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## Advances in Management and Intelligent Technologies

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# Students Compete and Unveil Honor and Shame: The Psychological Impact of Academic and Social Comparison Among Chinese High School Students

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**Abstract:** This study aimed to explore the influence of academic social comparison on academic shame in high school students. A total of 80 students from two classes in a high school in Jilin City were randomly selected for experimental research. The participants were divided into two groups (high-achieving group & low-achieving group) and surveyed using academic social comparison paradigms, academic social comparison questionnaires, and academic shame questionnaires. The results showed significant differences in academic social comparison on grades ( $t = -2.038$ ,  $p < 0.05$ ), while no significant differences were found in academic shame on grades. There was a significant positive correlation between academic social comparison and academic shame ( $r = 0.362$ ,  $p < 0.01$ ), a significant positive correlation between grades and academic social comparison ( $r = 0.225$ ,  $p < 0.05$ ), and no significant correlation between grades and academic shame. Academic social comparison positively predicted academic shame ( $\beta = 0.362$ ,  $t = 3.427$ ,  $p < 0.01$ ), with grades acting as a moderator between academic social comparison and academic shame ( $\beta = 0.363$ ,  $t = 3.531$ ,  $p < 0.01$ ). Therefore, it is crucial to observe students' emotional states timely after various examinations, and provide education and counseling based on individual characteristics.

**Keywords:** Academic Social Comparison; Academic Shame; Achievement; High School Student

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## 1.Introduction

With the development of the economy and the improvement of national education levels, schools have shifted from focusing solely on grades to cultivating high-quality talents with comprehensive development under the new educational reform. Today's students have significantly improved overall qualities compared to the past; however, academic performance continues to receive attention from various perspectives. When it comes to learning outcomes, students are often categorized into two groups: high-achieving students and low-achieving students.

High-achieving students are usually quick thinkers, eager learners who ask questions diligently and are hardworking; they also exhibit strong organizational skills and self-confidence<sup>[1]</sup>. However, they may also have some issues such as being self-centered, lacking awareness of equality in interactions, being concerned about others' opinions, or having fragile self-esteem<sup>[2]</sup>. Low-achieving students are generally perceived as having learning difficulties or falling behind academically<sup>[3]</sup>. Yet most low-achieving students are not incapable of completing their studies; studies have shown that there are instances of poor performance even among gifted students. Apart from outstanding individuals who combine talent with hard work and those

with poor intellectual abilities struggling academically, the gap between high-achieving and low-achieving students may not be substantial<sup>[4]</sup>. Regardless of being high-achieving or low-achieving students, they all face various exams during their academic life which not only pose challenges but also create situations conducive to academic social comparisons that may result in different cognitive, emotional, and behavioral outcomes<sup>[5]</sup>. Moreover, these comparisons may evoke corresponding academic emotions.

Research has shown significant correlations between academic emotions and self-assessment, learning motivation, learning strategies, cognitive resources, self-regulated learning, and academic achievement<sup>[6][7]</sup>. Among these emotions, academic shame is one of the most easily perceived and common among students' experiences in academia. Therefore, exploring the impact of academic social comparison on academic shame can provide valuable insights and help us better understand students' emotional fluctuations in their academic life, adjust teaching strategies timely, and provide educational interventions tailored to individual characteristics, thus laying a theoretical foundation for school education.

## 2.Literature Review

Social comparison refers to the process of comparing oneself with others in terms of situations and status, including abilities and viewpoints, leading to various cognitive, emotional, and behavioral outcomes<sup>[5]</sup>. As students' main task is learning, they inevitably compare their academic performance and study methods with those of their peers in order to assess their own academic situation, which is known as academic social comparison. Researchers have differing definitions of academic social comparison. Jiang<sup>[8]</sup> defined academic social comparison as the comparison of individual academic factors with others and the formation of cognitive and evaluative processes about oneself during this process. Song<sup>[9]</sup> defined academic social comparison as the process in which students compare their own learning conditions with those of others during their studies to gain an understanding and evaluation of their academic abilities and levels. This study adopts Song's definition of academic social comparison.

In recent years, with the deepening research on social comparison and the emergence of academic issues among adolescents, many researchers have begun to focus on the influence of academic social comparison on students. Tian et al.<sup>[10]</sup> found that upward academic social comparison plays a mediating role between goal-oriented orientation, grade-approaching orientation, grade-avoidance orientation, and subjective well-being in school students. Additionally, research has shown that different dimensions of academic social comparison among high school students significantly affect their levels of psychological health<sup>[11]</sup>.

In summary, academic social comparison has diverse effects on students' academics and psychological health. Academic shame is also a common emotional experience for students in their learning process.

In actual learning life, some students perceive academic failure subjectively. Shi and Qian<sup>[12]</sup> defined shame as an experience directed towards oneself that involves pain, embarrassment, and shame; Meng<sup>[13]</sup> identified the core feature of shame as attributing failures or mistakes to the entire self during evaluations. According to Pekrun et al.<sup>[14]</sup> and Blum<sup>[15]</sup>, operational definitions suggest that academic shame is an emotional experience characterized by resentment, pain, powerlessness, or self-disgrace arising from suboptimal or self-inconsistent academic performance or unfair treatment in academics; this may lead to external expressions, physiological reactions, or other psychological sensations.

Compared to research on shame, studies on academic shame are relatively scarce and have only recently begun focusing on factors related to it or which individuals are more prone to experiencing academic shame based on personality traits. Turner et al.<sup>[16]</sup> found that students with a high tendency for shame and high self-esteem experience more academic shame; this is also true for students facing academic failures or having avoidance-oriented goals, while students approaching goals do not experience much academic shame<sup>[17]</sup>. Research has shown that middle school students experience higher levels of academic shame; significant gender differences exist as well as differences between attending key schools; there is a significant positive correlation between levels of academic self-concept and academic shame<sup>[18]</sup>. Additionally, academically successful students may experience more academic shame<sup>[19]</sup>.

Based on these findings, this study proposes hypotheses: H1: Academic social comparison positively predicts academic shame; H2: Grades moderate the relationship between academic social comparison and academic shame.

### 3. Research Methodology

#### 3.1 Study Participants

Using cluster random sampling method in a high school in Jianshui City selecting two classes from Grade 11 (45 students/class). On the day of the experiment due to leave requests and skill training unavailable for 10 students in total from both classes participated in the experiment out of 80 students (46 males and 34 females). Among them were 38 non-only children and 42 only children; 44 rural Study Participants Using cluster random sampling method, two classes from the 11th grade were selected in a high school in Jianshui City, with 45 students per class. On the day of the experiment, 10 students were absent due to leave requests and skill training, resulting in a total of 80 participating students (46 males and 34 females). Among them, there were 38 non-only children and 42 only children; 44 students from rural areas and 36 from urban areas; all with normal vision or corrected vision; no history of mental illness. The participants received an experimental remuneration of 5.5 yuan per person.

#### 3.2 Research Tools

##### 3.2.1 General Demographic Questionnaire

A self-designed general demographic questionnaire including basic demographic information such as gender, age, and place of origin.

##### 3.2.2 Academic Social Comparison Questionnaire

The study utilized the “High School Students’ Academic Social Comparison Questionnaire” developed by Xu<sup>[20]</sup> for investigation. This questionnaire consists of 38 items divided into three factors: comparison orientation, comparison method, and comparison outcomes. The comparison orientation factor includes 6 items, the comparison method factor includes 21 items, and the comparison outcomes factor includes 11 items. Each item is rated on a five-point scale, where 1 indicates “completely disagree” and 5 indicates “completely agree”. The questionnaire demonstrates good reliability with an original alpha coefficient of 0.879 and a coefficient of 0.928 in this study.

##### 3.2.3 Academic Shame Questionnaire

The study used the “High School Students’ Academic Shame Questionnaire” developed by Xue<sup>[21]</sup> for investigation. This questionnaire comprises 17 questions divided into four dimensions: unfair treatment, inconsistency with self-expectations, public attention, and poor academic performance. Each question is rated using Likert’s five-point scale, where 1 represents “not shameful at all” and 5 represents “very shameful”. The retest reliability of the questionnaire ranges between 0.680-0.831, with CFI, NFI, and IFI fit indices all exceeding 0.90, indicating good reliability. In this study, the internal consistency coefficient  $\alpha$  value of this questionnaire was found to be 0.861.

#### 3.3 Research Procedure

On the day before the experiment, students were informed that the upcoming test would be a challenge and they would participate in the experiment the next day based on their performance results. The lead experimenter grouped the 80 student participants into two groups based on test scores: selecting the top-performing 50% (40 students) as the excellent group and the bottom-performing 50% (40 students) as the trailing group. On the day of the experiment, after announcing the lists for both groups to the students, questionnaires on academic social comparison and academic shame were distributed for immediate completion and collection.

#### 3.4 Data Analysis

After data collection and organization, data analysis was conducted using SPSS version 26.0.

### 4. Research Findings

Table 1: Differences in Academic Social Comparison and Academic Shame between Achievers and Underachievers (N=80)

|                            | Achievers<br>( $M \pm SD$ , $n=40$ ) | Underachievers<br>( $M \pm SD$ , $n=40$ ) | $t$    | $p$   |
|----------------------------|--------------------------------------|---|--------|-------|
| Academic Social Comparison | 108.800 $\pm$ 23.376                 | 118.225 $\pm$ 17.586                      | -2.038 | 0.045 |
| Academic Shame             | 61.525 $\pm$ 8.042                   | 61.900 $\pm$ 13.075                       | -0.155 | 0.878 |

As shown in the independent samples t-test results in Table 1, there is a significant difference in academic social comparison between achievers and underachievers (mean difference = -9.425,  $t = -2.038$ ,  $p < 0.05$ ), with underachievers scoring higher on academic social comparison. There was no significant difference in academic shame scores between achievers and underachievers ( $p > 0.05$ ), indicating that under the context of academic social comparison, there is no significant difference in academic pride and shame between achievers and underachievers.

Table 2: Correlation Test Results ( $N=80$ )

| Variables                  | Academic Social Comparison | Academic Shame | Achievement |
|----------------------------|----------------------------|----------------|-------------|
| Academic Social Comparison | 1                          |                |             |
| Academic Shame             | 0.362**                    | 1              |             |
| Achievement                | 0.225*                     | 0.017          | 1           |

Note: \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ ; “p” represents probability, reflecting the likelihood of an event occurring.

The correlation analysis shown in Table 2 indicates a significant positive correlation between academic social comparison and academic shame ( $r = 0.362$ ,  $p < 0.01$ ), meaning that higher scores in academic social comparison are associated with higher scores in academic shame. There is a significant positive correlation between achievement and academic social comparison ( $r = 0.225$ ,  $p < 0.05$ ), suggesting that higher achievement scores are linked to higher scores in academic social comparison. However, there is no significant correlation between achievement and academic shame ( $r = 0.017$ ,  $p > 0.05$ ).

Table 3: Academic Social Comparison and Academic Shame: The Moderating Role of Achievement ( $N=80$ )

| Model and Variables                             | Academic Shame |          |         |          |
|---|----------------|----------|---------|----------|
|   | Model 1        |          | Model 2 |          |
|   | $\beta$        | $t$      | $\beta$ | $t$      |
| Academic Social Comparison                      | 0.362          | 3.427**  | 0.480   | 4.547*** |
| Achievement                                     |                |          | -0.090  | -0.890   |
| Academic Social Comparison $\times$ Achievement |                |          | 0.363   | 3.531**  |
|   |                | 0.120    |         | 0.228    |
|   |                | 0.131    |         | 0.257    |
| $F$   |                | 11.742** |         | 8.763*** |

Note: \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ ; “p” represents probability, reflecting the likelihood of an event occurring.

The results of linear regression analysis as presented in Table 3 indicate that academic social comparison significantly positively predicts academic shame ( $\beta = 0.362$ ,  $t = 3.427$ ,  $p < 0.01$ ). Moreover, achievement moderates the relationship between academic social comparison and academic shame ( $\beta = 0.363$ ,  $t = 3.531$ ,  $p < 0.01$ ), where lower achievement enhances the impact of academic social comparison on academic shame.

## 5. Discussion

This study explored the relationship between academic social comparison and academic shame among high school students through experiments and questionnaire surveys. The experiment utilized a modified paradigm of academic social comparison to create a more realistic setting that aligns with actual academic situations, such as exams, to investigate the occurrence of academic social comparison in practical applications. Measurements were taken on students' academic social comparison



and academic shame. Results revealed significant differences in academic social comparison between underachievers and achievers, with underachievers demonstrating higher levels of academic social comparison.

Students engage in comparisons with various classmates or competitors during every exam, competition, or ranking event<sup>[22]</sup>. Achievers may reduce the likelihood of downward comparisons due to less consideration of comparability with lower-performing peers, while underachievers, lacking confidence or a sense of achievement in upward and lateral comparisons<sup>[23]</sup>, tend to engage more in downward comparisons to compensate for feelings of shame (see supplementary materials for specific results)<sup>[24]</sup>. The correlational analysis results of this study indicate a consistent relationship between increased academic social comparison and higher levels of academic shame. Moreover, grades as an essential factor in academic social comparison also exhibit a moderating effect on academic shame. Poorer grades enhance the impact of academic social comparison on academic shame.

Subsequent communication with students and analysis of research results revealed that using exam papers similar to regular monthly exams when initiating academic social comparison allows students to make comparisons based on their previous performance. Students' grades fluctuate, and achievers and underachievers have different directions in comparing themselves, varying self-expectations and family expectations. While most achievers set high standards for themselves with high expectations from schools and families, the fluctuation in grades may still lead to feelings of academic shame; underachievers have relatively lower self-expectations but room for improvement, with low long-term expectations from schools, families, and themselves leading to them being accustomed to falling behind or performing poorly. Therefore, the difference in shame measurement between achievers and underachievers is not significant. However, more frequent engagement in academic social comparison may lead to increased levels of academic shame among students. Hence, educators should remain vigilant about situations involving academic social comparison and promptly observe students' emotional states.

This study contributes to the existing research on the relationship between academic social comparison and academic emotions. With the insights gained from this study, educators can better understand students' psychological states and emotional responses when facing exams and grades. By combining these findings with student characteristics, educators can predict future learning activities and behaviors to enhance students' academic performance and mental well-being.

## Limitations and Future Directions

The sample size in this study was relatively small and should be expanded in future research. Subsequent studies may consider controlling for factors such as specialization or class quality or conduct longitudinal research on learning investment and interest. Based on the results of this study, further exploration can be conducted on the impact of academic social comparison on other academic emotions or behaviors.

## Conclusion

Academic social comparison significantly influences students' experience of academic shame as an academic emotion, with a more pronounced impact observed among those with poorer grades. Schools aim not only to nurture academically excellent individuals but also future pillars of society and elite members of the international community. Schools should make reasonable arrangements for assignments that trigger academic social comparisons, guide students in cultivating healthy comparative attitudes to develop rational academic emotions, adjust self-evaluations, improve classroom learning atmospheres, thereby enhancing students' psychological resilience and academic performance.

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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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# Intelligent Prediction-Inventory-Scheduling Closed-Loop Nearshore Supply Chain Decision System

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**Abstract:** This study proposes an intelligent prediction-inventory-scheduling closed-loop decision system for near-shore supply chain operations. By integrating three core modules-LSTM/Transformer demand forecasting, reinforcement learning inventory replenishment, and VRP path planning-the system achieves end-to-end collaborative optimization. An innovative “public health emergency” scenario generator is designed to quantitatively evaluate the system’s robustness under extreme risks and its cost-inventory balance capability. Through heterogeneous model fusion, multi-objective dynamic optimization, and closed-loop feedback mechanisms, a spatiotemporal coupled decision framework is established. The system effectively mitigates prediction error propagation, optimizes inventory-path coordination, and demonstrates significant resilience enhancement during simulated emergencies.

**Keywords:** Nearshore Supply Chain; Intelligent Prediction; Reinforcement Learning; Robust Optimization

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## 1.Introduction

The complexity and dynamic nature of nearshore supply chains demand real-time responsiveness and global optimization capabilities from decision-making systems. This paper proposes an integrated decision framework based on a closed-loop system combining intelligent forecasting, inventory management, and scheduling. By integrating three key modules-LSTM/Transformer-based demand forecasting, reinforcement learning for inventory replenishment, and VRP (Vehicle Routing and Programming) path planning-the framework achieves end-to-end collaborative optimization. The core innovation lies in introducing a “public health emergency” scenario generator, which quantifies system robustness and cost-inventory balance efficiency under extreme risks, providing methodological support for resilience management in nearshore supply chains.

## 2.Time series modeling and demand sensing of intelligent prediction module

### 2.1 Heterogeneous fusion architecture design of LSTM and Transformer

In the intelligent forecasting module, the heterogeneous fusion architecture combining LSTM and Transformer aims to leverage their temporal modeling advantages to enhance the accuracy and generalization capability of demand prediction. LSTM’s gating mechanism effectively captures long-term dependencies in supply chain demand data, making it particularly suitable for periodic or trend-based time series. Meanwhile, Transformer’s self-attention mechanism excels at uncovering

global dependencies across time steps, demonstrating outstanding performance when processing high-dimensional and non-stationary data<sup>[1]</sup>. This architecture employs a hierarchical fusion strategy: LSTM performs local feature extraction at the base layer, followed by global feature interaction through Transformer's encoding layer. The multi-scale predictions are ultimately generated via residual connections and normalization layers. This design not only mitigates overfitting risks in complex supply chain environments but also optimizes prediction contributions across different time windows through dynamic weight adjustment mechanisms. Additionally, a spatial embedding layer is introduced to encode geographical location's impact on demand distribution, enhancing spatiotemporal coupling in coastal supply chain scenarios. The architecture maintains high prediction stability under both demand abrupt changes and seasonal fluctuations, providing reliable input for downstream inventory and scheduling modules<sup>[2]</sup>.

