasks, and the alignment between assessment and learning outcomes. At the institutional level, blended teaching should be treated as a pedagogical strategy, not as a simple indicator of digital modernisation.

Table 1: Practical pathways for blended renewal of introductory management courses.

Pathway	Design emphasis	Expected contribution
Content around managerial tasks	Connect concepts with vocational situations such as coordination, service problems, and team supervision.	Stronger applied understanding and work-place relevance.
Three-stage learning loop	Link pre-class preparation, in-class application, and post-class reflection.	More coherent participation and learning continuity.
Embedded digital tasks	Use information search, collaborative documents, digital briefings, and basic data interpretation.	Gradual digital literacy development within disciplinary learning.
Interaction and assessment	Make preparation, discussion, peer feedback, and reflection visible and consequential.	Higher behavioural, cognitive, and emotional engagement.
Teacher capability	Strengthen task design, online facilitation, feedback, and use of learning traces.	Less superficial platform use and more adaptive instruction.
Institutional support	Provide stable platforms, resource banks, workload support, and quality assurance.	More sustainable course implementation across programmes.

6. Discussion

6.1 Implications for Management Education

The analysis suggests that blended teaching has special value in management education because it brings instructional practice closer to the communication patterns and problem-solving conditions of contemporary organisations. Management work increasingly involves digital coordination, distributed information, and collaborative decision-making. Introductory courses should therefore expose students early to learning forms that mirror these conditions^[4,5,16,22]. A course that integrates case discussion, platform-based preparation, peer feedback, and digital communication is not merely following a technological trend; it is rehearsing part of the environment in which students will later work.

6.2 Implications for Higher Vocational Colleges

For higher vocational colleges, the core lesson is that blended reform should begin from student capability and curriculum purpose rather than from technology procurement. Students need gradual support in digital practice, and teachers need time to redesign tasks. Institutional strategies that emphasise platform adoption without pedagogical adjustment are unlikely to produce deep change. Evidence from higher vocational settings indicates that blended learning often performs well when it combines practical relevance, teacher support, and appropriate resources^[19,25]. This means that reform efforts should remain grounded, selective, and closely tied to course characteristics.

6.3 Limitations and Future Research

This paper is conceptual and practice-oriented. It does not test causal relations through original survey or experimental data. Its value lies in clarifying a mechanism framework and translating existing scholarship into a coherent set of pathways

for introductory management courses. Future research can build on this framework in at least three ways. First, empirical studies may examine whether digital literacy and learning engagement operate as parallel or sequential mediators in blended management courses. Second, comparative studies may investigate differences across majors, institutional types, or student groups. Third, qualitative work may explore how students actually experience the shift from lecture-centred teaching to blended course design in vocational contexts.

Conclusion

Blended teaching can renew introductory management courses in higher vocational colleges, but its value does not lie in the simple coexistence of online and face-to-face activities. Its real contribution lies in redesigning how students prepare, participate, apply knowledge, and receive feedback. The analysis developed in this paper argues that digital literacy and learning engagement are the two central mechanisms in that process. Digital literacy enables students to work productively in a technology-mediated learning environment, while engagement converts access and flexibility into sustained learning effort. For vocational management education, this argument has practical implications. Course reform should reorganise content around managerial tasks, establish coherent learning loops across class stages, embed meaningful digital tasks, recognise process-based engagement in assessment, strengthen teachers' digital-pedagogical capability, and provide institutional support. When these elements are aligned, blended teaching can move foundational management courses away from abstract transmission and towards applied, participatory, and digitally informed learning. That is the direction in which introductory management education needs to move if it is to remain educationally credible and vocationally relevant.

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Reframing Vocational Teachers' Roles in the Digital Turn: School–Enterprise Partnership and AI-Enabled Pedagogy in Liaoning Province

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Abstract: Digital transformation in vocational education is often discussed in terms of platforms, infrastructure, or curricular modernization. Less attention has been paid to the redistribution of pedagogical and organizational work that accompanies these changes. This article examines how vocational teachers' professional roles are being reshaped at the intersection of school–enterprise partnership and AI-enabled pedagogy. The study adopts an integrative review of scholarship on vocational education digitalization, teacher professionalism, work-based learning, and artificial intelligence in education, combined with a policy-text analysis of national Chinese and Liaoning provincial documents. The analysis shows that digital transformation does not simply add new tools to existing routines. It expands teachers' work in five directions: learning design, boundary-spanning coordination with industry, data-informed mentoring, curriculum and resource curation, and ethical governance of AI use. School–enterprise partnership functions as an organizational mechanism because it redistributes curriculum development, assessment, and practice supervision across institutional boundaries. AI-enabled pedagogy functions as a pedagogical mechanism because it changes how teachers diagnose learner needs, organize practice, provide feedback, and monitor progression. In Liaoning Province, where digital campus construction and industrial upgrading are advancing together, the coupling of these two mechanisms is especially visible. The article argues that the future vocational teacher is neither a traditional lecturer nor a mere platform operator, but a professional who connects occupational standards, digital resources, and student development. On this basis, the paper proposes practical pathways for vocational colleges, including teacher industry residency, discipline-specific AI professional development, workload recognition for partnership work, and human-centered governance of educational data and AI applications.

Keywords: Vocational Education; Digital Transformation; Teacher Roles; School–Enterprise Partnership; Artificial Intelligence; Liaoning Province; Educational Management

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1. Introduction

Digital transformation has moved from a supporting function to a structuring force in vocational education. In China, education digitalization is no longer framed simply as an issue of hardware access or online resource supply; it is increasingly tied to governance reform, smart platforms, curriculum modernization, and the building of a national learning infrastructure ^[1]. This shift matters especially in vocational education because occupational standards, production processes, and required

technical skills are being reshaped by industrial digitalization. Recent policy directions have therefore linked vocational education reform with industrial upgrading, stronger enterprise participation, and the cultivation of digitally capable technical talent ^[2].