## 2.2 Dynamic feature extraction mechanism driven by multi-source data

In the intelligent forecasting module of the near-shore supply chain, a multi-source data-driven dynamic feature extraction mechanism serves as the critical component for enhancing demand perception accuracy. Supply chain demands are influenced by highly complex factors, including temporal characteristics such as historical sales data and seasonal fluctuations, as well as external dynamic variables like market trends, macroeconomic indicators, and social media sentiment. To effectively integrate heterogeneous data sources, this mechanism employs a hierarchical feature extraction strategy: First, preprocessing raw data through time alignment and missing value filling to ensure spatiotemporal consistency across multi-source data. Subsequently, convolutional neural networks are utilized to extract spatial local features, while graph neural networks model the topological relationships between supply chain nodes. For dynamic external variables, an online learning module is introduced to dynamically update feature weights, preventing prediction bias caused by environmental abrupt changes in static models. Additionally, attention mechanisms dynamically allocate contribution weights across data sources-such as enhancing sentiment data weight during pandemic peaks and prioritizing historical sales patterns during stable periods. This mechanism not only strengthens the model's ability to capture nonlinear relationships but also provides decision-makers with interpretable insights through feature importance analysis, thereby supporting the coordinated optimization of downstream inventory and path planning modules<sup>[3]</sup>.

## 2.3 Analysis of the transmission of forecast error to downstream inventory decision

In the intelligent prediction-inventory-scheduling closed-loop system, the propagation mechanism of demand forecast errors directly impacts the robustness and cost efficiency of inventory strategies. Forecast errors can be categorized into systematic deviations and random fluctuations, which create cascading effects through replenishment decisions: systematic deviations cause long-term inventory levels to deviate from optimal values, manifesting as persistent overstock or stockouts; while random fluctuations trigger frequent adjustments in short-term replenishment quantities, increasing operational costs. To quantify this transmission process, this paper constructs an error-inventory dynamic response model that decomposes forecast errors into three dimensions-amplitude, direction, and persistence-which correspond to safety stock coefficients, reorder point thresholds, and replenishment cycle adjustment strategies. Research findings indicate that Transformer models exhibit lower directional errors when capturing sudden demand spikes, but their amplitude errors amplify inventory fluctuations through reinforcement learning strategies. In contrast, LSTM's smoothing characteristics suppress short-term volatility but may obscure trend changes, leading to delayed responses. To address this, the system introduces an error compensation mechanism: dynamically adjusting confidence intervals in downstream inventory modules and re-evaluating forecast reliability based on rolling time windows, thereby achieving adaptive buffering within the error propagation chain. This analytical framework provides theoretical foundations for understanding the vulnerability of prediction-inventory coupling systems and points to improvement directions for robustness optimization under public health emergencies<sup>[4]</sup>.

# 3. Dynamic inventory replenishment strategy based on reinforcement learning

## 3.1 Markov decision process and inventory cost modeling

In the design of dynamic replenishment strategies for near-shore supply chains, the Markov decision process provides a formal framework for inventory optimization, integrating inventory states, replenishment actions, and cost-return

considerations into a unified temporal decision system. The inventory state space encompasses three-dimensional coupling of current inventory levels, in-transit orders, and forecasted demand, with transition probabilities dominated by demand uncertainty. The action space defines combined strategies for replenishment quantity and timing, requiring simultaneous consideration of supplier response delays and transportation constraints. The cost function adopts a dual-objective optimization paradigm: explicit costs include procurement costs, holding costs, and stockout penalties, where stockout penalties during public health emergencies are modeled as time-dependent exponential functions to reflect increasing marginal losses under crisis scenarios. Implicit costs are captured through reinforcement learning's advantage function, such as long-term cooperation risks arising from declining supplier reliability. To balance exploration and exploitation, the strategy network employs near-end optimization algorithms while avoiding training instability through KL divergence constraints. Additionally, an LSTM-based historical demand encoder is introduced as a state feature extractor to enhance the model's adaptability to non-stationary demand patterns. This modeling approach not only achieves end-to-end coordination between inventory decision-making and forecasting modules but also provides robust input for subsequent VRP scheduling through its stochastic dynamic planning characteristics<sup>[5]</sup>.

### 3.2 Design of reward function for dual objective optimization

In reinforcement learning-based dynamic inventory replenishment strategies, designing reward functions requires precise balancing of the dynamic interplay between stockout losses and holding costs, which constitutes the core challenge for supply chain cost optimization. Stockout losses exhibit nonlinear growth characteristics in extreme scenarios like public health emergencies, encompassing not only direct sales losses but also indirect costs such as declining customer trust and shrinking market share. Holding costs include warehousing expenses, capital occupation, and product expiration risks. Notably, regional warehouse resource constraints in nearshore supply chains lead to spatial heterogeneity in unit inventory costs. This study employs a segmented reward function architecture: during normal operations, linear weighting converts two cost categories into a unified reward signal with dynamically calibrated weights based on historical data. During crisis scenarios, the system switches to an asymmetric penalty mode, imposing exponentially increasing penalties for stockout states while introducing inventory turnover constraints to prevent overstocking. To enhance adaptability, the function incorporates a demand fluctuation sensing module that automatically adjusts penalty curvature parameters when detecting sudden demand changes. This dynamic equilibrium mechanism not only resolves the failure of traditional static weighting strategies during emergencies but also enables the system to gradually approach Pareto optimality boundaries through reinforcement learning's policy gradient updates, providing an inventory benchmark<sup>[6]</sup> that balances economic efficiency and robustness for future VRP scheduling.

### 3.3 Real-time feedback mechanism of forecast results and inventory strategy

In the intelligent prediction-inventory-scheduling closed-loop system, the real-time feedback mechanism between forecast results and inventory strategies serves as the core link for dynamic optimization. This mechanism establishes a two-way information flow, continuously comparing and calibrating the outputs from upstream forecasting modules with the execution effects of downstream inventory decisions, thereby forming an adaptive strategy adjustment cycle<sup>[7]</sup>. Specifically, demand distribution parameters provided by the forecasting module not only serve as initial inputs for inventory strategies but also undergo real-time matching with operational data such as actual inventory consumption and replenishment delays through time-sliding windows, calculating confidence metrics. When confidence falls below a threshold, the system automatically triggers a strategy optimization process: On one hand, reinforcement learning agents reassess value functions based on latest data to adjust replenishment cycles and safety stock levels; on the other hand, prediction error characteristics are backpropagated to LSTM/Transformer models, prompting online fine-tuning of network parameters. To address extreme scenarios like public health emergencies, the feedback mechanism features a crisis response mode that activates inventory buffer strategies through scenario generators simulating disturbance signals, gradually reverting to normal strategies during post-event recovery phases. This closed-loop feedback architecture not only resolves the disconnect between prediction and execution in traditional supply chains but also significantly enhances decision resilience and operational efficiency in nearshore supply chains under uncertain environments through continuous self-correction, as shown in Table 1.



*Table 1 Comparison of key performance indicators between forecast results and real-time feedback mechanism of inventory strategy*

| metric                               | No feedback mechanism | Closed-loop feedback mechanism | Improvement magnitude (%) |
|--------------------------------------|-----------------------|--------------------------------|---------------------------|
| Prediction accuracy (MAPE)           | 18.2%                 | 12.5%                          | 31.3%                     |
| Inventory Turnover Rate (times/year) | 6.8                   | 8.4                            | 23.5%                     |
| Stockout rate                        | 15.7%                 | 9.2%                           | 41.4%                     |
| Average restocking response time (h) | 24.5                  | 18.3                           | 25.3%                     |
| Total operating cost reduction rate  | -                     | 17.6%                          | -                         |

Note: The data is based on a six-month system test cycle, comparing the traditional static strategy with the closed-loop feedback mechanism proposed in this paper. The improvement is calculated based on the no-feedback mechanism.

## 4. Closed-loop collaborative optimization of VRP scheduling module

### 4.1 Joint constraint modeling of demand-inventory-path

In the closed-loop collaborative optimization of VRP scheduling modules, the joint constraint modeling of demand-inventory-path integration serves as a critical technical approach to achieve dynamic coupling across supply chain stages. This framework constructs a multidimensional decision space that unifies temporal characteristics of upstream demand forecasting, safety stock strategies in inventory management, and spatial topological structures of path planning, forming a spatiotemporal constraint network. Temporally, the model incorporates dynamic updates in demand forecasting by quantifying the alignment between replenishment cycles and delivery windows as soft constraints, enabling flexible scheduling through penalty functions for sudden demand surges. Spatially, leveraging the regional characteristics of near-shore supply chains, a dual-layer path network is designed: an upper layer handles trunk transportation between distribution centers, while a lower layer optimizes last-mile delivery at terminal facilities, interconnected via capacity constraints at inventory transfer nodes. Notably, the model introduces a dynamic accessibility matrix to dynamically adjust connectivity weights in response to regional lockdown risks caused by public health emergencies. The constraint solution employs an improved column generation algorithm that embeds inventory cost terms into the objective function, ensuring path planning minimizes both transportation distance and maintains node-level inventory balance. This integrated modeling methodology overcomes the limitations of traditional VRP problems that separate demand and path optimization, providing a globally oriented scheduling solution for closed-loop systems with significantly enhanced resilience under extreme disturbances<sup>[8]</sup>.

### 4.2 Real-time response algorithm for time-varying road network and dynamic order

In VRP scheduling for near-shore supply chains, time-varying network conditions and dynamic order fluctuations pose core challenges for path optimization. This algorithm establishes a spatiotemporal coupled response framework that enables bidirectional adaptation between traffic conditions and order demands. At the network modeling level, a spatiotemporal graph convolutional network captures dynamic traffic patterns, encoding historical traffic volumes, real-time events, and weather factors into multi-dimensional edge weights to reflect varying passage efficiency across time periods. For order processing, a trigger-based dynamic insertion mechanism is designed: when new orders arrive or demand forecasts update, the system rapidly evaluates their impact on existing path plans through constrained neighborhood search, then determines optimal insertion positions via regret value sorting. To balance real-time responsiveness with optimization efficiency, the algorithm employs a hierarchical optimization strategy: the top layer utilizes deep Q-networks to learn macro-level allocation strategies, while the bottom layer applies adaptive large-scale neighborhood search for local path fine-tuning. These components collaborate through shared spatiotemporal state representations. Notably, the algorithm integrates risk probability maps generated by scenario generators to preset detour redundancy during path evaluation when regional traffic restrictions occur due to public health emergencies. This real-time response mechanism transforms traditional static VRP optimization into a continuously evolving dynamic decision-making process, significantly enhancing service stability and cost controllability in

closed-loop systems under uncertainty through proactive interaction with changing environments.

### 4.3 Robust compensation of information delay in closed-loop system

In intelligent prediction-inventory-scheduling closed-loop systems, information delays pose critical challenges to real-time decision-making accuracy, particularly in complex nearshore supply chains with strong spatiotemporal dependencies. To address asynchronous information issues caused by data transmission delays, processing lags, or sudden network outages, this study proposes a multi-level robust compensation framework. At the data level, a sliding window buffering mechanism synchronizes time-series of key metrics like delayed demand forecasts and inventory status, reconstructing optimal estimates for missing periods through state estimators. At the decision-making level, a context-aware reinforcement learning framework enables inventory replenishment strategies to leverage historical delay patterns for analogical reasoning, preventing policy oscillations from information delays. For path planning, a prediction-correction mechanism predicts future network conditions using spatiotemporal attention weights generated by ST-GCN when real-time traffic updates are delayed, dynamically adjusting path redundancy. To address potential systemic communication failures during public health emergencies, the system integrates offline emergency modes that maintain basic operational capabilities through locally cached historical optimal strategy libraries. This compensation mechanism not only ensures closed-loop system stability via time-delay differential equation theory but also provides gradient-based solutions for various delay scenarios through modular design, fundamentally enhancing supply chain resilience and decision reliability in non-ideal information environments.

## 5. Robustness verification of public health emergency scenarios

### 5.1 Parametric design of extreme risk scenario generator

In robustness verification of public health emergency scenarios, the parametric design of extreme risk scenario generators serves as a critical foundation for assessing supply chain resilience. This generator employs a multi-level parameter system to structurally model the spatiotemporal characteristics, propagation patterns, and cascading impacts of emergencies on supply chains. At the macro level, it simulates population movement restrictions under different prevention policies using the SEIR epidemic model, mapping these constraints into attenuation coefficients for regional logistics capacity. At the meso level, a Bayesian network-based multi-tiered interruption probability transmission model is constructed to quantify node failure cascading effects across suppliers, distribution centers, and retail terminals. At the micro level, a dynamic demand disturbance function is designed to convert behavioral patterns like panic buying and medical supply bottlenecks into non-stationary demand curve mutations. The parameter calibration process integrates historical pandemic data with expert knowledge, employing Monte Carlo sampling to generate statistically significant risk scenario spectra covering severity levels from localized lockdowns to global pandemics. This parametric approach not only bridges abstract risks with operational constraints but also features a modular architecture that enables rapid rule updates according to emerging emergency evolution characteristics, providing scalable testing benchmarks for subsequent cost-inventory balance analyses.

### 5.2 Cost-inventory Pareto frontier analysis under supply chain disruption

In supply chain disruptions caused by public health emergencies, the trade-off between cost and inventory exhibits significant nonlinear characteristics, making traditional single-objective optimization frameworks inadequate for capturing their complex dynamics. This study establishes a multi-objective Pareto frontier analysis model to systematically quantify the strategic trade-off between inventory redundancy and operational costs during extreme risk scenarios. By incorporating disruption intensity, duration, and recovery resilience as core variables, the model employs the  $\epsilon$ -constraint method to generate non-dominated solution sets, revealing three distinct decision-making zones: Mild disruptions allow marginal inventory increases to significantly reduce stockout risks; Moderate disruptions present a critical trade-off threshold requiring dynamic safety stock threshold adjustments through reinforcement learning strategies; Severe disruptions demonstrate cost-sensitive regions where partial supply cutoffs become inevitable, necessitating prioritized protection of key nodes. The analytical framework incorporates spatiotemporal disturbance parameters from scenario generators, enabling Pareto frontiers to reflect regional lockdown variations on equilibrium points. This research not only provides decision-makers with a visual resilience management tool but also establishes a high-dimensional objective space as a benchmark environment for subsequent intelligent algorithm optimization.



### 5.3 Vulnerability diagnosis and improvement of inter-module collaborative failure

In extreme risk scenarios, the inter-module coordination of the intelligent prediction-inventory-scheduling closed-loop system may fail systematically due to information gaps, decision conflicts, or resource constraints. This study proposes a vulnerability diagnosis framework based on complex network theory. By constructing directed weighted graphs of module interactions, it quantifies the coupling effects between prediction error propagation, inventory strategy lags, and rigid path planning. The diagnostic model identifies three typical failure modes: 1) Temporal mismatch, where short-term demand fluctuations in forecasting fail to synchronize with long-term inventory replenishment strategies; 2) Spatial resource conflicts, where regional blockades cause geographical misalignment between VRP path optimization and inventory distribution; 3) Objective function divergence, where local optimal solutions from individual modules negatively compound overall costs. To address these vulnerabilities, the improved solution adopts a federated learning architecture to restructure module interfaces: designs cross-module attention mechanisms to align spatiotemporal decision granularity, introduces virtual inventory nodes to buffer geographical constraints, and coordinates multi-objective optimization weights through Nash bargaining models. This enhanced framework significantly improves the system's fault tolerance under continuous disturbances, providing a universal methodology for resilience design in nearshore supply chains.

## 6. Conclusions

The intelligent prediction-inventory-scheduling closed-loop system developed in this study significantly enhances decision-making efficiency for nearshore supply chains under both normal and risk scenarios through algorithmic integration and scenario-based validation. Theoretically, the heterogeneous model integration and closed-loop feedback mechanism establish a novel paradigm for supply chain resilience research. Practically, the sudden scenario generator reveals the system's adaptive boundaries under extreme disturbances, providing guidance for future research on dynamic weight adjustment and multi-agent collaboration.

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no

## Conflict of Interests

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

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# Implementation of Plan-Do-Check-Act (PDCA) Cycle for Product Quality Management: Evidence from a Manufacturing Enterprise in China

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**Abstract:** In the market with increased competition and a large number of choices, it is necessary for enterprises to improve the existing standards of product quality to meet the customer demand and achieve sustainable development. As for the manufacturing enterprises, continuous improvement supports in reducing defective rate of products and safety risks, which enhances the overall product quality. This paper discusses a case study in implementing Plan-Do-Check-Act (PDCA) to improve product quality of compressed natural gas (CNG) cylinders in a manufacturing enterprise in China. The outcome is the enterprise has successfully reduced the defective rate of the products from 50% to 27% and improved the production efficiency.

**Keywords:** Plan-Do-Check-Act (PDCA); Product Quality Management; Continuous Improvement; CNG Cylinder

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## 1.Introduction

With the advancement of urbanisation, the issue of environmental protection is becoming increasingly obvious, which has aroused great concerns from all countries (Prashar, 2017). According to Hao et al. (2016), vehicle emission has been highlighted in the various factors of urban environmental pollution and the natural gas vehicles are being developed for the replacement because of its low emission and cost-saving. One of most important products of manufacturing enterprises for automatic vehicles is the compressed natural gas (CNG) cylinders which will become the direction for the automatic cylinder in the future (Khan et al., 2015). In the attraction of the bright prospect, many manufacturing enterprises in China have entered the market to produce CNG cylinders. However, there remain many issues of this type of automatic products, and some enterprises even put substandard products on the market for the immediate profits, which seriously threatens the safety of consumers and the public (Majernik et al., 2015). As a high-pressure container, CNG cylinder may cause explosion accidents if the quality is below the standard or have defects. Therefore, quality has become one of the critical success factors among manufacturing enterprises and the winner is supposed to seize the opportunity that meet customer demand through the most reliable methods (Maminai & Barbados, 2011; Goetsch & Davis, 2014; Realyvásquez-Vargas et al., 2018; Potkany et al., 2022).