The literature on vocational education has captured important parts of this change. Existing studies describe the expansion of digital campuses, online resources, virtual simulation, and platform-based teaching in vocational settings ^[3,4]. Yet the more consequential question is professional rather than technical: what happens to the work of teachers when vocational education becomes more data-rich, industry-connected, and AI-aware? Long before the current wave of smart education, scholarship on vocational teacher quality had already emphasized that VET teachers occupy a complex professional position. Their work depends on the combination of occupational expertise, pedagogical judgement, and institutional role performance ^[5]. In this sense, digital transformation should be read not as a narrow technology project, but as a reorganization of teacher knowledge and responsibility ^[6].

Two processes are central to that reorganization. The first is school–enterprise partnership, which has long been treated as a defining feature of vocational education in China and elsewhere ^[7-10]. The second is the growing use of artificial intelligence in teaching, assessment, feedback, and student support ^[11-15]. These two strands are often discussed separately. Studies of school–enterprise cooperation focus on practice bases, curriculum relevance, and work-based learning, while studies of AI in education tend to concentrate on personalization, automation, analytics, or generative tools. Far less attention has been paid to how they operate together in the daily work of vocational teachers. That gap is significant in an industrial province such as Liaoning, where regional vocational education reform has been explicitly connected to digitalization, industrial transformation, and the modernization of school governance ^[16-18].

The difficulty is that these two processes rarely operate as separate reforms. In practice, a vocational teacher may redesign a course with enterprise engineers, move part of the training sequence onto a digital platform, use AI-supported feedback to monitor students' errors, and still remain responsible for occupational safety and formative judgement. Role change therefore emerges from the interaction between organizational arrangements and pedagogical tools. Treating digital transformation only as technology adoption risks missing this interaction; treating school–enterprise cooperation only as an external partnership similarly underestimates how teachers translate industrial knowledge into teachable tasks ^[5,7-10].

Against this background, the article asks three questions. First, what professional roles are being reconfigured in digitally transforming vocational education? Second, through what mechanisms do school–enterprise partnership and AI-enabled pedagogy drive that reconfiguration? Third, how does the Liaoning context shape these dynamics? The contribution of the paper is conceptual rather than statistical. It develops an analytical framework for understanding role change in vocational teaching and translates that framework into practical implications for college management and teacher development.

2. Materials and Methods

2.1 Review design and source selection

This article is a conceptual review rather than an empirical survey. It adopts an integrative review design in order to synthesize four bodies of literature that are usually treated as separate conversations: digital transformation in vocational education, vocational teacher professionalism, school–enterprise partnership, and artificial intelligence in teaching. This design is appropriate because the problem under discussion is not confined to one disciplinary lens. Role change in vocational education is simultaneously pedagogical, organizational, and policy-driven.

Peer-reviewed studies were selected because they addressed at least one of the following themes: the digital transformation of vocational education ^[3,4]; the knowledge base and institutional role of vocational teachers ^[5,6]; collaboration between schools and workplaces, including Chinese school–enterprise cooperation ^[7-10]; and AI-supported teaching, teacher professional development, or teacher roles in AI-rich environments ^[11-15]. In addition, official policy documents were included to capture the Chinese and Liaoning governance context in which vocational digitalization is currently being advanced ^[1,2,16-18]. Recent work on digital competence challenges in vocational education and on global teacher digital skills frameworks was also consulted to sharpen the discussion of implementation constraints ^[19,20].

2.2 Analytical procedure

The material was read through three analytical questions. First, what new tasks are teachers expected to perform under conditions of digital transformation? Second, through what organizational and pedagogical mechanisms do these tasks emerge? Third, which dimensions of professional judgement remain non-substitutable even when platforms and AI tools become more capable? The coding process therefore focused on recurring descriptions of teacher work, institutional arrangements, and boundary changes between school, workplace, and technology.

The aim was not to test causal mediation in a statistical sense. Instead, the review sought to build a coherent explanatory framework. The resulting analysis treats school–enterprise partnership as an organizational mechanism of role change and AI-enabled pedagogy as a pedagogical mechanism of role change. Liaoning Province is used as a policy-grounded regional context in which these mechanisms can be interpreted concretely.

2.3 Conceptual framing

For the purposes of this review, digital transformation is understood as an institutional process through which vocational colleges reorganize teaching, assessment, management, and industry-facing services around digital infrastructures. This definition is deliberately broader than the use of online courses or smart classrooms. It includes changes in curriculum decision-making, evidence collection, resource circulation, professional development, and governance. Teacher-role reshaping is understood as the redistribution of expectations attached to teachers' work, including what they design, whom they coordinate with, what evidence they interpret, and what forms of responsibility they carry.

The proposed framework distinguishes an enabling condition, two mediating mechanisms, and a professional outcome. Digital transformation functions as the enabling condition because it supplies the platforms, data systems, simulation tools, and AI applications that make new forms of teaching possible. School–enterprise partnership mediates this condition at the organizational level by bringing occupational standards, workplace tasks, and enterprise mentors into curriculum practice. AI-enabled pedagogy mediates it at the instructional level by changing diagnosis, feedback, personalization, and assessment. The outcome is not a single new role but a layered professional identity in which teachers combine pedagogical, technical, managerial, and ethical judgement ^[6,11-15].

3. Reconfigured Teacher Roles in the Digital Turn

Digital transformation in vocational education changes more than the tools available in classrooms. It alters the division of pedagogical labour, the tempo of curriculum updating, and the boundaries between teaching, mentoring, coordination, and governance. What emerges is not one new role, but a cluster of interrelated responsibilities.

3.1 Teacher as learning designer

One of the clearest shifts is from content delivery to learning design. In many vocational programs, teaching now moves across physical workshops, online platforms, virtual simulation systems, enterprise projects, and self-paced resource banks. Teachers must decide what is best learned through direct demonstration, what can be simulated, what requires enterprise exposure, and how these elements should be sequenced around work-process logic rather than textbook order ^[3,4].

This is not a minor technical adjustment. It requires teachers to organize tasks, evidence, and feedback across multiple learning environments. In vocational fields, the design question is especially demanding because knowledge is often procedural, contextual, and safety-sensitive. A digital resource that is adequate for theoretical explanation may be insufficient for judging whether a learner can complete a process under workplace conditions. TPACK, in this setting, becomes less a general theory of technology integration than a practical framework for curriculum engineering under conditions of occupational change ^[6].

The learning designer role also grows in importance because vocational knowledge does not remain stable for long. Where equipment, software, or production routines change quickly, teachers increasingly curate, adapt, and sometimes create teaching resources instead of relying on fixed printed materials. Their value lies not only in knowing content, but in shaping coherent trajectories through digital and practical learning tasks.

Learning design in this setting is also a matter of sequence. A teacher must decide which competences should be introduced through explanation, which should be rehearsed through simulation, which should be verified through workshop performance,

and which require enterprise-based exposure. A poorly sequenced digital course may look modern but still fail to produce occupational competence. The teacher's design work therefore has to preserve the logic of work processes rather than merely transferring existing lectures into digital formats ^[3,4,6].

3.2 Teacher as boundary-spanning coordinator

School–enterprise partnership adds a second role: the teacher as boundary-spanning coordinator. When vocational colleges move beyond symbolic cooperation and build sustained links with firms, teachers are drawn into negotiations over occupational standards, equipment updates, internship content, enterprise mentors, and assessment criteria ^[7-9]. In these settings, the teacher becomes a translator between the language of production and the language of schooling.

This translation work is frequently underestimated because it is less visible than classroom teaching. Yet it is indispensable if curriculum relevance is to be more than a slogan. Chinese research on school–enterprise cooperation has repeatedly shown that effective collaboration depends on stable institutional arrangements rather than one-off agreements ^[7,8]. International work on workplace collaboration points in the same direction, emphasizing that relevance in vocational education is strengthened when schools and workplaces jointly shape learning tasks, supervision, and evaluation ^[9].

Teacher industry placement sharpens this function further. Time spent in contemporary work settings gives teachers access not only to updated technical knowledge, but also to workflow expectations, communication patterns, tacit standards, and quality-control routines that are difficult to infer from documents alone ^[10]. This experience strengthens the teacher's capacity to coordinate across institutional boundaries and to keep school-based learning aligned with actual work processes.

Boundary spanning also affects teachers' authority. In a strong partnership, teachers are not passive recipients of enterprise requirements; they negotiate which workplace tasks are suitable for beginners, which standards can be assessed within school conditions, and where safety, cost, or confidentiality limits direct workplace reproduction. This negotiation is a professional activity. It requires enough technical knowledge to speak with firms and enough educational judgement to protect learning progression ^[7-10].

3.3 Teacher as data-informed mentor and evaluator

A third shift concerns feedback and evaluation. Digital platforms and AI-supported systems generate new forms of evidence about student participation, mistakes, progression, and response patterns. In principle, these data can support earlier intervention and more differentiated instruction ^[11-13]. In practice, however, raw data do not teach. Teachers remain responsible for interpreting what patterns mean, deciding which signals are educationally important, and linking digital traces to observable performance in classrooms, workshops, and practice settings.

This point is particularly important in vocational education. Platform analytics may indicate low quiz scores or limited engagement, but they cannot by themselves explain whether the difficulty lies in conceptual misunderstanding, tool misuse, weak procedural memory, or anxiety in performance situations. Vocational teachers therefore move toward a mentoring role in which they triangulate system-generated feedback, direct observation, and performance evidence. AI-supported education may extend the reach of formative feedback, but it also increases the need for professional interpretation ^[14].

The evaluator role changes accordingly. Assessment can no longer rely only on end-point testing. Teachers are increasingly asked to combine process evidence, digital records, practical demonstrations, and workplace-related outcomes. This does not reduce professional judgement; it makes that judgement more continuous and more explicit.

3.4 Teacher as ethical steward of AI use

The rise of generative AI introduces a fourth role: ethical stewardship. AI tools can now generate drafts, code, designs, explanations, and troubleshooting suggestions with remarkable speed. For vocational learners, this can be useful. It can also create new forms of opacity. Outputs may appear fluent while containing technical errors, weak reasoning, or unsafe assumptions. In assignments related to maintenance, accounting, marketing, programming, or design, the line between assistance and substitution becomes difficult to manage ^[14,15].

Teachers therefore retain an indispensable gatekeeping function. They must decide where AI use is pedagogically legitimate, how assessment should be redesigned to preserve diagnostic value, and how students should be taught to verify rather than merely accept AI outputs. UNESCO's recent guidance is clear on the need for human-centred governance, especially in

relation to privacy, bias, age appropriateness, and educational purpose^[15]. In vocational education, the issue is not abstract ethics alone. It concerns whether the use of AI supports sound occupational judgement or obscures its absence.

3.5 Teacher as curriculum and resource curator

A further role is curriculum and resource curation. Digital transformation increases the volume of available learning materials, including open resources, platform content, simulation modules, enterprise cases, and AI-generated examples. Abundance does not automatically improve teaching. Teachers must select resources that correspond to occupational standards, local equipment, student readiness, and assessment requirements. In this sense, curation becomes a professional filter between the digital knowledge environment and the vocational classroom^[3,4].

This curatorial role is particularly relevant in Liaoning, where different colleges may serve different industrial clusters and operate with uneven equipment conditions. A resource that is effective in one major, college, or enterprise setting may not be transferable without adaptation. Teachers therefore need the authority and time to localize digital resources, update cases, remove obsolete procedures, and combine enterprise materials with pedagogically usable scaffolds. Without this work, digital resource construction may become a repository project rather than a teaching reform.

Taken together, these changes suggest that the future vocational teacher is defined less by unilateral content transmission than by orchestration, translation, curation, interpretation, and judgement.

Table 1. Emerging teacher roles in digitally transforming vocational education

Emerging role	Core work	Institutional support
Learning designer	Organizes blended resources, virtual simulation, project tasks, and assessment around work-process logic.	Curriculum redesign time, platform access, and cross-departmental support.
Boundary-spanning coordinator	Aligns enterprise standards, internships, mentors, and classroom tasks; translates between industry language and curricular requirements.	Stable school–enterprise governance, teacher industry placement, and workload recognition.
Data-informed mentor	Uses analytics and AI-supported feedback to diagnose needs, monitor progression, and provide differentiated guidance.	Data literacy, redesigned assessment, and interoperable systems.
Ethical steward of AI use	Sets boundaries for acceptable AI use and addresses bias, privacy, safety, and academic integrity.	Institutional policy, human oversight, and discipline-specific AI guidelines.
Curriculum and resource curator	Selects, adapts, and updates digital resources, enterprise cases, and AI-generated materials according to occupational standards and local teaching conditions.	Time for resource localization, access to enterprise materials, and departmental review mechanisms.