Plan-Do-Check-Act (PDCA) cycle, also known as the Deming cycle, was proposed by Edwards Deming as an expert of quality management (Sokovic et al., 2010; Nguyen et al., 2020). In the process of total quality management (TQM), PDCA

cycle can be regarded as a basic approach for continuous improvement. This method is applicable to a wide range and can be implemented to the product quality management and reducing defects of manufacturing products. Thus, in this paper, the researcher will first have a literature review related to the content of quality management and PDCA cycle and adopts a case study of implementing PDCA cycle on product quality management of CNG cylinders from a manufacturing enterprise in China.

## 2. Literature Review

### 2.1 Quality Management

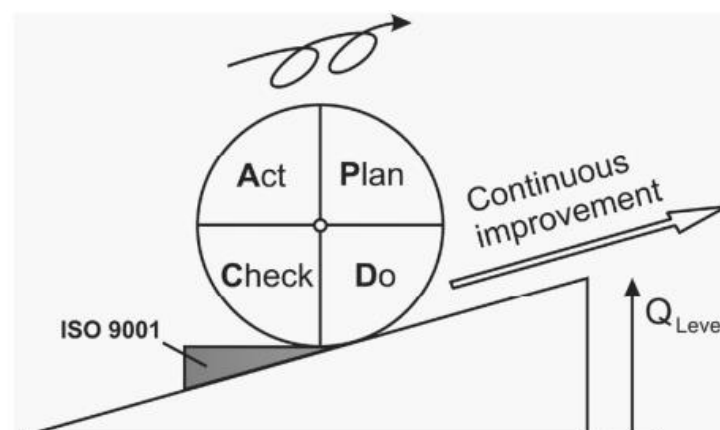
Quality is one of the objectives of quality management. According to (Goetsch & Davis, 2014), it is important that the enterprises should take quality into account for decision-making because the high quality of products bring the business profitability and promising development of the enterprises while low quality may result in deficit even loss of market. Thus, if the enterprise wishes to keep in sustainable development, it needs to improve the quality of the products and services. Lo et al. (2007) state that the rejection rate and a variety of consumption can be reduced in the high-quality manufacturing process, which save the cost in an invisible way and bring economic benefits to the enterprises.

According to Linderman et al. (2004), quality management can be defined as a method which the organisations use to continually improve the quality of products and services as well as make sure the result and the process of improvement have met the expectation of customers and other stakeholders. On the micro-level, the survival and development of enterprises cannot be separated with product quality because the customer requirement on the product quality has become higher as the time changes. Therefore, Jagusiak-Kocik (2017) states that the effective improvement of product quality will greatly improve the market competitiveness of enterprises and customer satisfaction. Any enterprise with social responsibility will regard quality management as a necessary measure to protect the interest and the security of the customers. On the macro-level, the enterprises should strategically consider the improvement of product quality in the international context in terms of the economic globalisation. The low quality and its negative impact should be avoided because the enterprises represent the image of the original countries to some degree. Additionally, total quality management (TQM) is the effective way of management that regards the quality of products and services as the core and total employee involvement as the basis to reach sustainable operation through benefiting the customers and all members in the organisation (Kaynak, 2003).

### 2.2 Plan-Do-Check-Act (PDCA) Cycle

PDCA cycle or Deming's cycle is regarded as one of the basic approaches of TQM (Sokovic et al., 2010; Nguyen et al., 2020). It divides the quality management into four steps including Plan, Do, Check and Act. It aims at explaining that the business process should be continuously improved and identifying the specific parts of the products which need to be improved. As is mentioned by Ning et al (2010), the PDCA cycle can be applied to the improvement processes in enterprise management through the dynamic round of Plan-Do-Check-Action. Omens (2006) add that the PDCA cycle is the essence of TQM activities, and it can be regarded as the common working process of the organization to develop and focus on the organisational needs.

*Figure 1 PDCA Cycle for Continuous Improvement*



Whilst the cycle can be applied to a wide range of contexts as a framework to solve the issues of quality management (Pietrzak & Paliszkievicz, 2015). For example, Prashar (2017) studies the improvement of energy management system in the energy-targeted small and medium-sized companies based on PDCA cycle. Jagusiak-Kocik (2017) carries a case study of implementing the cycle to product development in the plastics processing industry. Hasan & Hossain (2018) suggest the cycle can be used to improve the teaching quality of engineering experiment in the universities. As is shown in Figure 1 by Sokovic et al., (2010), PDCA cycle typically consists of four phases for continuous improvement of product quality.

Phase one: Plan. In this phase, the organisations should set up the targets and objectives of quality management as well as prepare the plan for it. There are normally four steps in detail: (1) Analyse the product quality and identify the issues. (2) Discuss the causes of product quality problems. (3) Find and target the main factors and causes. (4) Provide the solutions and plan direct at the main factors and predict the result of implementation.

Phase two: Do. This phase requires the organisations to implement and test the specific measures based on the plans and targets which have been proposed in phase one. The do phase is also regarded as step five in the cycle.

Phase three: Check. This phase or step six is to compare the implementation results with the proposed plans to check whether the implementation and effect of the measures are consistent with the expected results and objectives.

Phase four: Act. This phase includes two steps: (1) Summarise the achievements and lessons of the implementation. Successful experience will be applied in the future while the same issues should be avoided happening again (2) Put the issues which have not been solved in this cycle to the next round and begin to develop the quality plan for the next phase.

### **2.3 Benefit and Drawback of PDCA Cycle**

The benefits of the PDCA cycle have been widely marked in the relevant studies. One is that the cycle is an iterative process which can be used many times to resolve the issues (Sokovic et al., 2010). The value of the cycle cannot be ignored as a standard tool of TQM. The employees in the organisations will put efforts to the organisational improvement through different position roles if they are aware that there is a standard process for improvement to follow. The other is that a distinct competitive advantage can be brought by the PDCA cycle (Jagusiak-Kocik, 2017). The business productivity and customer satisfaction of the organisations will increase with the implementation of the dynamic cycle. Another important benefit of the cycle is risk control. According to Alyoubi et al. (2017), PDCA cycle is designed to mitigate the mistakes and faults in the process of performance improvement because the changes will be tested in a small range before being taken in the whole organisation.

Although there are few drawbacks of PDCA cycle can be found, it still exists in the process of implementation. Ning et al. (2010) mention that the PDCA cycle focuses on total involvement of the employees, but the current organisational culture may be challenged by applying the multi-step process into the organisation. Also, it takes a relatively long period of time to plan changes which are ineffective for dealing with urgent problems.

## **3.Product Quality Management with PDCA Cycle in Enterprise F**

### **3.1 Quality Management System of Enterprise F**

Enterprise F is a manufacturing enterprise located in Shanghai and mainly engaged in the research, development and production of aerospace and civil composite materials. The main products developed by the enterprise are applied in the space field such as satellite carrier rocket spacecraft and the field of high-speed railway and vehicles. The enterprise regards quality as one of the most important factors in the production process as well as has passed many attestations including ISO9001, ISO14001 and TS16949. Currently, the products in the civil aspects mainly encompass the composite cylinders for medical use and the compressed natural gas (CNG) cylinders for natural gas vehicles. According to the confidential, the data of quality improvement in 2017 is analysed in this paper.

In the process of further development, enterprise F constantly absorbs the lessons and experiences of management from domestic and international enterprises as well as accept the advanced management vision to its own management. Combined with the specific situation of the company and the standard of TS16949, the requirements for manufacturers in the automobile industry to implement ISO9001, enterprise F has designed its own quality management system (QMS) which emphasises the quality as the basic guarantee to improve management process. The company believes that the establishment of a scientific

and reasonable QMS is the positive way of taking social responsibility. The QMS of enterprise F is formulated based on PDCA cycle and the process has been divided into four phases which include preparation and targets setting, QMS strategic planning, implementation and the phase of inspection and assessment.

### 3.2 Implementing PDCA Cycle for Quality Improvement of CNG Cylinders

#### 3.2.1 Plan

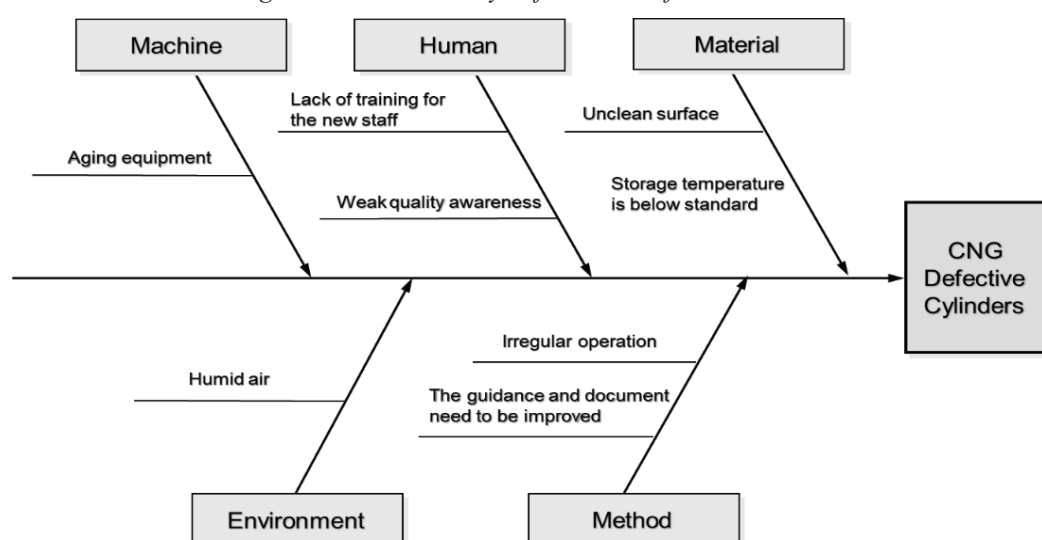
Although there are many factors can affect the quality of CNG cylinders, the minority of them are important. According to the data of defective cylinders, 50 products have been marked below the standard in the total figure of 808 and the defective rate is 6.2% in March 2017. As is shown in Table 1, the main factors to cause defective products are front pits and thread wears which are 36% and 24% respectively. As a result, these two factors should be focused on the improvement process of CNG cylinders.

Table 1 Defective CNG Cylinders of Enterprise F in March 2017

| Problems                   | Numbers | Percentage (%) |
|----------------------------|---------|----------------|
| Pits in the front          | 18      | 36             |
| Bottleneck capillary crack | 5       | 10             |
| Thread wears               | 12      | 24             |
| Air leakage                | 2       | 4              |
| Sticky surface             | 10      | 20             |
| Others                     | 3       | 6              |
| Total                      | 50      | 100            |

In terms of the factors to cause the quality problems of the cylinder are complex, a fishbone analysis is considered in this study. According to Luo et al. (2018), the fishbone diagram or Ishikawa diagram is regarded as a common tool of management that can be used to find the cause and effect of quality problems, analysing the relationship among the elements to affect the quality. Thus, the researcher has come up with a fishbone analysis based on the provided information to find the factors which result in the quality problems of CNG cylinders (See Figure 2).

Figure 2 Fishbone Analysis for CNG Defective Products



#### 3.2.2 Do

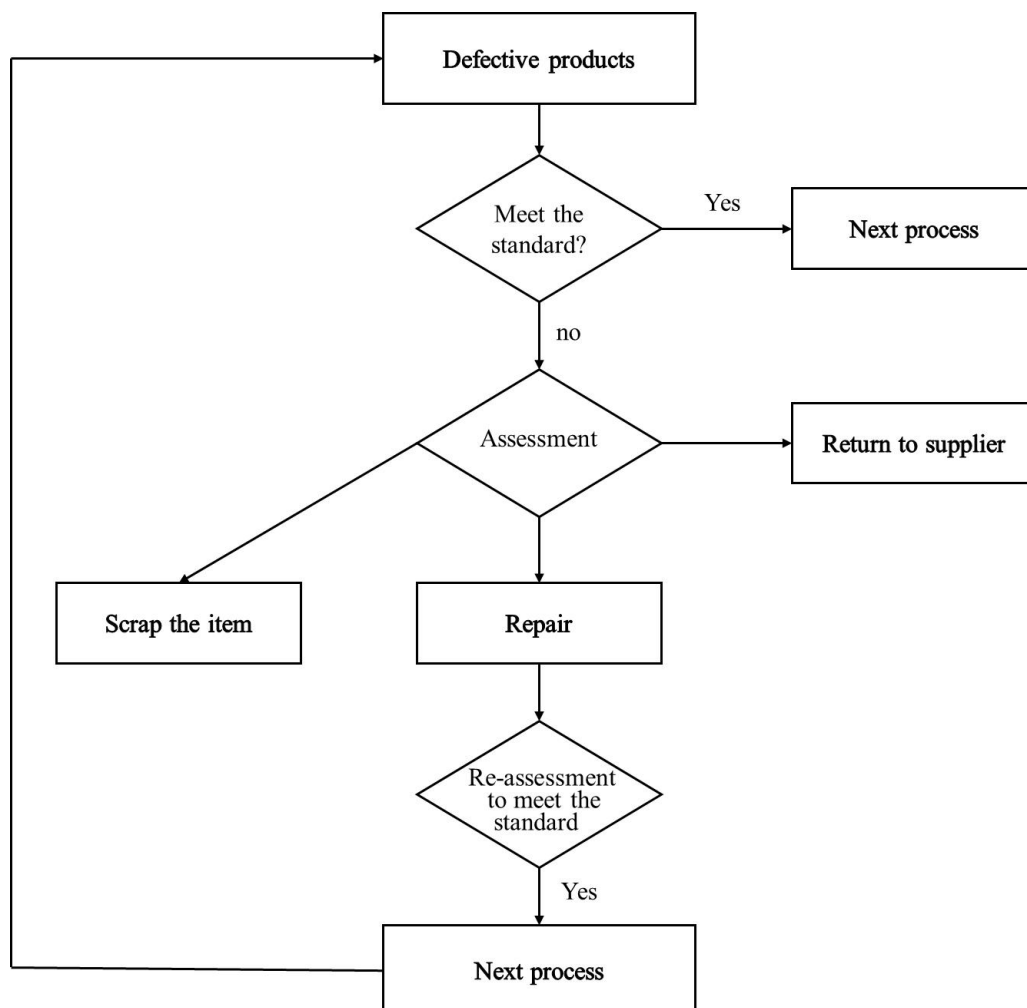
According to Goetsch & Davis (2014), quality control in the production process is an important part of product quality management to assure the quality of the products. In the entire process of producing CNG cylinders, quality control determines the quality of cylinders as well as indirectly reflect the level of quality management of the company. Thus, the

implementation has been taken on the main factors in terms of the identified problems in stage of plan (See Table 2). Also, enterprise F considers that the existing defective products should be incorporated into a unified management process to make sure the high-pressure vessels are under control. Figure 3 illustrates a flowchart process of managing the products below the standard in enterprise F for quality improvement.

Table 2 Strategic Plan for Mitigating Quality Problems of CNG Cylinders

| No | Problems                 | Statements  | Requirements             |
|----|--------------------------|---|--------------------------|
| 1  | Sticky surface of thread | <ul style="list-style-type: none"> <li>· Deploy staff to clean the items</li> <li>· Repurchase it every year</li> </ul>                               | List on the working plan |
| 2  | Pits on the products     | <ul style="list-style-type: none"> <li>· Handle with care in delivery</li> <li>· Put the soft materials on the corners of the working area</li> </ul> | Complete by next month   |
| 3  | Storage temperature      | <ul style="list-style-type: none"> <li>· Need to be checked by the inspectors every day</li> </ul>  | List on the working plan |
| 4  | Documents improvement    | <ul style="list-style-type: none"> <li>· Update the inspection records</li> </ul>   | Complete by next month   |
| 5  | Week awareness           | <ul style="list-style-type: none"> <li>· Provide systematic training on the methods of quality control to the staff</li> </ul>                        | Concise plan and content |

Figure 3 Process Flowchart of Defective Products



### 3.2.3 Check

In this stage, it is important to check the results after having improved the quality control of the production process of CNG cylinders as well as taken measures on the factors to cause defective products. There are 27 of 1010 products have not met



the standard and the defective rate is 2.7% in the next month which is April. In Table 3, the main factors are air leakage and bottleneck capillary crack which is 25.9% and 37.1% respectively in this time. Compared to data in last month, the main quality problems which are pits and thread wears have been efficiently improved and even the issue like the sticky surface has been fully solved. Thus, the results implied that enterprise F has taken the successful implementation on the product quality improvement.

*Table 3 Defective CNG Cylinders of Enterprise F in April 2017*

| Problems                   | Numbers | Percentage (%) |
|----------------------------|---------|----------------|
| Air leakage                | 7       | 25.9           |
| Bottleneck capillary crack | 10      | 37.1           |
| Pits                       | 3       | 11.1           |
| Thread wears               | 2       | 7.4            |
| Others                     | 5       | 18.5           |
| Total                      | 27      | 100            |

### 3.2.4 Act

The quality of the CNG cylinders is effectively improved after the implementation and the defective rate has declined from 6.2% to 2.7% in the comparison between two months. The problems of pits and thread wear of CNG cylinders have obviously reduced. Based on the systematic training of quality management, new staff and the employees with weak awareness of quality have fully understood the quality improvement requires total involvement and collaboration rather than only the work of the quality department. Also, according to Table 3, the comparison has found the air leakage and bottleneck capillary crack become the main factors to affect the quality of CNG cylinders which need to be taken to the next round of PDCA cycle.

To summarise, enterprise F has successfully implemented the quality improvement on CNG cylinders based on the PDCA cycle, which reduce the defective rate of the products from 50% to 27%. In the entire process, the company has found the factors which cause defective products as well as made the targeted plans on the main factors for the improvement. Finally, the enterprise has reached the expected goal of quality improvement, and the production efficacy has increased due to defective rate has declined.