4. Discussion: Dual Mechanisms of Role Change

4.1 School–enterprise partnership as an organizational mechanism

School–enterprise partnership reshapes teacher work because it redistributes parts of curriculum authority beyond the classroom. In a conventional arrangement, teachers teach within the school and the firm receives students during practice. Under deeper partnership, however, enterprise standards influence curriculum content, equipment selection, internship design, and competence expectations^[7-9]. The teacher’s task therefore expands into coordination, negotiation, and quality assurance.

This shift has strong implications for teacher professionalism. Vocational teachers have long occupied a dual position between education and occupation^[5]. Digital transformation makes that dual position more demanding, not less. When enterprises update software, process standards, and technical systems more quickly than schools can revise textbooks, teachers become the key translators who keep the curriculum legible to both sides. Partnership thus changes teacher roles not simply by increasing external contact, but by altering the institutional location of vocational knowledge itself.

4.2 AI-enabled pedagogy as a pedagogical mechanism

AI-enabled pedagogy works through a different pathway. It changes the micro-structure of teaching: content generation,

adaptive explanation, automated feedback, chat-based support, prediction of learning difficulties, and the analysis of large volumes of student interaction data ^[11-13]. Some of these uses save time. More importantly, they change the evidence available to teachers and the pace at which pedagogical decisions can be made.

Yet efficiency should not be mistaken for educational improvement. The practical value of AI depends on whether teachers can contextualize outputs, judge their reliability, and connect them to authentic vocational performance. Used well, AI may free time for coaching and allow teachers to focus on higher-value interventions. Used poorly, it can produce superficial assessment, encourage passive completion, or shift attention toward what systems can easily measure rather than what vocational competence actually requires ^[13-15].

4.3 Why the two mechanisms need to be read together

The current transformation of vocational teaching becomes clearer when these mechanisms are read together. AI without industry context may make learning more efficient while remaining weakly connected to real occupational tasks. School–enterprise partnership without digital capacity may remain episodic and administrative, dependent on individual contacts rather than stable systems. The coupling of enterprise-linked teaching and AI-enabled pedagogy is what makes the present moment distinctive.

When authentic enterprise tasks, digital platforms, simulation environments, and AI-assisted feedback are aligned, teachers can connect work-process knowledge, personalized support, and competence assessment within one learning architecture. That alignment, however, also raises the threshold for teacher competence and institutional support. From this perspective, role change is not a side effect of technology adoption. It is a structural consequence of reorganizing how vocational knowledge is produced, updated, and taught.

4.4 Role intensification and conditions for mediation

The mediation described above is not automatic. Both partnership and AI can intensify teachers' workload if they are introduced without institutional redesign. Enterprise cooperation may add meetings, documentation, internship coordination, and quality assurance duties. AI-enabled systems may add platform monitoring, data interpretation, prompt design, and new forms of academic integrity management. In such cases, role reshaping becomes role accumulation, and the professional benefits of digital transformation may be weakened.

Effective mediation therefore depends on organizational conditions. Teachers need protected time for curriculum redesign, access to enterprise practice, technical support for platform use, and recognition of coordination work in promotion and performance systems. They also need shared rules about data, authorship, privacy, and acceptable AI assistance. Where these conditions are absent, teachers may comply with digital reform requirements at the surface level while retaining traditional routines underneath ^[15,19,20].

5. Liaoning Province: Opportunities and Constraints

Liaoning offers a useful context for this discussion because vocational education reform there is tied closely to regional industrial restructuring. Provincial reports and policy documents have framed “digital vocational education” as part of the broader agenda of Digital Liaoning and intelligent manufacturing, while calling for the deep integration of internet-based tools, big data, cloud computing, and new-generation AI with vocational education ^[16-18]. The digital campus agenda is therefore not an isolated educational initiative; it is linked to regional economic strategy.

Recent provincial measures have included a dedicated plan for the construction of digital campuses in vocational education, the development of data bases and application systems, the expansion of online and virtual simulation resources, and the use of industry-facing platforms to improve the match between educational provision and enterprise demand ^[17,18]. Liaoning has also promoted or upgraded programs related to robotics, cloud computing, intelligent manufacturing, artificial intelligence, and other digitally intensive fields ^[16,18]. These developments reposition teachers at the interface of industrial upgrading and curriculum change.

Several opportunities follow from this. Liaoning's industrial base gives vocational colleges relatively strong grounds for enterprise-linked teaching. The provincial digital campus agenda creates conditions for shared resources, stronger data use, and more integrated governance. The pressure to prepare technicians for digitally transformed industries also increases the

strategic value of teachers' boundary-spanning work. In such a context, the vocational teacher becomes an important mediator between economic transformation and talent cultivation.

At the same time, the constraints are substantial. Digital competence in vocational education is uneven, and recent research suggests that teachers often face a gap between policy expectations and practical readiness^[19,20]. Generic training in software use rarely resolves discipline-specific problems, such as how AI should be used in logistics scheduling, hotel operations, mechatronics maintenance, e-commerce communication, or accounting practice. Workload systems may also undervalue enterprise coordination, platform design, and mentoring, treating them as peripheral rather than central forms of academic labour. There is a further risk of formalism: colleges may build platforms or sign agreements without changing the deeper organization of teaching.

These constraints are not merely technical. They concern the relationship between regional industrial change and college-level capacity. Liaoning's manufacturing, equipment, petrochemical, transportation, and service sectors require vocational graduates who can work with increasingly digitalized processes, yet colleges differ in their access to enterprise projects, updated equipment, and staff with recent industry experience. Digital transformation may therefore widen differences between institutions if infrastructure investment is not accompanied by teacher development and partnership governance.

The Liaoning case also suggests that local adaptation is essential. A provincial digital campus plan can provide standards and direction, but teacher-role change occurs in departments, workshops, training bases, and enterprise projects. Colleges serving advanced manufacturing may emphasize simulation, industrial software, and equipment data; colleges serving healthcare, logistics, tourism, or business services may face different AI and platform needs. A mature policy response should therefore combine provincial coordination with discipline-specific implementation, rather than assuming that one digital model can serve all vocational programs^[16-18].

6. Managerial and Policy Implications

First, teacher development in vocational colleges needs to move beyond one-off software training. A more credible model combines industry residency, enterprise project participation, and discipline-specific training in digital curriculum design and AI-supported teaching. Industry exposure matters not only because it updates technical knowledge, but because it helps teachers understand workflow, communication norms, quality standards, and tacit forms of judgement that AI systems often fail to capture.

Second, college management should recognize partnership work as real academic labour. Curriculum co-development with firms, internship supervision, enterprise liaison, platform-based course redesign, and co-assessment should count in workload allocation and promotion decisions. Without such recognition, school-enterprise partnership depends excessively on personal goodwill and becomes difficult to institutionalize.

Third, AI governance should be brought closer to pedagogy. Institutions need clear guidelines on data use, privacy protection, academic integrity, and acceptable forms of student AI assistance. These rules should not remain abstract or generic. The governance questions that arise in nursing, mechanical design, digital media, and business simulation differ in both risk and pedagogical purpose. Human oversight should remain explicit in high-stakes assessment and in tasks with safety implications. Fourth, digital campus construction should focus on interoperability rather than platform accumulation. When learning management systems, virtual simulation tools, student support platforms, and industry-facing systems do not communicate well, teachers face higher clerical burdens and fragmented evidence. Integration matters because the mentoring and coordination roles described in this article depend on teachers being able to move across data, tasks, and institutional boundaries without excessive administrative friction.

Fifth, teacher evaluation systems should be adjusted to capture the invisible labour of digital transformation. Course redesign, platform maintenance, enterprise communication, digital assessment design, and AI governance are often time-consuming but weakly represented in conventional teaching-load calculations. If these tasks remain unrecognized, colleges may unintentionally discourage the very practices that digital reform requires.

Sixth, vocational colleges should build discipline-based communities of practice. General training on AI or digital platforms is useful at the introductory stage, but teachers ultimately need examples from their own occupational fields. Communities

that bring together teachers, enterprise engineers, instructional designers, and data-support staff can turn isolated experimentation into shared routines, reusable resources, and more stable professional learning.

Seventh, school–enterprise cooperation should be governed through joint accountability rather than episodic contact. A useful arrangement is to specify, for each cooperative major, which enterprise tasks will enter the curriculum, which teachers and enterprise mentors will co-assess student performance, how often cases and equipment standards will be reviewed, and how feedback from internships will be returned to course teams. These arrangements reduce dependence on informal personal relations and make partnership knowledge visible inside the college. They also help prevent AI-supported teaching from drifting away from occupational practice, because the validity of digital tasks can be checked against enterprise expectations and safety requirements ^[7-10,15].

7. Limitations and Future Research

This article is limited by its conceptual review design. It synthesizes policy documents and relevant scholarship, but it does not measure the strength of mediation statistically or compare institutions through field data. The terms “school–enterprise partnership” and “AI-enabled pedagogy” also cover diverse practices. Some partnerships are deeply integrated into curriculum and assessment, whereas others remain ceremonial. Similarly, AI use may range from simple content generation to sophisticated learning analytics. Future research should distinguish these levels more carefully.

Further empirical work could examine how different categories of vocational teachers experience role change. Useful designs include interviews with teachers and enterprise mentors, classroom observations of AI-supported vocational tasks, surveys of digital competence and role strain, and comparative case studies across Liaoning cities or industrial sectors. Quantitative studies could test whether school–enterprise partnership and AI application operate as mediating variables between digital transformation and teacher-role reshaping. Such studies would help move the present framework from conceptual explanation to empirical verification.

8. Conclusion

Digital transformation in vocational education should not be understood as the simple introduction of platforms, smart classrooms, or AI tools. Its deeper consequence is the reconfiguration of teacher professionalism. The analysis developed here argues that vocational teachers are increasingly required to work as learning designers, boundary-spanning coordinators, data-informed mentors, curriculum and resource curators, and ethical stewards of AI. School–enterprise partnership and AI-enabled pedagogy operate as dual mechanisms in this shift: the former reorganizes institutional relationships and curriculum authority, while the latter changes the micro-processes of teaching, feedback, and evaluation.

In Liaoning Province, where digital campus construction and industrial upgrading are advancing together, these dynamics are especially visible. The central challenge is therefore not whether teachers use technology, but whether institutions can support a new form of teacher work that is collaborative, judgement-intensive, and closely tied to industrial change. Future empirical research can test this framework across different vocational sectors and compare role configurations across institutions with different levels of digital capacity and enterprise engagement.

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Explainability, Human Oversight, and Procedural Justice in AI-Assisted Promotion Decisions: An Integrative Review for Chinese Organizations

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Abstract: AI tools are increasingly used to support internal talent decisions, yet promotion decisions pose a distinct governance problem because they involve future potential, not only past performance. Existing research has concentrated on recruitment screening or model accuracy, while the combined role of explainability, human oversight, and procedural justice in promotion contexts remains less settled. This paper develops an integrative review of research across human resource management, information systems, human-computer interaction, and AI governance to examine how managers and employees may respond to AI-assisted promotion decisions, with particular attention to Chinese organizations. Four conclusions emerge. First, explanations can improve perceived transparency, but they do not automatically protect users from poor AI advice. Second, human oversight only adds value when managers have both the authority and the criteria to question model output. Third, fairness in promotion decisions depends on voice, correctability, relevance of data, and accountability, rather than on statistical performance alone. Fourth, the Chinese regulatory context places additional emphasis on transparent and fair automated decision-making, which makes documentation, review, and appeal mechanisms especially important. On that basis, the paper proposes a practical framework for responsible AI-assisted promotion decisions built around data governance, interpretable evidence, structured human review, and employee contestability. The central argument is that organizations should not aim for uncritical trust in AI. They should aim for disciplined, reviewable, and job-relevant use.