## 4. Conclusion

In conclusion, the PDCA cycle is closely related to the process of product quality management (Goetsch & Davis, 2014). This dynamic cycle can be applied to various types of process management for the enterprises in the manufacturing industry to figure out the causes and factors of problems and promote continuous improvement (Sokovic et al., 2010). In the case study, the quality of CNG cylinders of enterprise F reduce the overall defective rate of product from 50% to 27% with the implementation of PDCA cycle. The main factors to cause the defective products to have reduced with the overall percentage of the pass has increased, which has reached the expected target. However, besides the positive outcomes of the product quality management, problems always appear in the process of continuous improvement. As is stated by Steinfeld (2004) that the enterprises intend to maintain the status quo and stop to move ahead when some effective results of improvement are achieved or because of the project progress and cost pressure. As a result, these troubles may reduce the efficiency of implementing the PDCA cycle. Therefore, it is important for manufacturing enterprises to put more efforts and overcome the main obstacles which constrain the quality management and business benefits. Based on the PDCA cycle, the processes in a manufacturing enterprise have become controllable, which supports the continuous improvement of product quality (Alyoubi et al., 2017).

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# The Integration of Artificial Intelligence into Smart Policing Systems: Applications and Risk Governance

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**Abstract:** With the rapid advancement of artificial intelligence (AI), smart policing has emerged as a strategic priority in the modernization of public security systems. AI technologies such as facial recognition, video surveillance, big data analytics, and intelligent command systems have significantly enhanced the operational efficiency and precision of law enforcement. However, these technological gains are accompanied by structural risks, including data misuse, privacy violations, algorithmic bias, expanded police authority, and erosion of procedural justice. This paper reviews the current applications and development trends of AI in smart policing and critically examines the legal and ethical risks arising from such integration. It proposes a multi-dimensional governance framework comprising legal regulation, algorithm oversight, public accountability, and ethical training. The study argues that a balance between efficiency, safety, and fairness is essential for sustainable smart policing. Moving forward, it is imperative to synchronize AI governance with policing practices and promote international cooperation to establish unified standards for data protection and AI ethics.

**Keywords:** Smart Policing; Artificial Intelligence; Data Governance; Algorithmic Bias; Rule of Law Risk

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## 1.Introduction

Artificial Intelligence (AI), as a central force of the Fourth Industrial Revolution, is rapidly transforming industries and public administration alike. Technologies such as big data analytics, deep learning, computer vision, and natural language processing are moving beyond the laboratory to become integral tools in the governance of modern societies. Among various domains, the field of public security has emerged as one of the most prominent arenas for AI deployment. In China, the Ministry of Public Security has actively promoted the construction of “smart policing” systems supported by AI, cloud computing, and integrated data platforms, aiming to enhance operational efficiency and modernize governance structures.

Smart policing refers to the comprehensive integration of AI, the Internet of Things (IoT), and advanced information systems into law enforcement activities. It emphasizes data-driven decision-making, risk forecasting, and proactive intervention, marking a significant shift from traditional models of policing based on manpower, physical infrastructure, and basic surveillance. With guidance from policy documents such as the National Guidelines for Smart Policing Development and The Framework for Big Data and AI Integration in Public Security, local police departments across China have implemented AI-driven platforms for facial recognition, predictive policing, and emergency response coordination. These efforts are reshaping how crime is monitored, analyzed, and managed.

However, the rise of AI in policing is not without profound legal and societal implications. The large-scale collection and processing of personal data, often conducted without clear boundaries or informed consent, risk infringing on individuals' rights to privacy and autonomy. Moreover, AI algorithms—frequently trained on biased or incomplete datasets—may reproduce or even amplify discriminatory patterns in decision-making, leading to disproportionate scrutiny of certain demographic groups. The “black box” nature of algorithmic systems also challenges traditional principles of administrative accountability and procedural transparency, making it difficult for the public to understand or contest decisions made by machines.

In this context, the integration of AI into policing raises urgent questions about how to balance technological efficiency with legal legitimacy and ethical integrity. This paper aims to analyze the current development and practical applications of AI in smart policing, identify the core risks that accompany its implementation, and propose a set of governance mechanisms to mitigate these risks. By addressing both the potentials and pitfalls of AI-driven law enforcement, this study contributes to the broader discourse on responsible innovation and the future of public safety governance in the digital age.

## **2.Literature Review**

### **2.1 International Research Landscape**

The integration of artificial intelligence into law enforcement has become a central topic in interdisciplinary research across law, computer science, public administration, and ethics. Early studies predominantly focused on the functional value of AI tools in policing. For example, Perry et al. (2013) introduced the concept of predictive policing, which uses historical crime data and statistical models to anticipate future criminal activity and allocate police resources more efficiently. Over time, however, attention has shifted toward the risks and ethical dilemmas embedded in algorithmic systems.

Legal scholars and civil society advocates have raised concerns about the inherent biases in algorithmic policing tools. Ferguson (2017), for instance, argues that predictive algorithms often reinforce systemic inequalities, particularly when trained on biased datasets that disproportionately reflect minority communities. Pasquale (2015) emphasized the risks of opacity in algorithmic decision-making, warning that black-box systems can undermine democratic oversight and due process.

In response, the European Union has proposed regulatory initiatives such as the draft Artificial Intelligence Act, which aims to impose stricter controls on high-risk AI applications, including those used in law enforcement. These frameworks emphasize principles like transparency, human oversight, and proportionality. In the United States, while the adoption of AI policing tools is widespread, critical discourse continues to highlight the need for external audits, public accountability, and ethical AI design.

Overall, international scholarship has developed a robust critique of AI in policing, focusing on data ethics, algorithmic governance, and the protection of civil liberties. These insights provide valuable references for developing normative frameworks suitable to China's sociopolitical and legal context.

### **2.2 Domestic Research Developments in China**

In recent years, Chinese scholars have increasingly turned their attention to the intersection of AI and public security, particularly in the context of smart city development and police modernization. Current domestic research can be broadly divided into three thematic areas:

First, studies focusing on the construction of smart policing systems emphasize the technical and organizational transformation of policing. Scholars such as Wang Dawei (2019) propose that smart policing should rely on a closed-loop operational model of “perception–analysis–command–action–feedback,” underpinned by big data and integrated platforms. These studies primarily adopt a problem-solving perspective, aiming to improve the efficiency and responsiveness of police operations.

Second, research on the application of AI technologies in police work explores the deployment of facial recognition, video surveillance, natural language processing, and big data analytics. Scholars such as Li Zhenxing (2020) analyze the strengths and limitations of AI tools in assisting criminal investigations, pointing to both efficiency gains and potential overreliance on machine judgment.

Third, an emerging body of literature examines the legal and ethical implications of AI policing. Chen Ruihua (2021) has argued that the deployment of AI in law enforcement must operate within the constraints of China's Constitution, Criminal Procedure Law, and Personal Information Protection Law. Other scholars have drawn attention to the procedural risks posed by automated decision-making systems and called for the codification of boundaries for data collection and algorithmic processing by police.

While domestic scholarship provides a valuable foundation for understanding AI in policing, much of it remains focused on technical feasibility and administrative implementation. There is still a notable gap in research addressing deeper issues such as algorithmic accountability, rights-based governance, and public trust.

## 2.3 Synthesis and Research Gaps

In sum, both international and domestic studies recognize the transformative potential of AI in public security while emphasizing the need for caution and normative safeguards. International literature offers more mature reflections on algorithmic fairness, human rights, and regulatory innovation. In contrast, Chinese research tends to prioritize system-building and practical applications, often under the guidance of state policy.

This paper seeks to bridge this gap by combining technological insight with legal reasoning. It adopts a problem-oriented perspective to examine how AI tools are reshaping policing practices in China and how associated risks—such as data overreach, discrimination, and procedural opacity—can be effectively mitigated through law and governance. The ultimate goal is to contribute to a model of smart policing that aligns with both public safety objectives and constitutional principles.

## 3. Research Methodology

This study adopts a multi-method approach that integrates legal analysis, policy evaluation, and empirical case review to examine the application of artificial intelligence in China's smart policing systems and explore its associated risks. The goal is to develop a structured and normative framework that addresses both technological benefits and legal challenges in a balanced manner. The specific research methods employed are as follows:

### 3.1 Literature Review and Normative Analysis

A comprehensive literature review was conducted to establish the theoretical foundation of the study. This included both international and domestic academic publications, government reports, policy guidelines, and legal commentaries. Particular attention was paid to studies concerning algorithmic regulation, data governance, law enforcement ethics, and public administration.

Through normative analysis, the study interprets relevant laws such as the Constitution of the People's Republic of China, Criminal Procedure Law, Personal Information Protection Law, and Data Security Law. This legal framework was evaluated to determine its adequacy in regulating AI applications in policing and to identify areas where legal reforms or institutional innovations are needed.

### 3.2 Case Study Method

To capture the practical realities of AI in policing, the study utilizes case studies of specific AI-powered law enforcement systems and initiatives in China. These include, for example, the implementation of facial recognition in urban surveillance networks, predictive policing platforms used in high-risk districts, and risk-scoring systems designed to categorize individuals based on behavioral data.

Each case was examined with regard to its technical architecture, operational logic, and socio-legal implications. This method enabled a grounded analysis of how AI tools affect policing practices and how potential overreach or misuse may occur in the absence of proper regulatory safeguards.

### 3.3 Comparative Analysis

A comparative dimension was introduced to contextualize China's experience with global developments. Policing AI systems and regulatory responses in the United States, the European Union, and selected Asian jurisdictions were examined to highlight different governance strategies. Particular emphasis was placed on algorithmic accountability, public oversight mechanisms, and rights-based frameworks.

The goal of this comparison is to extract valuable lessons that can inform the development of China's AI policing governance

model, while recognizing the unique institutional, cultural, and political factors that shape domestic policy choices.

### **3.4 Problem-Oriented and Governance-Focused Approach**

This study adopts a problem-oriented approach that prioritizes the identification and resolution of key risks associated with AI policing—namely, privacy infringement, algorithmic bias, procedural opacity, and the expansion of police powers. Rather than focusing solely on technical capabilities, the research emphasizes governance challenges and legal design.

By situating AI policing within the broader framework of public law and administrative ethics, the study aims to offer governance-oriented solutions that can balance efficiency with accountability and safeguard the foundational principles of due process and human dignity.

## **4. The Role of AI in Smart Policing: Applications and Development Trends**

The integration of artificial intelligence into public security has reshaped the landscape of policing in both operational and strategic dimensions. As AI technologies become increasingly embedded in law enforcement, their applications now span surveillance, data analysis, criminal investigations, risk forecasting, and decision-making. This section provides an overview of the core concepts behind smart policing and outlines key AI-driven applications, followed by a comparative assessment of domestic and international development trajectories.

### **4.1 Conceptualizing Smart Policing**

Smart policing refers to a data-driven and technology-enabled model of public security management that leverages AI, the Internet of Things (IoT), big data platforms, and cloud computing. Its objective is to improve crime prevention, resource allocation, and real-time responsiveness by automating detection, enhancing prediction, and supporting decision-making processes.

Unlike traditional policing models that rely heavily on manpower and reactive strategies, smart policing emphasizes precision, proactivity, and integration. It creates a dynamic feedback loop encompassing intelligent sensing, algorithmic analysis, automated command, and digitalized execution. This model is particularly well-suited to address complex urban security challenges, such as organized crime, cyber threats, and mass emergencies.

### **4.2 Core Applications of AI in Policing**

#### **4.2.1 Intelligent Video Surveillance and Facial Recognition**

AI-enhanced video surveillance systems are capable of automatically detecting individuals, vehicles, and suspicious behaviors through real-time image processing and pattern recognition. Facial recognition is a cornerstone technology that enables rapid identity verification, suspect tracking, and alert generation. Deployed across transport hubs, business districts, and residential areas, these systems significantly improve the speed and precision of law enforcement.

However, widespread deployment of such systems also triggers concerns about privacy erosion and mass surveillance. Without strict legal boundaries and public accountability, facial recognition may become a tool of intrusive state control rather than legitimate crime prevention.

#### **4.2.2 Big Data Analytics and Predictive Policing**

Predictive policing involves the use of statistical models and machine learning algorithms to analyze historical crime data, spatial patterns, and behavioral indicators. These insights are used to forecast potential criminal incidents and inform the allocation of patrol units and resources. In practice, some jurisdictions in China have implemented AI-powered platforms to assess the risk levels of individuals and neighborhoods based on diverse datasets.

While predictive models can enhance efficiency and reduce crime rates, they risk reinforcing existing social biases, especially if trained on discriminatory or incomplete data. Predictive policing can also lead to over-surveillance of marginalized communities, raising ethical and legal concerns.

#### **4.2.3 Natural Language Processing and Case Assistance Systems**

AI-driven voice recognition and semantic analysis technologies are increasingly used in the collection, transcription, and categorization of investigative records. Law enforcement officers can use AI systems to generate electronic case files, organize evidence, and detect inconsistencies in testimonies. These tools reduce repetitive manual work and improve procedural consistency.

Advanced language models can also assist in interpreting interrogations, detecting emotional cues, and evaluating credibility, although the accuracy and fairness of such interpretations remain under scrutiny.

#### **4.2.4 Smart Patrol Robots and Command Platforms**

In densely populated public areas such as airports, train stations, and commercial centers, patrol robots equipped with thermal sensors, biometric scanners, and voice interaction modules are deployed to monitor security risks and interact with civilians. At the command level, AI-enabled platforms aggregate real-time data feeds to assist with emergency response, dispatch coordination, and resource optimization.

These systems enable law enforcement agencies to operate with greater flexibility and responsiveness. However, their reliance on algorithmic decision-making introduces new challenges related to transparency, accountability, and due process.

### **4.3 Comparative Development Trends: China vs. Western Countries**

#### **4.3.1 China: Operational Efficiency and System Integration**

China's approach to smart policing is characterized by strong government leadership, centralized coordination, and a focus on operational outcomes. Initiatives such as the "Sharp Eyes Project," the "Snow Bright System," and the "Integrated Command Platforms" exemplify the country's ambition to create seamless, multi-layered security infrastructures. These efforts emphasize real-time surveillance, centralized databases, and interdepartmental data fusion to support rapid response and precision governance.

China's smart policing development is closely tied to its broader strategy of digital state-building, where technological tools serve as instruments for social control, stability maintenance, and crime deterrence.

#### **4.3.2 United States and Europe: Emphasis on Rights and Regulation**

In contrast, Western countries have adopted a more cautious and rights-oriented approach. In the United States, predictive policing systems like PredPol have faced criticism for algorithmic bias and racial profiling, leading to their suspension or discontinuation in several cities. Civil society organizations and legal scholars have advocated for stronger oversight, transparency mandates, and public engagement.

The European Union has taken a regulatory-first stance, proposing the Artificial Intelligence Act, which imposes strict requirements on high-risk AI systems, including those used in law enforcement. These regulations mandate human oversight, risk assessments, and justification protocols, ensuring that AI applications do not undermine fundamental rights and democratic values.

This chapter demonstrates that while AI has become a transformative force in policing, its application must be guided by context-specific norms and institutional safeguards. China's emphasis on integration and efficiency contrasts with the rights-based, regulatory frameworks emerging in the West. Both models offer insights—and cautionary lessons—for the responsible evolution of smart policing worldwide.

## **5. Risk Assessment: Legal, Technical, and Ethical Challenges of AI Policing**

While the integration of artificial intelligence into smart policing systems brings about substantial benefits in efficiency, precision, and responsiveness, it also introduces profound risks that can compromise individual rights, erode public trust, and challenge the foundations of rule-based governance. These risks are not incidental, but structural in nature—arising from the very logic of data-centric, algorithm-driven systems. This section provides a comprehensive analysis of the key challenges associated with AI policing, categorized into four major domains: data governance, algorithmic bias, procedural justice, and the expansion of police power.

### **5.1 Data Security and Privacy Infringement**

#### **5.1.1 Ambiguity in Data Collection and Use**

One of the most pressing concerns is the extensive collection of personal information without clear legal boundaries or sufficient public awareness. AI-powered policing systems routinely harvest biometric data, movement patterns, digital communication records, and behavioral profiles. In many cases, this is done without informed consent or judicial oversight, which violates core principles of necessity, proportionality, and legality.

The lack of clarity in how data is obtained, processed, and stored creates significant potential for misuse. When surveillance



becomes ubiquitous and unregulated, it risks transforming public spaces into zones of constant observation, undermining citizens' sense of autonomy and anonymity.

### **5.1.2 Vulnerability to Data Breaches and Cyber Attacks**

The technical infrastructure of smart policing systems—often reliant on centralized databases and cloud platforms—poses serious cybersecurity risks. Without robust protections, these systems become attractive targets for malicious actors. Data leaks involving sensitive personal information can not only harm individual rights but also severely damage the credibility of law enforcement agencies.

Recent high-profile incidents of alleged data leaks from public security networks have underscored the urgent need to upgrade security protocols, strengthen data encryption, and impose strict access controls within policing systems.

## **5.2 Algorithmic Bias and Discriminatory Decision-Making**

### **5.2.1 Inherited Bias from Historical Training Data**

AI systems do not operate in a vacuum. Their performance depends on the quality and representativeness of the data they are trained on. In policing, historical data often reflects pre-existing social inequalities, racial profiling, or enforcement patterns skewed toward specific communities. When fed into predictive models, these biases are reproduced and amplified, perpetuating cycles of over-policing and stigmatization.

Such algorithmic bias is particularly dangerous because it can appear neutral and objective, cloaked in the legitimacy of data science, while in fact reinforcing structural injustice.

### **5.2.2 Lack of Transparency and Accountability in Algorithmic Decisions**

The opaque nature of many AI models—commonly referred to as the “black box” problem—presents a significant barrier to accountability. Law enforcement officers and affected individuals often lack the means to understand how AI systems arrive at their conclusions. Without explainability, it becomes difficult to question, appeal, or audit AI-generated decisions, undermining both administrative fairness and legal due process.

This lack of transparency also weakens public oversight, as civil society, media, and legal institutions are unable to meaningfully scrutinize the use and impact of algorithmic tools in policing.