Keywords: Explainable AI; Human Oversight; Procedural Justice; Promotion Decisions; Chinese Organizations; HR Analytics

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1. Introduction

Artificial intelligence is no longer confined to recruiting chatbots or résumé screening. Across the human resource cycle, organizations are experimenting with AI to support performance management, retention analysis, capability mapping, succession planning, and internal mobility decisions^[1-3]. This expansion is understandable. Internal talent decisions generate large amounts of digital trace data, and firms hope that algorithmic tools will improve consistency, speed, and predictive accuracy. Yet the move from hiring to promotion raises a different set of managerial questions.

Promotion decisions are not routine classification tasks. They allocate future opportunity, signal what the organization values, and affect how employees interpret merit, recognition, and upward mobility. A promotion case often combines structured indicators, such as past performance ratings or tenure, with harder-to-codify judgments about leadership, collaboration,

learning agility, or readiness for a broader role. For this reason, promotion decisions are especially vulnerable to what Newman et al. describe as algorithmic reductionism: the tendency to compress a person into the variables that happen to be measurable^[4].

Many discussions of AI in human resource management treat the central problem as one of technical quality. The usual questions are whether the model is accurate, whether biased variables have been removed, and whether the recommendations outperform intuitive judgment. Those questions matter, but they do not exhaust the issue. Managers asked to rely on AI-assisted promotion recommendations also want to know how the system reached its conclusion, whether relevant context was omitted, who remains responsible for the final decision, and whether the affected employee can challenge the outcome. These are questions about process as much as prediction.

The Chinese context gives these process questions additional practical importance. Digital transformation has accelerated the use of data-driven management tools, while the Personal Information Protection Law (PIPL) places explicit emphasis on transparency and fairness in automated decision-making^[5]. At the same time, organizational justice research has long shown that employees evaluate decisions not only by their outcomes but also by the fairness of the procedures through which those outcomes are produced^[6]. A promotion system can therefore generate resistance even when its statistical performance appears strong, if the process looks opaque, rigid, or unchallengeable.

Existing scholarship offers useful pieces of the puzzle, but the evidence is scattered. Research on explainable AI has examined trust and user understanding. Work on algorithmic HR has studied discrimination, applicant reactions, and managerial adoption. Human-computer interaction research has investigated contestability and oversight. What remains less settled is how these strands fit together when the decision at stake is an internal promotion rather than a recruitment screen.

This paper addresses that gap by asking a focused question: how do explainability, human oversight, and procedural justice jointly shape responsible use of AI-assisted promotion decisions in Chinese organizations? The discussion makes three moves. First, it shifts the center of attention from general AI acceptance to the more specific governance demands of promotion decisions. Second, it synthesizes mixed evidence on explainability and human review rather than treating either as a universal remedy. Third, it develops a practical framework for organizations that want to use AI in promotion processes without turning managerial judgment into ritual approval.

2. Review Design

This study adopts an integrative review design. That choice reflects the state of the field. Research relevant to AI-assisted promotion decisions is distributed across human resource management, organizational behavior, information systems, human-computer interaction, and AI governance. The literature is therefore conceptually rich but methodologically uneven, and it does not lend itself neatly to a narrow systematic review focused on one outcome variable.

The review concentrated on peer-reviewed journal articles and influential conference papers dealing with four overlapping themes: AI-assisted HR decisions, explainability and user understanding, human oversight and contestability, and procedural justice in algorithmic decision-making. Most of the reviewed work has appeared since 2019, which is when research on employment-related AI intensified, although a small number of earlier studies on trust in automation and organizational justice were retained because they remain foundational for the argument developed here^[6,12,13].

Because empirical work on AI-assisted promotion decisions remains limited, the review also draws on adjacent HR contexts, especially recruiting, personnel selection, and algorithmic management. This is justified when the underlying mechanism is transferable, for example when the concern is overreliance on automated output, the effect of explanations on user judgment, or the role of voice and correctability in perceived fairness. At the same time, the paper treats promotion as a distinct case. Internal candidates carry longer organizational histories, and promotion decisions are judged not only as selection choices but also as statements about future trust and internal legitimacy.

The aim of the review is interpretive rather than bibliometric. It does not estimate pooled effect sizes or claim exhaustive coverage of every study in the field. Instead, it identifies where the evidence converges, where it remains mixed, and what those patterns imply for the design and governance of AI-assisted promotion systems in Chinese organizations.

3. Results

3.1 Explainability and Managerial Sensemaking

Explainability is often presented as the obvious response to algorithmic opacity. In broad terms, that intuition has empirical support. Studies in explainable AI show that explanations can improve perceived understanding, trust, and willingness to engage with algorithmic output^[7,8]. There is, however, an important qualification. What users say they want is not always what they prioritize when stakes become concrete. Evidence also suggests that people may value interpretability in principle but still prefer accuracy when they see the two as competing objectives^[9].

For promotion decisions, the function of explanation is not limited to reassurance. Managers need explanations because they must convert model output into organizationally defensible judgment. A promotion recommendation becomes usable only when managers can see which job-relevant features drove the recommendation, how strong the evidence is, what the model cannot observe, and whether the case falls inside or outside the system's intended range. In this sense, explainability supports managerial sensemaking rather than mere interface friendliness.

The literature also shows why this distinction matters. Explanations do not automatically improve decision quality. In a personnel selection task, Cecil et al. found that explainability did not offset the negative impact of incorrect AI advice^[10]. Reviews of the relationship between explainability and fairness reach a similar conclusion: the fairness benefits of explainable AI are real in some settings, but they are conditional, limited, and often overstated when treated as a stand-alone solution^[11]. A plausible-sounding explanation can create a veneer of rationality around a recommendation that is still based on weak data, unstable proxies, or conceptually thin measures.

This is especially problematic in promotion contexts because promotion decisions involve future potential as well as past record. If the model relies heavily on indicators that are easy to digitize, such as tenure, appraisal scores, or recent output, then even a clear explanation may still be explaining the wrong thing. In high-stakes settings, Rudin argues that organizations should prefer models that are interpretable by design rather than black-box systems explained after the fact^[22]. That point is particularly relevant to promotion decisions, where a polished post hoc explanation may do less practical good than a modest model whose boundaries are intelligible.

The implication is straightforward. Useful explanations in promotion systems should be local, job-related, and bounded. They should identify the evidence that influenced the recommendation, indicate the level of uncertainty, and make explicit when human review is required. Explanations that merely increase apparent sophistication or confidence are of limited value. What organizations need is calibrated understanding, not decorative transparency.

3.2 Human Oversight beyond Symbolic Review

Organizations often respond to concerns about HR algorithms by insisting that a human manager remains in the loop. On paper, that sounds reassuring. In practice, the phrase covers very different arrangements. A manager may meaningfully interrogate the recommendation, compare it with contextual evidence, and record a reasoned final judgment. Just as easily, the manager may simply confirm the output because the system is seen as objective, fast, or politically safer than visible discretion.

The trust-in-automation literature helps explain why symbolic oversight is not enough. Appropriate reliance depends on whether users understand what the system can and cannot do, how reliable it is under different conditions, and where its failure modes lie^[12,13]. Without that grounding, human review can drift toward two opposite but equally unhelpful patterns. One is algorithm aversion, where users reject the system after visible mistakes^[14]. The other is passive overreliance, where the apparent neutrality of automated output discourages careful scrutiny^[15].

Evidence from fairness research points in the same direction. Yurrita et al. show that oversight and contestability shape fairness perceptions when they create a genuine opportunity to question, revise, or appeal a decision^[16]. Similarly, Neumann et al. find that giving human decision-makers structured autonomy in how algorithmic recommendations are used can improve perceptions and even predictive validity^[17]. In other words, human involvement matters most when it is substantive enough to affect the process, not when it serves as a formal signature on a pre-determined result.

Applied to promotion decisions, meaningful oversight requires at least three conditions. First, managers must have authority

to depart from the recommendation when relevant evidence justifies doing so. Second, that departure must be guided by explicit criteria, otherwise the organization simply reintroduces bias through undocumented intuition. Third, confirmations and overrides should be logged. This creates accountability in both directions: managers cannot rubber-stamp the algorithm, but they also cannot ignore it without reason.

Human oversight, then, should be treated as a governance arrangement rather than a moral slogan. The real question is not whether a person is nominally present. It is whether the person has the information, authority, and procedural obligation necessary to turn AI from a hidden decision-maker into a reviewable decision aid.

3.3 Procedural Justice in Promotion Decisions

Promotion decisions are unusually sensitive to procedural justice because they affect status, identity, pay progression, and access to future leadership roles. Organizational justice research has consistently shown that people care about voice, consistency, accuracy of information, correctability, and ethical treatment, not only about whether the final outcome benefits them personally^[6]. In internal promotion contexts, these concerns are amplified because employees usually know something about the candidates, the organizational history, and the informal work that may never appear in a formal dataset.

This helps explain why fairness objections to AI-assisted HR decisions cannot be reduced to questions of statistical parity. Newman et al. argue that a system can reduce one kind of bias yet still feel unfair if it narrows the person into a thin bundle of measurable indicators^[4]. The concern is not sentimental resistance to measurement. It is that the model may redefine merit in a way that excludes relational, developmental, or context-specific contributions that matter in actual organizational life.

Promotion decisions provide many examples of this risk. It is relatively easy to encode past appraisal scores, absenteeism, certification history, or sales output. It is much harder to encode whether a candidate stabilized a troubled team, mentored junior staff, absorbed extra coordination work during a transition, or demonstrated leadership under ambiguous conditions. Those elements are not always suitable for algorithmic measurement, but removing them from the decision frame can still distort what the organization means by readiness and merit.

Systematic reviews of algorithmic decision-making in HR show that discrimination concerns often stem from proxy variables, historical bias, weak job relevance, and poor data governance rather than from obviously sensitive variables alone^[18]. Empirical work on algorithmic recruiting also suggests that perceived fairness depends on how transparency is communicated and how the system presents itself to users^[19]. Beyond HR, studies of algorithmic management show that people interpret automated decisions through the lenses of fairness, trust, and emotion, especially when those decisions affect their status or autonomy^[20].

For AI-assisted promotion decisions, procedural justice therefore requires more than a score or ranking. It requires a process in which relevant context can enter, questionable inferences can be challenged, and final responsibility remains visible. Statistical fairness metrics still matter, but they address a narrower problem. They do not tell employees whether the organization listened, reasoned carefully, or left room for correction.

3.4 Governance Challenges in Chinese Organizations

The Chinese context sharpens these issues in two ways. First, the regulatory environment gives formal weight to transparency and fairness in automated decision-making. Under Article 24 of the Personal Information Protection Law, automated decision processes are expected to be transparent and fair, especially when they materially affect individuals^[5]. For organizations using AI in promotion decisions, this raises the threshold for defensibility. A model cannot be treated as acceptable merely because it performs well on internal validation metrics.

Second, AI-assisted promotion systems usually rely on cumulative employee data. These may include performance evaluations, learning records, attendance logs, competency assessments, or other forms of digital trace data. Once aggregated, such data may carry forward organizational patterns that were never intended to function as measures of promotability. Reviews of AI in HRM repeatedly note that data quality, representativeness, and governance remain unresolved problems even in organizations with strong digital ambitions^[1-3].

A further complication is that promotion decisions sit at the boundary between efficiency and legitimacy. They do not merely allocate roles; they also communicate what counts as talent. Research on algorithmic management suggests that digital

systems can both enable and constrain managerial autonomy^[21]. The same duality is likely to appear in promotion decisions. An AI system may help standardize evaluation and flag overlooked candidates, but it may also narrow the range of acceptable reasoning if managers begin to treat the output as neutral evidence rather than as one input among several.

For Chinese organizations, responsible implementation should therefore begin with provenance and review. Managers and HR teams should know which historical decisions trained the model, which groups were underrepresented, which variables may be acting as proxies, and which cases require secondary review rather than direct adoption. In practical terms, this means that governance should focus not only on whether the model predicts something, but also on whether the recommendation can be justified under managerial scrutiny and, where necessary, challenged by the affected employee.