## **5.3 Challenges to Procedural Legitimacy and Rule of Law**

### **5.3.1 Legality of Evidence Collection via AI Technologies**

When AI systems are used to collect evidence—such as through facial recognition, license plate tracking, or digital footprint analysis—it raises serious questions about the legality and admissibility of such evidence in judicial proceedings. If data is acquired without proper authorization, procedural safeguards, or judicial warrants, it may be deemed inadmissible and could violate the rights of the accused.

The absence of standardized protocols for AI-assisted evidence collection risks creating a gray area where technologically enabled surveillance circumvents existing legal requirements.

### **5.3.2 Over-Reliance on Technology and the Erosion of Human Judgment**

Another concern is the growing dependence of law enforcement officers on automated systems. While AI can support decision-making, it should not replace human judgment, especially in complex or ambiguous cases. The “automation bias”—a cognitive tendency to over-trust machine outputs—can lead to uncritical acceptance of flawed recommendations and diminish the role of discretion, empathy, and contextual understanding in policing.

The delegation of authority from humans to machines, without adequate checks and balances, risks hollowing out the procedural protections that form the cornerstone of a fair and just legal system.

## **5.4 Blurring Boundaries of Police Power and Public Trust Deficit**

### **5.4.1 Expansion of Surveillance Powers Without Legal Mandate**

AI technologies have the potential to significantly expand the reach of police authority, often without corresponding updates in legal frameworks. For instance, behavior-tracking algorithms, cross-platform data integration, and real-time profiling tools can be used to create “risk lists” or monitor individuals without their knowledge or consent. When such practices are deployed without explicit legal authorization, they amount to a de facto expansion of state power, eroding the principle of

legality and the democratic accountability of law enforcement.

This uncontrolled expansion poses long-term threats to civil liberties and can foster a culture of pre-emptive policing that undermines the presumption of innocence.

#### **5.4.2 Legally Permissible but Substantively Unjust Practices**

Even when technically legal, certain AI-enabled practices may violate the spirit of fairness, equality, and nondiscrimination. Systems that automatically categorize individuals based on data-driven assumptions—such as predicting future criminality based on socioeconomic status or past associations—can result in discriminatory treatment without due cause.

Such practices reveal a troubling gap between formal legality and substantive justice. They highlight the risk of relying on “technologically rational” but socially harmful solutions that undermine public confidence in law enforcement institutions.

In summary, the adoption of AI in policing brings forth a dual-edged transformation. On one hand, it enhances the capability and responsiveness of law enforcement. On the other, it introduces systemic vulnerabilities that, if left unaddressed, may compromise the very principles of legality, accountability, and justice that underpin the rule of law. Effective governance of AI policing must therefore begin with a clear-eyed understanding of these risks—and a commitment to mitigating them through robust institutional design.

### **6. Suggestion For Institutional Pathways for Risk Governance in AI-Driven Policing**

Addressing the risks associated with artificial intelligence in policing requires more than technical refinements—it demands the construction of a robust, multi-dimensional governance framework. Such a framework must align technological innovation with the principles of legality, accountability, transparency, and human dignity. This section outlines institutional strategies across four key dimensions: legal regulation, algorithmic oversight, participatory accountability, and ethical capacity-building (European Commission, 2021).

#### **6.1 Strengthening Legal and Regulatory Foundations**

##### **6.1.1 Enacting Specialized Legislation or Technical Guidelines**

Currently, China lacks a comprehensive legal framework specifically tailored to the governance of AI in law enforcement. Although general laws such as the Criminal Procedure Law, Data Security Law, and Personal Information Protection Law provide partial coverage, they do not adequately address the complex challenges posed by AI applications in policing.

To close this regulatory gap, there is a pressing need to develop either specialized legislation or authoritative technical guidelines that clearly delineate the scope, procedures, and limits of AI use in policing. Such instruments should define permissible use cases, establish approval and review processes for high-risk systems, and require ongoing evaluation of their legal compliance and social impact.

##### **6.1.2 Clarifying the Boundaries of Data Collection, Use, and Sharing**

A central element of effective governance is the clear articulation of boundaries for data processing activities. Legal instruments should enforce the principle of “minimum necessary use,” limit the scope of personal data collected, and impose strict conditions on data sharing across agencies or platforms.

Furthermore, citizens should be granted enforceable rights to access, correct, and delete their personal data held within policing systems. These measures will help shift AI policing away from opaque mass surveillance models and toward a more transparent, accountable, and rights-respecting paradigm.

#### **6.2 Enhancing Algorithmic Oversight and Technical Safeguards**

##### **6.2.1 Establishing Mechanisms for Algorithmic Explainability and Auditing**

To address the “black box” nature of AI systems, institutions must implement algorithmic explainability requirements, especially for high-stakes applications such as facial recognition, risk scoring, and predictive policing. These requirements should include:

- Mandatory documentation of model logic and training datasets
- Ex ante testing of algorithmic fairness, accuracy, and bias
- Development of user-friendly interfaces that allow officers and affected individuals to understand system outputs
- Logging of decision-making trails for retrospective auditing

Transparent algorithms are not only more accountable but also foster public trust and reduce the risk of unlawful outcomes.

### **6.2.2 Introducing Independent Audits and Ethical Review Procedures**

Technical safeguards alone are insufficient without institutional checks. Independent third-party audits and ethical review boards should be established to evaluate AI policing tools before and after deployment. These bodies—comprising legal experts, technologists, civil society representatives, and ethicists—should assess the necessity, proportionality, and societal impact of proposed systems.

Such procedures can prevent function creep, identify unintended consequences, and offer an external check on internal police decision-making processes, thereby improving legitimacy and governance quality.

## **6.3 Fostering Multi-Stakeholder Participation and Accountability**

### **6.3.1 Expanding the Right to Know and Appeal**

AI policing systems must be subject to mechanisms that ensure public transparency. Authorities should disclose:

- The types of AI systems in use
- The purposes of their deployment
- The categories of data collected
- The decision-making criteria applied

Moreover, individuals should be able to file appeals if they believe they have been unfairly targeted or misclassified by an AI system. Establishing administrative complaint channels, legal remedies, and public reporting systems will strengthen citizen oversight and institutional integrity.

### **6.3.2 Appointing Independent Data Protection Officers**

Drawing inspiration from the European Union's General Data Protection Regulation (GDPR), Chinese law enforcement institutions could benefit from appointing dedicated Data Protection Officers (DPOs). These officers, independent of operational command structures, would be tasked with:

- Monitoring data processing compliance
- Evaluating algorithmic systems for risk and fairness
- Coordinating responses to public complaints and data breaches
- Liaising with external regulators and oversight bodies

Institutionalizing this role would create a firewall between technological ambition and regulatory responsibility.

## **6.4 Promoting Ethical Awareness and Human-Centered Training**

### **6.4.1 Building AI Literacy Among Law Enforcement Personnel**

The misuse of AI systems is often rooted not in malice, but in misunderstanding. As such, police officers must be trained not only in how to operate AI tools but also in how to interpret their outputs critically. Training programs should emphasize:

- The limitations and uncertainties of AI recommendations
- The importance of corroborating automated outputs with contextual analysis
- The legal responsibilities attached to AI-assisted decisions
- Recognizing and mitigating automation bias

A more informed law enforcement community is key to responsible AI adoption.

### **6.4.2 Integrating Ethical Reasoning and Public Values**

AI systems are not value-neutral. Their use in public security must reflect ethical considerations such as dignity, fairness, and non-discrimination. Accordingly, police ethics education should include modules on digital ethics, algorithmic justice, and human rights.

Moreover, the institutional culture of law enforcement should shift from “techno-centrism” to “human-centered governance,” where technological tools serve—not substitute—principled judgment and community trust.

In conclusion, effective governance of AI in policing requires a comprehensive institutional design that blends legal authority with social legitimacy and ethical responsibility. Only through a holistic approach can the state fully harness the benefits of intelligent law enforcement while safeguarding the foundational values of justice, accountability, and public trust.



## 7. Conclusion and Future Prospects

### 7.1 Summary of Key Findings

Artificial intelligence has emerged as a transformative force in the modernization of policing, offering powerful tools to enhance surveillance, improve decision-making, and optimize public safety operations. Through facial recognition, predictive analytics, and intelligent coordination systems, AI has significantly expanded the capabilities of law enforcement agencies.

However, the study finds that this transformation is accompanied by profound legal, technical, and ethical risks. These include violations of privacy rights, algorithmic discrimination, lack of procedural safeguards, and the unchecked expansion of police power. Crucially, these are not marginal issues—they stem from the structural logic of data-driven governance and must be addressed through a coherent and principled framework.

This paper proposes a multi-dimensional governance strategy that includes:

- Establishing specialized legal and regulatory frameworks for AI in policing
- Requiring algorithmic transparency and independent oversight
- Enabling public participation and rights-based remedies
- Promoting ethical reasoning and responsible use of technology within law enforcement

Only by aligning smart policing with the foundational principles of legality, fairness, and public accountability can the benefits of AI be fully realized without compromising civil liberties.

### 7.2 Future Prospects

#### 7.2.1 Synchronizing AI Governance with Policing Practice

The future of AI in law enforcement hinges on the ability to integrate advanced technology with institutional safeguards. China must accelerate the development of a coherent AI governance regime that addresses the specific challenges posed by policing applications. This requires collaboration across legislative bodies, law enforcement agencies, technologists, ethicists, and civil society actors.

Smart policing should be seen not merely as a technological project but as a governance challenge. Embedding algorithmic accountability, data transparency, and human rights protections into the design and operation of AI systems will ensure that technology remains a tool for justice—not a threat to it.

#### 7.2.2 Promoting International Norms and Cross-Border Collaboration

As AI technologies transcend national boundaries, so too must the regulatory and ethical frameworks that govern them. China should actively engage in international dialogue and help shape global standards for responsible AI use in public security. This includes participating in the development of shared ethical codes, cross-border data governance protocols, and multilateral accountability mechanisms.

In the long term, international cooperation will be vital to addressing issues such as surveillance overreach, AI-driven discrimination, and cyber vulnerabilities. Global consensus on these matters will contribute to a more secure, just, and trustworthy digital order.

### 7.3 Final Remarks

The rise of artificial intelligence in policing presents both opportunity and peril. If used responsibly, AI can revolutionize public safety, strengthen rule-of-law institutions, and enhance trust between the state and society. If misused or left unregulated, it can erode rights, entrench inequality, and undermine democratic governance.

The task ahead is to ensure that AI serves not only the goal of efficient policing but also the higher ideals of justice, transparency, and human dignity. Through deliberate policy choices and thoughtful institutional design, societies can shape the future of AI-driven policing in ways that are both innovative and just.

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# Coupling Relationship Between Land Use Changes and Surface Thermal Environment in China's Three Major Urban Agglomerations

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**Abstract:** This study focuses on China's three major urban agglomerations—Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta. Based on a review of literature data, it examines the spatial and temporal patterns of urban and agricultural land use changes from 2005 to 2024, as well as their impacts on the surface heat environment. The results show that urban land has continued to expand significantly across all three regions, while agricultural land has declined sharply. As a result, the urban heat island effect has become increasingly severe. Urban land contributes much more to surface temperature rise compared to agricultural land. There are clear differences among the three city clusters in terms of land use structure and the evolution of their heat environments. The main driving forces behind these differences include rapid urbanization, industrial restructuring, population growth, and the lack of effective land use planning. This study provides theoretical support for better understanding the coupling relationship between urban land use and the ecological environment system. It also offers useful insights into urban land management and strategies to mitigate heat-related environmental impacts.

**Keywords:** Three Major Urban Agglomerations; Surface Thermal Environment; Land Use Change; Urban Heat Island Effect

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## 1.Introduction

In recent years, with the rapid and sustained growth of China's economy, the urbanization process has accelerated significantly, leading to continuous expansion of urban construction and a growing demand for urban land. Land use change is not only a spatial manifestation of urban development but also reflects the complex coupling relationship among industrial restructuring, population migration, and socio-economic dynamics (Ge et al., 2022). As one of the most populous developing countries, China is experiencing large-scale population concentration in urban areas, especially in its three major urban agglomerations: Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta. This trend has greatly intensified the pressure on urban land resources, resulting in a continued decline in per capita arable land and triggering a series of environmental issues, such as resource depletion, ecological degradation, and pollution (Seifollahi Aghmiuni et al., 2022; Wassie, 2020).

To ease land resource pressures and enhance ecological carrying capacity, the Chinese government has introduced ecological restoration policies such as returning farmland to forests and converting farmland to lakes. These policies aim to

balance urban development with environmental protection and promote sustainable land use. However, despite some early achievements in ecological conservation, current urban land development still faces challenges, including insufficient land-use intensification and poorly planned spatial layouts. Problems such as land waste, inefficient use, mixed land functions, and urban sprawl remain widespread (Awuah & Abdulai, 2022; Frederic Deng & Huang, 2004). Meanwhile, the surface cover changes caused by urban land expansion have intensified the urban heat island (UHI) effect, worsened air pollution, and increased pressure on water resources, further threatening the stability and resilience of urban ecosystems (Zhou & Chen, 2018).

In response to these challenges, national policies such as the “National Territorial Spatial Planning Outline” and the “Three Plans Integration” initiative have emphasized the need to optimize urban land use structures, improve land-use efficiency, address land supply-demand imbalances, and establish a development model that is resource-efficient and environmentally friendly. Against this policy backdrop, analyzing the spatial-temporal evolution of urban land use and its coupling with the surface thermal environment has become a key research direction to support high-quality urban development and ecological civilization.

This study focuses on China’s three major urban clusters and systematically reviews and integrates relevant research findings. Drawing on processed remote sensing imagery, land surface temperature (LST) retrieval data, and GIS-based spatial pattern analysis, it conducts a spatial-temporal comparative study of urban land expansion and thermal environment change. By summarizing key indicators such as urban heat island intensity (UHI), land use intensity (LUI), and spatial structure characteristics from representative studies, the research explores the evolution paths of land use structures at different development stages and their impacts on urban thermal patterns. Existing studies have shown that excessive expansion of construction land is the main driver of the intensifying UHI effect, while the reduction of ecological spaces such as green areas and water bodies has significantly weakened the regulating capacity of urban environments (Huang et al., 2019).

The primary aim of this study is to provide scientific evidence for improving the efficiency of urban land resource allocation and promoting coordinated development within urban agglomerations. By deeply analyzing the coupling mechanisms between land use structure and the thermal environment, this research contributes to building a resource-efficient and ecologically friendly territorial development pattern. Ultimately, it seeks to shift China’s urban development model from quantitative expansion toward qualitative improvement, facilitating a balance between economic growth and ecological protection and promoting the sustainable use of land resources.

## 2.Literature Review

With the accelerating pace of urbanization, the spatial pattern of urban land use and its impact on the ecological environment—particularly the urban thermal environment—has become a key research focus in urban geography and spatial planning. Existing studies mainly concentrate on the spatial distribution of urban land expansion, the coupling relationship between land use structure and the thermal environment, and the influence of land use intensity on urban sustainability (Xiao et al., 2024; Li et al., 2020).

Some scholars have pointed out that the characteristics of urban land use, the distribution of functional zones, and the evolution of land use structure significantly shape urban spatial patterns and determine ecological responses (Deng et al., 2009). Research on China’s three major urban agglomerations has found that cities within each cluster differ markedly in land use efficiency, expansion modes, and spatial organization. These differences lead to varying spatial patterns of urban thermal environments (He et al., 2019).

With advances in remote sensing and GIS technologies, the spatial and temporal evolution of urban land use can now be described with greater precision. Many studies use remotely sensed land surface temperature (LST), normalized difference vegetation index (NDVI), and other indicators, combined with time-series data, to analyze the dynamic relationship between urban heat island (UHI) effects and land use. For example, Liu et al. (2021) used multi-temporal satellite imagery to reveal a strong coupling between land use change and heat environment in the Pearl River Delta, identifying continuous expansion of built-up land as the primary driver of UHI intensification. At the same time, indicators such as land use intensity, spatial clustering, and landscape pattern indices have been widely applied to assess the efficiency and ecological impacts of land use

(Weinstoerffer & Girardin, 2000). Other studies have also found that urban heat environments are influenced not only by land use types but also by socioeconomic factors such as road density and population distribution (Sun et al., 2018).

In addition, from the perspective of temporal evolution, some research has used high-resolution remote sensing data to construct long-term time series, analyzing the pathways and trends of land use pattern changes. These efforts have provided data support and modeling foundations for predicting future urban development and evaluating the effectiveness of heat environment improvements (Ye et al., 2022).

Overall, current research on the spatial patterns of urban land use and thermal environments is becoming more sophisticated. The methods are increasingly diverse, shifting from static distribution analysis to dynamic evolution studies, and from quantitative description to mechanism exploration. These advancements offer important theoretical insights and practical guidance for optimizing land resource allocation, improving spatial structure, and enhancing urban environmental quality.

### **3.Characteristics of Urban and Agricultural Land Use Changes in the Three Major Urban Agglomerations**

#### **3.1 Temporal and Spatial Trends of Urban and Agricultural Land Use**

From a spatial and temporal perspective, urban land in major cities across mainland China showed a general trend of expansion between 2005 and 2014, although the rate of increase varied considerably. Among these, the three major urban agglomerations—Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta—experienced significantly faster urban land expansion compared to other regions. Urban boundaries continued to shift outward, and the trend of urban sprawl became more pronounced (Liu et al., 2024).

Second, in terms of land use change, urban construction land underwent a period of fluctuation between 2006 and the end of 2008. During this time, urban land area first declined slightly and then increased rapidly. This pattern was likely influenced by several factors, including national policies on real estate market regulation, industrial restructuring, and changes in land management policies (Zou et al., 2022). Overall, both urban and agricultural land in the three major city clusters showed an upward trend during this period. However, urban expansion primarily encroached upon low-efficiency agricultural land, leading to changes in agricultural land structure and the gradual marginalization of agricultural space (Wang et al., 2024).