4. Discussion

The reviewed literature supports a simple but demanding proposition: responsible AI-assisted promotion decisions depend on the alignment of four layers of governance. The first is data relevance. The variables used in the model must have a clear job-related rationale, and the organization must be able to explain why those variables count as evidence of promotability. The second is interpretable evidence. Explanations must be specific enough to support managerial reasoning, not merely broad enough to soothe skepticism. The third is meaningful human review. Managers must be able to confirm, question, or override the recommendation according to documented criteria. The fourth is employee contestability. Individuals affected by the decision need a path to receive reasons, present omitted context, and trigger review where appropriate.

These layers reinforce one another. Explanations without contestability are one-way communication. Human oversight without criteria is informal discretion. Data governance without managerial capability produces blind dependence on technical teams. Conversely, when the four layers are aligned, AI can support disciplined promotion deliberation without displacing accountability. The goal is not to maximize trust in the system. It is to create calibrated trust: enough confidence to use the tool seriously, and enough skepticism to question it when the case demands that.

One practical implication is that organizations should resist deploying promotion models as stand-alone ranking devices. Their most defensible use is often narrower: surfacing comparable cases, flagging unusual patterns, or structuring panel discussion around explicitly defined criteria. A recommendation score may help focus attention, but promotion should still require a written rationale that links the recommendation to job demands and contextual evidence. In that sense, prediction and justification should remain analytically distinct even when they interact in practice.

A second implication concerns managerial capability. The relevant skill is not deep technical fluency in model architecture. Managers do not need to become machine-learning engineers. What they do need is the ability to ask disciplined questions. Which variables mattered most in this case? What data were missing? How stable is the recommendation? Under what conditions does the model perform poorly? What evidence justifies an override? This is a more practical form of AI literacy for promotion governance than abstract familiarity with technical jargon.

A third implication is organizational. Appeal and review mechanisms should not be treated as optional extras added after deployment. They are part of what makes the process fair in the first place. Employees are more likely to accept adverse decisions when they believe that relevant evidence can still be heard and that the process remains open to correction. Over time, this affects not only individual reactions but also the credibility of digital HR systems as a whole.

Table 1. Governance Design Priorities for AI-Assisted Promotion Decisions

Governance lever	Practical question	Minimal organizational practice	Main risk if absent
Data relevance and provenance	Why were these variables chosen as evidence of promotability?	Document job relevance, data source, update cycle, and proxy-risk checks before deployment.	Historically biased or weakly relevant signals are treated as merit indicators.
Interpretable evidence	Can managers see what drove the recommendation and where uncertainty remains?	Provide case-level explanations, uncertainty cues, and clear escalation triggers for unusual cases.	Explanations become cosmetic and create false confidence.

Governance lever	Practical question	Minimal organizational practice	Main risk if absent
Structured human review	Who can challenge or override the recommendation, and on what grounds?	Use documented review criteria, require written reasons for overrides and confirmations, and retain an audit trail.	Managers rubber-stamp the system or reintroduce bias through undocumented discretion.
Employee contestability	Can the affected employee request reasons and present missing context?	Offer explanation, review, and appeal channels for materially significant decisions.	Adverse decisions are seen as opaque, final, and procedurally unfair.
Accountability and audit	Who owns the final decision and monitors system effects over time?	Assign decision ownership, review outcome patterns, and periodically test for drift or group disparities.	Responsibility becomes diffused between HR, managers, and vendors.

4.1 Limitations and Directions for Future Research

This paper is conceptual and has two clear limits. First, the empirical literature on promotion-specific uses of AI remains thin, which means that some arguments here draw on adjacent evidence from recruiting, personnel selection, and algorithmic management. That transfer is theoretically defensible, but it is not a substitute for direct evidence from promotion settings. Second, the paper emphasizes governance in Chinese organizations without claiming that all Chinese firms face identical institutional or organizational conditions. Private firms, state-owned enterprises, and multinational subsidiaries may differ materially in how they define merit, document decisions, and manage employee appeals.

Future research should therefore move in three directions. One is to examine how middle managers actually use AI-assisted recommendations during promotion deliberations rather than asking only whether they trust the system in principle. Another is to test which forms of explanation help managers calibrate judgment without creating false confidence. A third is to compare how review and appeal rights shape employee reactions after adverse promotion outcomes. These questions are particularly important in Chinese organizations, where digital management capability and compliance expectations are both developing rapidly.

5. Conclusion

This paper has argued that the governance challenge in AI-assisted promotion decisions is not solved by predictive accuracy alone. Explainability helps, but its value depends on whether it improves understanding rather than appearance. Human oversight matters, but only when it is structured and consequential. Procedural justice remains central because employees judge promotion decisions as social and moral processes, not as optimization problems.

For Chinese organizations, these issues carry both managerial and compliance significance. Systems used in promotion decisions should be transparent enough to review, limited enough to interpret, and contestable enough to correct. AI can support more disciplined talent decisions, but only when the organization treats algorithmic output as evidence to be examined rather than as a verdict to be obeyed.

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Conflict of Interests

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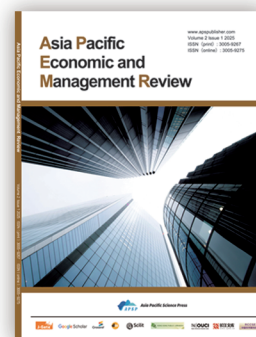
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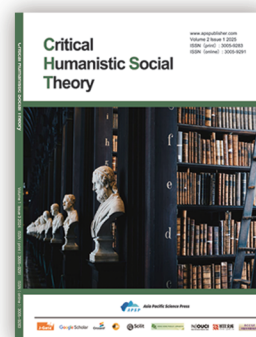
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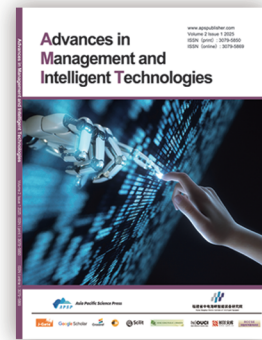
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