Third, the urban heat island (UHI) effect also showed a clear upward trend from 2007 to the end of 2014. Surface temperatures in urban areas increased year by year, especially in densely built-up zones, where UHI intensity rose significantly (Chang et al., 2020). This trend is closely linked to the growth of impervious surfaces, the reduction of green spaces, and rising population density. As a result, the UHI effect has become one of the major ecological challenges to sustainable urban development (Liu et al., 2017).

Fourth, regarding the spatial and temporal characteristics of the thermal environment, the three major city clusters generally exhibited a warming trend from 2005 to 2014. The thermal environment showed strong spatial clustering, with significantly higher temperatures in central urban areas compared to suburban zones. Some studies have pointed out that during this period, climate warming combined with rapid urban expansion led to a cumulative heating effect across regions (Yu et al., 2019).

More recent studies have shown that from 2015 to 2023, urban construction land continued to expand, while agricultural land faced dual pressures from structural adjustment and spatial reduction (Chen et al., 2024). At the same time, UHI intensity increased more rapidly in the Yangtze River Delta and the Pearl River Delta. In contrast, the Beijing-Tianjin-Hebei region experienced a slower rise in urban heat due to policy regulations and the implementation of ecological restoration projects.

#### **3.2 Patterns of Urban and Agricultural Land Use**

Analysis of land use change rates and trends in climatic factors such as temperature and precipitation indicates that as of 2016, the three major urban agglomerations still exhibited inefficiencies in land resource allocation. Agricultural land was continually compressed, while urban land continued to expand. A marked shift in land use was observed—from traditional cropland to non-agricultural purposes, especially in sectors like services, transportation and logistics, and real estate development (Fu et al., 2022).

Driven by rising economic development and expanding urban populations, the growth of newly constructed land was largely

influenced by industrial restructuring and population migration. Functional zones related to the tertiary sector—such as real estate, wholesale and retail, and logistics hubs—proliferated, becoming key directions of urban expansion (Hesse, 2016). In this process, a significant amount of agricultural land was converted into urban construction land. Agricultural production spaces have become increasingly marginalized and compressed. However, agricultural land use is also evolving toward larger-scale, more intensive practices, emphasizing efficiency (Shi et al., 2016).

On the downside, the adjustment of urban spatial structure and the increase in impervious surfaces have led to higher surface runoff coefficients, reduced rainwater infiltration capacity, and more frequent flood events. The expansion of impervious areas prevents rainwater from naturally percolating into the soil. Instead, it is rapidly channeled into water bodies, causing a rise in surface water pollutant concentrations, particularly nitrogen, phosphorus, and heavy metals (Sharma & Malaviya, 2021).

Additionally, in subtropical monsoon-influenced regions like the Yangtze River Delta and Pearl River Delta, heavy rainfall is frequent. However, increased UHI effects and a decrease in water surface coverage have introduced climatic instability, such as more frequent localized heavy rainfall events and concurrent urban flooding.

### 3.3 Driving Factors of Land Use Changes

The transformation of urban and agricultural land use in the three major urban agglomerations is driven by a complex interplay of factors, including policy, economic development, population dynamics, and ecological conditions. The main driving forces include:

#### (1) Unbalanced Urban Land Structure and Low Land Use Efficiency

Urban land structures remain suboptimal, characterized by low functional integration and fragmented spatial layouts. In northern China, arable land is primarily dry farmland with relatively low agricultural proportions, while the south is dominated by paddy fields, orchards, and economic forests—resulting in a north-south imbalance in land function distribution. Suburban areas have become prime locations for urban expansion, with farmland often located along transportation corridors or near densely built-up zones, making it highly vulnerable to urban encroachment (Xie et al., 2023). Such imbalances lower land use efficiency and increase the risk of farmland degradation and conversion.

#### (2) Accelerated Urbanization Intensifying the Urban Heat Island Effect

Rapid urbanization has led to a dramatic increase in impervious surfaces and a decrease in vegetation cover, exacerbating the UHI effect. The intensity of UHI is closely correlated with land use changes, particularly the proportion of construction land, which has a significant positive relationship with rising surface temperatures (Tran et al., 2017). In addition, population clustering in city centers has worsened thermal inequality and heightened ecological stress in urban environments.

#### (3) Lack of Forward-Looking Urban Planning and Land Management

In some cities, short-sighted planning and uncontrolled expansion have failed to adequately consider urban boundaries, ecological red lines, or land carrying capacity. In pursuit of GDP growth, many cities have promoted large-scale expansion of real estate and industrial parks, leading to excessive farmland conversion, fragmentation of green spaces, and ecological degradation. Rapidly growing demand for transportation, housing, and public services has further intensified land development, exacerbating urban–rural spatial imbalances and supply-demand mismatches.

#### (4) Increasing Risk of Agricultural Non-Point Source Pollution

The intensification of modern agriculture has led to the overuse of fertilizers and pesticides, contributing to non-point source pollution and a decline in soil quality and sustainable farmland productivity. Urban expansion also causes reverse pollution of adjacent agricultural zones through the spread of heavy metals, domestic sewage, and construction waste, further shrinking agricultural ecological spaces and degrading land function (Yang et al., 2020).

#### (5) Limited Farmland Reserves and Declining Ecological Carrying Capacity

High land development intensity in urban agglomerations has depleted high-quality farmland resources, and the potential for reserve land development is increasingly constrained. Meanwhile, industrialization-related pollution of water and soil has made it more difficult to develop new farmland, resulting in a continued decline in per capita arable land area.

## 4. Evaluation of Surface Thermal Environment Effects in the Three Major Urban Agglomerations



## 4.1 Influencing Factors of the Urban Surface Thermal Environment

The urban surface thermal environment is driven by a complex interplay of both natural and anthropogenic factors. With the advancement of remote sensing and GIS technologies, significant progress has been made in quantitatively identifying and assessing these influencing factors. Based on the Anthropogenic Impact on Climate Index (AICI) and national standards such as the Code for Urban Ecological Planning, the primary factors influencing the surface thermal environment in China's three major urban agglomerations can be summarized as follows:

### (1) Land Use Type and Surface Cover Change

Different land use types exert varying degrees of regulation on the thermal environment. Urban construction land, characterized by a high proportion of impervious surfaces, typically has low heat capacity and high thermal conductivity, which makes it prone to forming urban heat islands (UHIs). In contrast, agricultural land, forests, and water bodies exhibit stronger cooling and humidity-regulating functions (Tan et al., 2020).

### (2) Underlying Surface Characteristics and Microtopography

The thermal physical properties of underlying surfaces—such as heat capacity, thermal conductivity, and albedo—are significantly influenced by slope, aspect, and elevation. In peri-urban zones, the conversion of forests or farmland into impervious surfaces increases solar radiation absorption and contributes to localized high-temperature zones. Changes in biodiversity among different habitat types also affect microclimatic regulation, leading to spatial heterogeneity in surface temperatures (Hu et al., 2021).

### (3) Land Use Intensity and Spatial Layout

Land use intensity is closely related to spatial development density. Highly developed urban centers often exhibit a “core heat island” pattern, while less developed peripheral areas tend to remain cooler. Excessive concentration of urban development can obstruct ventilation corridors, impair airflow and heat dissipation, and thereby intensifying thermal accumulation (Guo et al., 2023). Furthermore, areas with low land use diversity are more likely to form thermal “hotspots” due to weaker climate regulation capacity.

### (4) Human Activity Intensity and Socioeconomic Drivers

High population density, energy consumption, and traffic frequency are all strongly associated with surface temperature variations. Urban cores with dense populations and developed transportation infrastructure generally record higher land surface temperatures than surrounding areas. Additional anthropogenic heat from industrial emissions, building energy use, and vehicle exhaust further exacerbates the urban heat island effect (Molina Gómez et al., 2022). A strong positive correlation exists between human activity frequency and the magnitude of surface temperature changes.

## 4.2 Spatial Patterns of Surface Thermal Environment Effects on the Three Major Urban Agglomerations

The spatial distribution of urban thermal environments is influenced not only by geographic and climatic conditions but also by land use structure, transportation infrastructure, urban landscape patterns, and industrial development (Chen et al., 2022).

### (1) Meteorological Conditions

Meteorological factors such as wind speed and solar radiation play a significant role in modulating the spatial pattern of surface temperature. High wind speeds promote ventilation and cooling, while low wind speeds and intense solar radiation contribute to UHI formation, especially in city centers. In the Beijing-Tianjin-Hebei (BTH) region, lower winter temperatures and higher wind speeds result in a relatively dispersed heat island pattern. In contrast, the Yangtze River Delta (YRD) and Pearl River Delta (PRD), characterized by humid climates and high urban density, exhibit more concentrated and intense UHI effects.

### (2) Density and Expansion of Transportation Infrastructure

The density of transport networks and the extent of paved surfaces are key determinants of urban thermal patterns. Roads, railways, and parking lots—composed predominantly of impervious materials—store heat efficiently and serve as major contributors to localized warming. Rapid expansion of transport infrastructure in urban and suburban areas has intensified regional UHI effects. In the YRD region in particular, thermal patches along major transportation corridors have become increasingly dense and spatially continuous.

### (3) Urban Landscape Configuration and Ecological Coverage

Urban green spaces and water bodies serve as essential buffers for mitigating surface temperature. The number, shape index, and connectivity of green space patches significantly influence the spatial configuration of thermal fields (Gao et al., 2022). When green spaces become fragmented or disconnected, their cooling effectiveness diminishes. In the PRD, due to the presence of a dense water network and well-developed ecological corridors, the boundaries of heat islands are more diffused, and heat hotspots exhibit non-uniform distributions.

### (4) Spatial Ring Structure of Urban Heat Islands

The three urban agglomerations exhibit a typical concentric-ring spatial pattern of heat distribution. Urban cores, characterized by intensive development, high building density, and low vegetation coverage, consistently show the highest surface temperatures. In contrast, suburban and rural transition zones experience milder thermal conditions.

### (5) Industrial Transformation and Underground Space Development

As the tertiary sector continues to grow, coordinated development of both above-ground and underground urban spaces—such as subways and underground malls—has altered the surface energy balance. Although large-scale underground development can alleviate surface land pressure, it may also modify heat flux transmission paths and raise local surface temperatures (Yang et al., 2022). Additionally, the relocation of industrial facilities and the clustering of service industries have shifted the spatial focus of UHIs toward specific functional zones, reshaping the regional thermal landscape.

## **5. Comparison of Thermal Environmental Effects between Urban and Agricultural Land**

### **5.1 Thermal Environmental Factors of Urban and Agricultural Land**

#### (1) Land Use Intensity and Human Activity Factors

Land use intensity increases significantly with higher population density, building density, and frequency of economic activities. Urban areas, characterized by dense residential, industrial, and transportation infrastructure, experience intense land development. The predominance of impervious surfaces significantly raises the heat capacity and thermal conductivity of the land surface, contributing to a pronounced urban heat island (UHI) effect. In contrast, agricultural land—comprising cropland, forest, and grassland—typically features higher vegetation cover, which promotes evapotranspiration and cooling, thereby mitigating surface temperature rise.

#### (2) Green Space Degradation and Ecosystem Weakening

Urban expansion has led to the conversion of vast areas of agricultural and forest land into built-up areas, reducing ecological green spaces and constraining urban ventilation corridors. This process weakens ecosystem regulatory functions. Although some former agricultural land is designated as urban green belts, these often lack ecological continuity and vegetation diversity, limiting their cooling effectiveness compared to natural farmland.

#### (3) Transportation Development and Thermal Load

The rapid growth in urban motor vehicle use has increased exhaust emissions and noise pollution, while also expanding land allocated for transportation. These changes significantly intensify urban thermal loads. Although agricultural regions are also experiencing mechanization and infrastructure development, their overall transportation density remains low, resulting in weaker thermal impacts.

#### (4) Thermal Regulation Role of Agricultural Land

Agricultural land, with its high vegetation coverage, soil moisture content, and lower development intensity, plays a vital role in regulating the thermal environment. Irrigated farmland, shelterbelts, and mosaic zones of cropland and forest can effectively reduce land surface temperature through evapotranspiration and shading. These areas serve as important “cool source zones” around urban agglomerations, buffering UHI effects (Hesslerová et al., 2019).

#### (5) Pollution Load and Land Degradation

Despite the ecological buffer functions of agricultural land, the excessive use of pesticides and fertilizers, as well as the intensification of livestock farming, has led to increasing non-point source pollution. In densely populated or industrial regions, agricultural soil degradation and ecosystem imbalance have become increasingly evident, potentially disrupting



surface energy balance and weakening the land's thermal regulatory capacity (Liou & Kar, 2014).

## 5.2 Spatiotemporal Evolution of Thermal Effects in Urban and Agricultural Land

The thermal environmental effects of urban and agricultural land exhibit clear spatiotemporal differences, reflecting changes in land use structure, regional economic development, human activity intensity, and natural geographic features. With accelerating urbanization, these two land types show markedly divergent patterns in surface temperature trends, heat accumulation, and energy exchange.

From a temporal perspective, urban land in China's three major city clusters has expanded rapidly since the early 21st century. As the scale of built-up areas grows, the proportion of impervious surfaces increases, leading to higher regional land surface temperatures and intensifying the UHI effect. Meanwhile, agricultural land has been increasingly marginalized and compressed. The declining area of farmland and forests—both of which play critical roles in thermal regulation—has weakened the overall buffering capacity of the thermal environment.

From a spatial perspective, eastern coastal clusters such as the Yangtze River Delta and Pearl River Delta demonstrate stronger thermal effects due to high construction density and economic vitality (Li, Han, et al., 2020). In contrast, central city clusters, like the Central Plains urban agglomeration, although undergoing rapid expansion, generally retain thermal conditions consistent with the warm temperate and semi-humid to semi-arid zones, leading to relatively milder changes in thermal environments (Pan et al., 2023).

Regionally, cities in the north and northwest, such as those in the Beijing-Tianjin-Hebei region, display distinct thermal evolution patterns. Northwestern areas, characterized by low elevation and arid climates, show large seasonal fluctuations in land surface temperature, especially during winter and spring when diurnal temperature ranges are extreme. In contrast, northeast and north China experience colder winters, but their summer UHI effects remain notable, resulting in complex spatiotemporal coupling of thermal dynamics.

In summary, urban land—with its high construction density and low ecological coverage—generates strong heat accumulation and increasingly pronounced thermal effects. Agricultural land, by contrast, offers strong thermal buffering through vegetation and ecological function. However, in urban-rural fringe zones, agricultural land is also gradually showing signs of “thermal urbanization,” making it a critical transitional zone requiring close attention.

## 5.3 Mechanisms Driving Thermal Environmental Effects of Urban and Agricultural Land

The thermal environmental effects of urban and agricultural land are driven by a combination of meteorological conditions, topography, human activities, and land cover changes. Coupled analyses of land use/land cover change (LUCC) and regional meteorological data reveal that rising air temperature is a key factor in intensifying surface thermal conditions. With continued urbanization, the proportion of impervious surfaces—such as roads and buildings—increases, enhancing the land's heat capacity and thermal conductivity, which in turn raises near-surface temperatures and exacerbates the UHI effect.

First, rising temperatures increase thermal pressure. High temperatures lower average surface humidity and weaken evapotranspiration, constraining vegetation growth and accelerating land degradation. This is especially evident in urban cores, which develop concentrated “hot spots” with reduced ecological regulation capacity (Li et al., 2019). While agricultural land can buffer these effects through strong evapotranspiration and vegetation coverage, its thermal regulation capacity declines under intensive human disturbance.

Second, transportation infrastructure and urban expansion further contribute to thermal differentiation. Higher road and network density disrupts surface energy balances, increases heat accumulation, and impedes natural airflow, reducing wind-driven cooling. At the same time, the rise in building density and vertical development intensifies heat aggregation, creating more uneven spatial heat distributions (He et al., 2025).

Third, topography and regional climate modulate the spatial heterogeneity of thermal effects. China's varied terrain and significant north-south temperature gradients amplify this effect. In winter, northern cities often experience thermal inversions and stagnant air conditions, leading to pollution buildup and heat retention—what is known as a “winter-type cold heat island.” In summer, however, southern cities, despite high land surface temperatures, benefit from high humidity and rainfall, which partially alleviates thermal stress through water vapor exchange. Seasonal and spatial variations in precipitation also

influence soil moisture and surface energy distribution, further shaping regional thermal environments.

Ultimately, urban land systems are complex physical and chemical coupling networks involving surface materials, vegetation, water bodies, and the atmosphere. Their thermal effects are governed by solar radiation intensity, land surface structure, thermal properties of construction materials, and land cover ratios. While agricultural land has inherent thermal regulatory capacity, this too is challenged by agricultural restructuring and the urban-rural integration process, posing increasing threats to thermal environmental stability.

## 6. Conclusion

This study focuses on China's three major urban agglomerations, systematically analyzing the spatial distribution, thermal environmental effects, and evolution mechanisms of urban and agricultural land use. By integrating land use data, regional meteorological variables, and human activity intensity, it reveals the trends and regional disparities in thermal environmental changes driven by land spatial restructuring amid ongoing urbanization.

The findings indicate that the continuous expansion of urban land and the increasing proportion of impervious surfaces have become the primary drivers of surface thermal environmental changes. Although agricultural land retains strong ecological buffering capabilities, its ability to regulate thermal conditions is weakening due to intensified human disturbance and mounting pressure on arable land resources. Moreover, the spatial evolution of the urban heat island effect is closely linked to land use patterns, climatic conditions, topographical features, and landscape structures, reflecting a complex interplay of multiple factors.

This research highlights that differences in thermal environmental effects between urban and agricultural land are mainly influenced by irrational land use structures, unscientific urban planning, constraints on cultivated land, and ecological degradation. These factors jointly contribute to the spatial heterogeneity and temporal dynamics observed across the three city clusters.

The study provides theoretical support and decision-making references for optimizing land use and managing the thermal environment in China's urban agglomerations. However, future research should further advance in the areas of multi-scale spatial analysis, long-term series modeling, and the identification of compound driving mechanisms through empirical validation.

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# The Development of Low-Altitude Logistics and Smart City under the era of Digital Economy

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**Abstract:** The booming development of digital economy has injected new vitality into the transformation and upgrading of urban economies. In this context, low-altitude logistics and smart city construction have become hot topics in both academic and practical fields. Low-altitude logistics, as an important branch of smart logistics, has been widely researched and applied in practice. The paper aims to explore the collaborative development path between low-altitude logistics and smart city construction in the context of digital economy. By constructing a theoretical framework and discussing the applications of IoT technology in low-altitude logistics and smart city construction, the research results are expected to enrich and improve the theoretical system of smart city and low altitude logistics, providing new perspectives and ideas for research in related fields.

**Keywords:** Digital Economy; Low-Altitude Logistics; Smart City

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## 1.Introduction

As the digital economy is booming, smart cities are gradually emerging as a new urban development model around the world. With the help of advanced information and communication technologies, smart cities have achieved comprehensive improvements in urban management, public services and quality of life (Silva, Khan, and Han, 2018). Especially in the field of logistics, with the rapid development of intelligent technology, low-altitude logistics is becoming a new force in the construction of smart cities, injecting new vitality into modern urban logistics and distribution with its high efficiency and flexibility (Minaei, 2022).

With its powerful connection and data processing capabilities, the Internet of Things (IoT) technology plays a vital role in the construction of smart cities. Through IoT, various devices and systems can achieve efficient data interaction and information sharing, thereby greatly improving the level of intelligent urban management. In the field of low-altitude logistics, the application of IoT technology has promoted the innovation of logistics distribution (Huang, Fang, Wu, Wang, and Yang, 2024). With the help of advanced technologies such as drones and intelligent dispatching systems, low-altitude logistics not only improves distribution efficiency, but also greatly reduces logistics costs, providing more convenient and faster services for urban residents (Yao, An, He, Li, and Shan, 2022).

In recent years, more and more provinces and cities in China are beginning to regard the low-altitude economy as a new development focus. The Central Economic Work Conference also clearly proposed the need to create strategic emerging industries such as the low-altitude economy (Liu and Liu, 2025). Against this background, low-altitude logistics, as an important part of the low-altitude economy, has broad development prospects. The Central Financial and Economic



Commission also emphasized the need to optimize the logistics system and encourage the development of new logistics models that are combined with low-altitude economy, which provides strong policy support for the development of low-altitude logistics.

In the process of building smart cities, research on low-energy buildings and intelligent thermal energy circulation systems has also made significant progress (Ting, 2024). The studies not only help reduce urban energy consumption and improve energy efficiency, but also provide new ideas for the sustainable development of smart cities. Although these studies seem to have no direct connection with low-altitude logistics, they are actually important components of the grand framework of smart cities, and together they promote the intelligent and green development of cities (Lizana, Chacartegui, Barrios-Padura, and Ortiz, 2018; Ting, 2024).

Low-altitude logistics also faces many challenges in its development. Among them, the issue of low-altitude safety control is particularly prominent. How to ensure the safe flight of low-altitude aircraft such as drones and avoid collisions with buildings, other aircraft or ground obstacles is a key issue that must be solved in the development of low-altitude logistics. In this regard, relevant research have also being carried out in depth in order to provide strong guarantees for the safe and stable development of low-altitude logistics (e.g., Deng, Yang, and Peng, 2023; Zhang, Tian, Feng, Wu, and Zhong, 2023).

In the context of the digital economy, exploring the applications of intelligent technology in low-altitude logistics of smart cities is of great significance on multiple levels. From the perspective of smart city construction, low-altitude logistics can help improve the overall efficiency of urban operations with its efficient and intelligent operation mode. The introduction of intelligent technology enables low-altitude logistics to achieve more refined management in terms of route planning, real-time monitoring, and risk management, thereby promoting the pace of smart city construction (Huang, Fang, Wu, Wang, and Yang, 2024). Specifically, through IoT technology, low-altitude logistics system can perceive the city's traffic conditions in real time, dynamically adjust the delivery route, reduce traffic congestion and energy consumption, and provide more convenient and green logistics services for urban residents (Shee, Miah, and De Vass, 2021).

Accordingly, the paper will explore the applications of intelligent technology, especially the Internet of Things (IoT) technology, in the field of low-altitude logistics. The successful practice of low-altitude logistics will provide useful reference for other industries. Research on the applications of IoT technology in low-altitude logistics has far-reaching significance. It not only helps promote the construction and development of smart cities, but also optimizes the structure of the logistics industry, improves logistics efficiency, and provides new impetus and support for the development of digital economy.

In terms of research methods, the paper uses a combination of concept review and case analysis. Through the concept review, we can fully understand the latest research progress in the field of IoT technology and low-altitude logistics, laying a theoretical foundation for subsequent research. Case analysis enables us to analyze the actual application of IoT technology in low-altitude logistics in a specific and in-depth manner, and understand its operating mechanism and effect more intuitively.

Thus, the contributions of the paper is mainly reflected in the comprehensive and in-depth discussion of the applications of IoT technology in low-altitude logistics of smart cities in the era of digital economy. The paper first analyzes the profound impact of digital economy on the construction of smart cities and the development of the logistics industry, and reveals the internal logic and development laws behind. Second, it systematically explains the key role of intelligent network of IoT technology in low-altitude logistics, and demonstrates its strong application potential and actual effect. In addition, combined with typical cases, it objectively and comprehensively evaluates and summarizes the application effect of IoT technology in low-altitude logistics, providing valuable experience and inspiration for subsequent practice. Finally, innovatively suggestions and methods for optimizing low-altitude logistics operation are provided, aiming to provide useful reference for the development of low-altitude logistics in smart cities.

## **2.Digital Economy and Smart City Development**

### **2.1 Definition and development of digital economy**

Before delving into the impact of digital economy on the development of smart cities, the definition of digital economy and its importance shall be clarified. The digital economy is not only an economic form, but also a new social development trend (Williams, 2021). It is based on digital knowledge and information, and promotes profound changes in all areas of the

economy and society through continuous innovation in digital technology.

The rapid development of digital technologies, such as big data, cloud computing, and the Internet of Things, has provided strong technical support for the rise of digital economy. The integrated applications of the technologies has significantly improved the ability to collect, process and analyze data, thereby promoting the digital transformation of various industries (Javaid, Haleem, Singh, and Sinha, 2024). The digital economy is developing rapidly around the world and has become an important engine driving global economic growth. Driven by the digital economy, traditional industries have been deeply transformed and new industries have emerged (Su, Su, and Wang, 2021). This transformation has not only greatly improved production efficiency and reduced costs, but also brought consumers more abundant and diverse products and services.

More importantly, the development of the digital economy has had a profound impact on the construction of smart cities. As a new model of urban development, smart cities aim to improve the level of intelligent urban management, optimize urban resource allocation, and improve the quality of life of urban residents through the extensive application of information technology (Javed, Shahzad, ur Rehman, Zikria, Razzak, Jalil, and Xu, 2022). The digital economy can provide strong data support and technical guarantee for the construction of smart cities. Through the application of big data technology, smart cities can achieve real-time monitoring and prediction of urban operation status, providing a scientific basis for government decision-making. At the same time, the popularization of Internet of Things technology makes it possible to manage urban infrastructure intelligently, greatly improving the efficiency and convenience of urban management (Rejeb, Rejeb, Simske, Treiblmaier, and Zailani, 2022). In addition, the digital economy has also promoted the rapid development of smart transportation, smart medical care, smart education and other fields, providing more convenient and efficient services for urban residents.

## **2.2 Current status of smart city construction**

Smart cities are gradually realizing the intelligence, networking and refinement of various fields of cities with the help of cutting-edge technologies such as the Internet of Things, cloud computing, big data and Artificial Intelligence. At present, the construction of smart cities around the world has achieved a series of remarkable results, which not only improved the efficiency of urban management and the level of public services, but also injected new impetus into the urban economy.

In the process of building smart cities, various modern information technologies have been widely used. Internet of Things technology realizes the intelligent management of urban infrastructure by connecting various smart devices. Cloud computing technology provides cities with powerful data processing and storage capabilities, supporting the efficient operation of various smart applications (Alam, 2021). Big data technology reveals the laws and trends of urban operation through the mining and analysis of massive data, providing a scientific basis for decision-making (Olaniyi, Okunleye, and Olabanji, 2023). Artificial Intelligence technology plays an important role in the fields of smart transportation, smart security, and smart medical care, improving the city's intelligence level and service capabilities (Herath and Mittal, 2022). As a result, with the continuous advancement of technology and the continuous expansion of application scenarios, the construction of smart cities will present a broader development prospect. In the future, smart cities will realize more in-depth intelligent applications in the fields of energy management, environmental protection, and public safety, providing citizens with a more convenient, efficient and comfortable living environment. At the same time, the construction of smart cities will promote the development and innovation of related industries and inject new vitality into the sustained growth of the urban economy.

However, the construction of smart cities is not something that can be achieved overnight, but rather a process that requires long-term investment and continuous optimization. During the construction process, the joint efforts and collaboration of the government, enterprises, and all sectors of society are needed to ensure the smooth progress and sustainable development of smart city construction. In addition, with the continuous evolution of technology and the changing needs of citizens, the construction of smart cities also needs to be constantly adapted and adjusted to meet the actual needs of urban development and the expectations of citizens.

Smart city construction is becoming an important trend in global urban development. By using modern information technology to achieve intelligence, networking and refinement in all areas of the city, it will have a profound impact and change on urban development. In the future, with the continuous advancement of technology and the continuous expansion of

application scenarios, smart cities will bring more convenience and comfort to people's lives and become a new direction and new driving force for urban development. We should also note that in the process of building smart cities, data acquisition, processing and application are crucial links. The use of big data technology enables city managers to grasp the city's operating conditions in real time and predict future development trends, thereby making more scientific and reasonable decisions. This not only improves the efficiency of urban governance and the level of public services, but also brings more convenience and security to citizens' lives (Yan and Jie, 2025). The construction of smart cities has also promoted the development of related industries. For example, the research and development and production of IoT equipment, the provision of cloud computing services, the application of big data analysis, and Artificial Intelligence technology, have formed new industrial chains and injected new vitality into the development of urban economy. The development of the industries has not only created a large number of employment opportunities, but also driven the growth and transformation and upgrading of urban economy.

### **2.3 Impact of digital economy on the logistics industry**

Against the backdrop of the rapid development of digital economy, the logistics industry is undergoing unprecedented changes. The widespread application of digital technologies, especially the Internet of Things, big data, cloud computing and other intelligent Internet technologies, is reshaping the operation model and business processes of the logistics industry (Zhou, Ma, bin Samsurijan, and Xie, 2024).

The digital economy has promoted the digital transformation and upgrading of the logistics industry. The traditional logistics industry relies on manual operations and paper records, which are inefficient and prone to errors. The application of digital technology enables the logistics industry to realize the automation and real-time tracking of goods, improving the visibility and controllability of logistics. For example, through the Internet of Things technology, the location and status of goods can be monitored in real time to ensure that the goods arrive at the destination on time and safely (Ding, Jin, Li, and Feng, 2021). At the same time, big data technology can analyze and mine historical logistics data, helping logistics companies optimize warehousing management, distribution routes and transportation methods (Huang, Yao, Krisp, and Jiang, 2021), thereby improving logistics efficiency and reducing logistics costs.

The rise of the digital economy has also promoted innovation and development in the logistics industry. With the help of digital technology, the logistics industry continues to introduce new service models and product forms. For example, drone delivery, as an emerging delivery method, has the advantages of high efficiency, speed, and flexibility, especially in the "last mile" delivery in cities. Drone delivery can not only improve delivery efficiency, but also effectively alleviate urban traffic pressure and reduce environmental pollution (Manju, Pooja, and Dutt, 2021). In addition, smart warehousing is also one of the logistics innovations driven by digital economy. Through the application of Internet of Things and AI technologies, smart warehousing can realize automated management and optimized storage of goods, improving warehousing efficiency and space utilization (van Geest, Tekinerdogan, and Catal, 2021). The booming development of digital economy has also intensified competition and change in the logistics industry. In the era of digital economy, market competition in the logistics industry has become more intense, and logistics companies need to continuously innovate and improve service quality to adapt to changes in market demand. At the same time, the application of digital technology has also made the supervision of the logistics industry more complex and diversified. The government and relevant departments need to strengthen supervision to ensure the healthy development of the logistics industry.

The impact of digital economy on the logistics industry is multifaceted and far-reaching. It not only promotes the digital transformation and upgrading of the logistics industry, promotes the innovation and development of the logistics industry, but also intensifies the competition and change in the logistics industry. In the era of digital economy, the logistics industry needs to actively embrace digital technology, continuously innovate and improve service quality to adapt to changes in market demand and competitive pressure. At the same time, the government and relevant departments also need to strengthen supervision to ensure the healthy development of the logistics industry.

## **3.Applications of Internet of Things (IoT) Technology in Low-Altitude Logistics**

### **3.1 Overview of IoT Technology**

In the era of digital economy, low-altitude logistics, as an emerging logistics method, has achieved unprecedented efficiency

and accuracy thanks to the deep integration of Internet of Things (IoT) technology. The specific application of IoT technology in low-altitude logistics is mainly reflected in the following aspects.

(1) Real-time cargo tracking and monitoring

Through IoT technology, each piece of cargo can be assigned a unique identification code, and thus every link in the transportation process can be tracked and monitored in real time. This transparency not only enhances customers' trust in the logistics process, but also helps logistics companies to promptly identify and solve problems such as delays, loss or damage. In low-altitude logistics, especially drone delivery, real-time tracking technology ensures flight safety and on-time delivery of goods (Li, Zhang, and Lu, 2024).

(2) Intelligent warehouse management

Through big data analysis, IoT technology can predict the demand and flow patterns of goods, thereby optimizing the use of storage space. In low-altitude logistics, this means that inventory management at drone take-off and landing points, transfer stations, and final delivery points can be more intelligent, reducing the backlog and waste of goods. In addition, through technologies such as RFID (Radio Frequency Identification), the warehousing, storage, and outbound processes of goods can be automated, greatly improving efficiency (Geetha, Arunachalam, Deepikarani, and Shanmugam, 2023).

(3) Delivery route optimization

By leveraging intelligence technologies in IoT, low-altitude logistics can analyze traffic conditions, weather conditions, and customer needs in real time, thereby dynamically adjusting the delivery routes of drones. This optimization not only reduces transportation time and costs, but also improves service reliability and customer satisfaction (Zhang, Tian, Feng, Wu, and Zhong, 2023).

(4) Safety risk warning and prevention

Safety is always the primary concern in low-altitude logistics (Li, Zhang, and Lu, 2024). By integrating various sensors and monitoring systems, IoT technology can monitor the flight status, battery status and changes in the surrounding environment of the drone in real time, and promptly detect and warn of potential safety risks. At the same time, through real-time communication with the ground control system, it can respond quickly to ensure the safe completion of the flight mission.

(5) Customer service and feedback system

With the help of IoT technology, low-altitude logistics can establish a complete customer service and feedback system. Customers can check the transportation status of goods in real time through mobile applications or other digital platforms, and make service requests or complaints. This interactivity not only improves customer experience, but also helps logistics companies continuously improve and optimize service processes.

The applications of IoT technology in low-altitude logistics is comprehensive, which can not only improve logistics efficiency and reduce costs, but also greatly improve service quality and customer satisfaction. With the continuous advancement of technology and the expansion of application scenarios, IoT technology will play a more important role in the field of low-altitude logistics.

### 3.2 Application scenarios of IoT in low-altitude logistics

Driven by IoT technology, the field of low-altitude logistics is undergoing a profound transformation. IoT technology can provide new application scenarios and solutions for low-altitude logistics, enabling the logistics industry to operate more efficiently and intelligently.

As an outstanding representative of IoT technology in low-altitude logistics, drone delivery is gradually changing our daily lives. Imagine that in a busy city, a drone carries your package, flies lightly over high buildings, and accurately delivers the package to you. This delivery method is not only extremely fast, but also can effectively avoid ground traffic congestion, greatly improving delivery efficiency. At the same time, drone delivery also has the advantage of low cost, bringing tangible economic benefits to both logistics companies and consumers.

In addition to drone delivery, the IoT technology has also demonstrated its strength in warehouse management, cargo tracking, safety supervision and other aspects of low-altitude logistics. Through IoT technology, logistics companies can grasp the location and status of goods in real time to ensure the safety of goods during transportation. At the same time,

the application of big data enables logistics companies to accurately predict transportation needs, thereby optimizing transportation routes and distribution plans and improving logistics efficiency.

In actual applications, some advanced logistics companies have begun to try to apply IoT technology to the field of low-altitude logistics. They have achieved full monitoring and scheduling of drone delivery by building an intelligent logistics management system. The intelligent management method not only improves delivery efficiency, but also greatly reduces logistics costs. At the same time, in order to ensure the safety of drone delivery, the companies have also equipped drones with advanced safety equipment, such as anti-collision systems, and emergency landing systems, etc., to ensure timely response in emergency situations.

In general, the application scenarios of IoT technology in low-altitude logistics are extensive and in-depth. It has not only changed the traditional logistics distribution mode, but also brought unprecedented development opportunities to the logistics industry. With the continuous advancement of technology and the continuous expansion of application scenarios, we have reason to believe that IoT technology will play a more important role in the field of low-altitude logistics in the future.

### **3.3 Technical challenges and solutions for IoI applications**

In the era of digital economy, IoT technology has brought unprecedented opportunities for low-altitude logistics but is also accompanied by a series of technical challenges. The challenges mainly focus on the endurance, flight stability and safety of drones.

The endurance of drones is one of the most pressing issues to be addressed. Due to the limitations of battery technology, the flight time of drones is relatively short, which seriously restricts their application in the field of low-altitude logistics (Neveling, Götz, Zoghlami, Dominik, Babetto, and Stumpf, 2023). In order to overcome this problem, researchers are actively exploring new battery technologies, such as solid-state batteries and fuel cells, in order to improve the endurance of drones (Huang, Li, Ma, Huang, Zheng, and Song, 2024). In addition, by optimizing the aerodynamic design and flight control algorithm of drones, energy consumption can be reduced to a certain extent, thereby extending the flight time (Zhang, Zhao, Mao, Bai, Li, and Pavlova, 2024).

Flight stability is another important technical indicator of drones in low-altitude logistics. In complex urban environments, drones need to fly accurately and hover stably to ensure that the goods can be delivered accurately. To achieve this goal, researchers are using advanced sensors and control systems to improve the flight stability of drones. For example, by introducing technologies such as Inertial Measurement Units (IMUs), GPS, and visual sensors, drones can more accurately perceive their own position and posture, thereby achieving more stable flight (Watts, Perry, Smith, Burgess, Wilkinson, Szantoi, and Percival, 2010; Xu, Liao, Tan, Ye, and Lu, 2020).

Safety is another key factor that must be considered when applying IoT technology in low-altitude logistics. UAVs may encounter various emergencies during flight, such as bad weather and electromagnetic interference, which may pose a threat to the safe flight of UAVs. In order to ensure safety, on the one hand, it is necessary to strengthen the supervision and management of UAVs and formulate strict safety standards and flight specifications (Teng, Wang, Wang, and Yao, 2024). On the other hand, it is also necessary to use technical means to improve the autonomous obstacle avoidance and emergency handling capabilities of UAVs. For example, machine vision and deep learning technologies can be used to identify and avoid obstacles, and the fault tolerance of UAVs can also be improved by designing redundant systems (Mittal, Singh, and Sharma, 2020).

In response to the technical challenges, specific solutions can be adopted. First, strengthening the research and development of drone technology is the key. By investing more in the research and development of battery and flight control technologies, the performance of drones can be continuously improved. Second, it is also crucial to establish a sound drone safety supervision system. This includes formulating detailed flight specifications, setting up special regulatory agencies, and establishing emergency response mechanisms. Finally, strengthening the integrated applications of technology and low-altitude logistics is also an important way to promote the development of the industry. By deepening technology applications, optimizing logistics processes, and improving service quality, the market space for low-altitude logistics can be expanded and its competitiveness can be enhanced.



## **4. Low-altitude logistics operation strategies**

### **4.1 Operation model of low-altitude logistics**

As an important part of smart city logistics system, the choice of operation model of low-altitude logistics is directly related to logistics efficiency, cost and customer satisfaction. Drone delivery, with its unique advantages, occupies a pivotal position in the field of low-altitude logistics. This delivery method uses drones to deliver goods quickly and accurately, which not only effectively shortens the delivery time, but also greatly reduces logistics costs. At the same time, drone delivery shows extremely high adaptability and flexibility in dealing with complex terrain and adverse weather conditions, which effectively solves the “last mile” delivery problem. However, drone delivery is not a panacea. When faced with the need to deliver large or urgent goods, helicopter delivery shows its irreplaceable advantages. Helicopters have greater load-carrying capacity and stronger flight stability, and can quickly deliver important materials to their destinations. When responding to emergencies or making long-distance deliveries, the efficiency and reliability of helicopter delivery are fully demonstrated. In addition, the operation of low-altitude logistics is not static. In the actual operation process, factors such as the nature of the goods, delivery requirements, and external environment shall be comprehensively considered. For example, when delivering small and time-sensitive goods, drone delivery is the best choice; when dealing with large or urgent goods, helicopter delivery can play a greater role.

### **4.2 Strategy formulation for low-altitude logistics**

In the era of digital economy, low-altitude logistics is an important part of smart city logistics system, and its strategy formulation is particularly critical. In order to ensure the efficient, safe and sustainable development of low-altitude logistics, it is necessary to start from multiple dimensions and comprehensively consider various factors to formulate a scientific and reasonable strategy.

It is necessary to clarify the positioning of low-altitude logistics in smart cities. Low-altitude logistics should be regarded as an important supplement to the urban logistics system, focusing on solving the “last mile” distribution problem and improving logistics efficiency. By coordinating with traditional ground logistics, low-altitude logistics can give full play to its advantages of high speed and high flexibility to provide more convenient and efficient distribution services for urban residents.

Market demand and competition are important bases for developing low-altitude logistics strategies. We need to have a deep understanding of consumers’ demands for delivery speed, service quality and other aspects, as well as competitors’ service characteristics and pricing strategies. On this basis, we can develop competitive marketing strategies and service models by combining our own resource advantages and technical strengths. For example, we can develop in-depth cooperation with E-commerce platforms to provide customized delivery services to meet the increasingly diverse needs of consumers.

Safety supervision and the construction of laws and regulations are important links in the formulation of low-altitude logistics strategies. In order to ensure the safe operation of low-altitude logistics, a sound safety supervision system must be established to strictly control the quality and flight supervision of drones and other flight equipment. At the same time, the development of relevant national laws and regulations must be paid close attention. In the process of strategy formulation, how to reduce operating costs and improve operating efficiency to achieve sustainable development of low-altitude logistics shall also be fully considered.

In addition, low-altitude logistics strategies needs to focus on environmental protection and green development. In digital economy, green development has become a global consensus. Therefore, when formulating low-altitude logistics strategies, how to reduce energy consumption and emissions and promote low-altitude logistics shall be considered to develop a more environmentally friendly and sustainable industry.

### **4.3 Optimization of low-altitude logistics operation model**

In the era of digital economy, low-altitude logistics is an important part of smart cities, and the optimization of its operation model is particularly important. In order to achieve efficient, safe and sustainable development of low-altitude logistics, the optimization of operation model can be carried out from the following aspects.

First, technological research and development are the core of optimizing low-altitude logistics operation model. By



continuously investing in drone technology, the endurance and flight stability of drones can be significantly improved. This can not only expand the delivery range of drones, but also reduce cargo damage and safety accidents caused by unstable flight, thereby reducing operating costs. At the same time, the use of advanced positioning technology, sensor technology and communication technology can also achieve precision and intelligence in drone delivery, further improving delivery efficiency.

Second, establishing a sound distribution network and logistics system is the key to optimizing low-altitude logistics operation model. By building a widely covered, efficient and convenient distribution network, rapid diversion and timely delivery of goods can be achieved. In addition, strengthening the informatization of logistics system, and using big data, cloud computing and other technical means to process and analyze logistics information in real time can help companies better grasp logistics dynamics, optimize distribution routes, and improve distribution efficiency. By establishing a sound cargo tracking and supervision system, the safety and traceability of goods can also be ensured.

Strengthening cooperation and coordination with other logistics industries is also an important way to optimize low-altitude logistics. As an emerging logistics method, low-altitude logistics has unique advantages compared with traditional logistics methods. However, in the actual operation process, low-altitude logistics still needs to be effectively connected and coordinated with traditional logistics methods. By establishing close cooperative relations with E-commerce platforms and express delivery companies, resource sharing and complementary advantages can be achieved. In addition, actively participating in international exchanges and cooperation, learning from and absorbing international advanced experience of technological achievements, will help enhance the international competitiveness of low-altitude logistics.

Finally, strengthening talent training and team building is a strong guarantee for the optimization of low-altitude logistics operation mode. As a technology-intensive industry, low-altitude logistics has high requirements for talents. Therefore, enterprises need to attach importance to talent training, establish a sound talent training system, and cultivate high-quality talents with professional skills and innovative spirit. Thus, strengthening team building and building a team of unity, cooperation and efficient execution can provide a strong talent guarantee for the development of the enterprise.

## **5. Case analysis of IoT in Low-altitude Logistics: SingPost**

### **5.1 Background of SingPost**

As a world-renowned smart city, Singapore has been committed to promoting the deep integration of technology and urban management. In recent years, Singapore Post (SingPost) has collaborated with the technology startup, FLYTE, to explore the application of drone delivery in the postal field, and achieved remarkable results. Since the introduction of IoT technology, Singapore has achieved remarkable results in low-altitude logistics. First, the efficiency of logistics and distribution can be greatly improved. Compared with traditional delivery methods, drone delivery greatly shortens delivery time and can improve consumer satisfaction. Second, logistics costs can be effectively reduced. The application of IoT technology also reduces labor costs and vehicle usage costs, bringing tangible economic benefits to logistics companies.

Since Singapore introduced IoT technology, the field of low-altitude logistics has undergone tremendous changes. Take drone delivery as an example, through precise GPS positioning and advanced flight control systems, drones can accurately and quickly complete delivery tasks in complex urban environments. FLYTE provides its self-developed drone delivery system, which integrates advanced flight control systems, navigation systems and automatic obstacle avoidance technology to ensure the safe flight of drones in complex urban environments. This not only greatly improves the efficiency of logistics distribution and reduces labor costs, but also brings unprecedented convenience to consumers.

In terms of logistics management, Singapore's IoT technology enables real-time update and management of warehouse cargo information. Through IoT, each cargo is given a unique identification, making the processes of cargo entry, exit, and inventory simple and efficient. This not only reduces human errors, but also improves the operational efficiency of the warehouse. Singapore's SingPost also uses its existing logistics management system to integrate with FLYTE's drone delivery system to achieve intelligent scheduling and route planning for drone delivery. IoT technology also plays a crucial role in optimizing delivery routes. Through big data analysis and AI algorithms, the system can automatically plan the optimal delivery route, avoiding congestion and unnecessary detours, further improving the efficiency of logistics distribution.

In terms of logistics and transportation, the drone delivery in Singapore's "last mile" can effectively avoid ground traffic congestion, quickly deliver packages to the destination, and improve delivery efficiency. In addition, drone delivery can overcome the limitations of inconvenient ground transportation, deliver packages to remote areas, and expand the scope of logistics services. In emergency scenarios, drone delivery can also respond quickly to emergencies and deliver important materials to the destination in a timely manner.

In terms of safety supervision, Singapore has established a complete drone safety supervision system. Through IoT technology, regulatory authorities can monitor the flight status and trajectory of drones in real time to ensure that they comply with flight rules and airspace restrictions. The system can also remotely control and handle emergencies for drones to reduce the risk of flight accidents. In addition, IoT also helps regulatory authorities to conduct qualification review and flight plan approval for drone operating companies to ensure the standardization and safety of the low-altitude logistics market.

## 5.2 Lessons learned from the case

Through the case of low-altitude logistics in Singapore, we can obtain the following inspirations. First, we must keep pace with the digital era, actively introduce new technologies and new concepts, and promote innovation and development in the industry. Second, we must focus on the combination of technology and practice to ensure technology be truly implemented. Third, we must pay attention to the construction of industry standards and laws and regulations to provide strong guarantees for the standardized applications of technology.

Among them, policy support is the key. The Singapore government has provided a good policy environment for drone delivery, including support in airspace management and safety supervision. Technological innovation is the driving force. FLYTE's drone delivery technology and SingPost's intelligent dispatching platform are the key factors for the success, and Win-win cooperation is the model. The cooperation between SingPost and FLYTE thus provides a reference for other companies to promote the development of low-altitude logistics through complementary advantages.

In the future, with the continuous development and improvement of IoT technology, it is believed that the low-altitude logistics field will usher in broader development space and application prospects. The successful practice of Singapore will also provide useful reference and lessons for other cities.

## 5.3 Evaluation on the case

After the analysis of IoT applications in Singapore's low-altitude logistics, we then conduct a comprehensive evaluation on its effectiveness. The results show that the introduction of IoT has brought revolutionary changes to the field of low-altitude logistics.

From the perspective of efficiency, the applications of IoT technology has greatly improved the city's logistics and distribution efficiency. Through real-time cargo tracking and intelligent warehouse management, information asymmetry and delay problems in the logistics process have been effectively solved. In addition, the use of big data technology to optimize delivery routes has significantly reduced ineffective transportation and waiting time, thus shortening the cargo delivery time by nearly half. This change not only improves the operational efficiency of logistics companies, but also brings consumers a faster and more convenient service experience.

In terms of improving the intelligence level of warehouse management and cargo safety, IoT technology has also shown great potential. Through the applications of IoT technology, real-time monitoring and early warning of cargo status are achieved, greatly improving the safety of cargo during warehousing and transportation. At the same time, the intelligent warehouse management system effectively reduces the possibility of human operational errors and further ensures the safety of goods.

The successful practice of the case not only provides a useful reference for the development of low-altitude logistics for other smart cities, but also reveals the broad application prospects of IoT technology in the future. This practice fully proves that the deep integration of IoT technology and low-altitude logistics will be an important way to promote the construction of smart cities, optimize the structure of the logistics industry, and improve logistics efficiency.

# 6. Conclusions

## 6.1 Research summary

Through systematic analysis, the paper draws the following important conclusions. First, IoT technology has great application

potential in the field of low-altitude logistics. Through the integrated applications of other technology, IoT can realize intelligent management and optimization of the process of low-altitude logistics. This not only helps to improve logistics efficiency and reduce logistics costs, but also brings a more convenient and efficient service experience to the logistics industry. Furthermore, as an important part of smart cities, the development of low-altitude logistics is of great significance to promoting the process of urban intelligence. The applications of IoT technology has enabled the intelligence and automation of low-altitude logistics in terms of cargo distribution and warehouse management, further improving the overall efficiency of the urban logistics system.

The paper also demonstrates the specific application effects of IoT in low-altitude logistics through case study. The case of Singapore shows that the introduction of IoT technology has significantly improved logistics distribution efficiency and cargo safety, injecting new vitality into the development of the urban logistics industry. It also further proves the application value and broad prospects of IoT technology in the field of low-altitude logistics. However, the applications of IoT technology in low-altitude logistics still faces challenges and problems, which requires joint efforts and collaboration from the government, enterprises, scientific research institutions and other parties. It is also necessary to strengthen policy guidance and supervision to ensure the standardized, safe and efficient development of low-altitude logistics.

## 6.2 Future prospects

The applications of IoT in low-altitude logistics of smart cities in the era of digital economy has broad prospects and important practical significance. Therefore, we should further strengthen technological research and development, promote the applications of technology in the field of low-altitude logistics, and inject new impetus and vitality into the construction and development of smart cities. Among them, IoT technology will further enhance the automation and intelligence level of low-altitude logistics and achieve more efficient cargo distribution and warehousing management. For example, by integrating more advanced IoT and AI technology, real-time monitoring and prediction of goods as well as automated sorting and loading can be achieved, thereby greatly improving logistics efficiency. In addition, the operation model of low-altitude logistics will be more diversified and flexible. In addition to drone delivery, more low-altitude transportation tools, such as flying cars, may appear in the future for logistics delivery. With the improvement of urban air traffic management systems, route planning and flight safety of low-altitude logistics will be better guaranteed. The applications of IoT technology will also promote the deep integration of low-altitude logistics with other areas of smart cities. For example, through collaboration with intelligent transportation systems, smart grids and other fields, more efficient energy utilization and reduced carbon emissions can be achieved, promoting the green development of cities.

As the low-altitude logistics market continues to expand and competition intensifies, major logistics companies will pay more attention to service quality and customer experience. With the help of intelligent technology, logistics companies can accurately grasp and quickly respond to customer needs and provide more personalized and high-quality services.

In summary, the applications of IoT technology in low-altitude logistics has broad development prospects and huge potential. In the future, with the continuous advancement of technology and the continuous expansion of market, low-altitude logistics will become an important part of the development of smart cities, bringing more convenience and efficiency to people's lives. At the same time, governments, enterprises and research institutions should strengthen cooperation, jointly promote the innovation and applications of technology in low-altitude logistics, and contribute to the sustainable development of smart cities.

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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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# The Impact of Meaning in Life on Academic Self-Efficacy: The Moderating Role of Psychological Resilience

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**Abstract:** This study aims to investigate the impact of meaning in life on the academic self-efficacy of university students and the moderating role of resilience in this relationship. A questionnaire survey was conducted among 540 university students using the Meaning in Life Questionnaire, the Academic Self-Efficacy Scale for University Students, and the Resilience Scale. Data were analyzed using SPSS. The results showed that: (1) Meaning in life, resilience, and academic self-efficacy were all significantly positively correlated with each other ( $p_s < 0.001$ ); (2) Meaning in life significantly and positively predicted academic self-efficacy ( $\beta = 0.325$ ,  $t = 8.639$ ,  $p < 0.001$ ); (3) Resilience played a significant moderating role in the relationship between meaning in life and academic self-efficacy ( $B = -0.0023$ ,  $p < 0.05$ ). Specifically, for students with low resilience, the positive impact of meaning in life on academic self-efficacy was more pronounced, whereas this effect was weaker for students with high resilience. The findings suggest that enhancing students' meaning in life is an effective way to boost their academic confidence, and that meaning in life serves as a crucial compensatory protective factor, especially for students with lower levels of resilience.

**Keywords:** Meaning in Life; Academic Self-Efficacy; Resilience; Moderating Effect; University Students

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## 1. Introduction

A sense of meaning in life is considered a core human motivation, referring to an individual's perception of the purpose, comprehension, and value of their existence<sup>[1-3]</sup>. A substantial body of research has confirmed that a strong sense of meaning in life is a vital psychological capital that promotes individual well-being, stimulates positive coping strategies<sup>[4]</sup>, and provides sustained motivation for pursuing personally important goals<sup>[5]</sup>. For university students, their mental health, adaptability, and academic achievement are integral components of their overall development. Among these, academic self-efficacy—a student's belief in their ability to successfully achieve academic goals—is a key predictor of academic success, persistence, and positive adjustment to university life<sup>[6-9]</sup>. Therefore, exploring the deep-seated psychological factors that influence academic self-efficacy is of great significance for promoting students' healthy development and fostering a well-rounded personality. Recent research has extended the theory of meaning in life to the educational context, finding that when students derive a sense of meaning from their educational pursuits, their academic self-efficacy is significantly enhanced<sup>[6, 10]</sup>. This "existential" level of importance appears to be an effective way to inspire students' belief in their capacity to succeed academically.



However, university life is fraught with various pressures and challenges, and not all students can smoothly translate their perception of meaning in their studies into firm self-efficacy beliefs. In this process, resilience may play a crucial role. Resilience is defined as an individual's ability to maintain or quickly recover psychological functioning when faced with adversity or significant stress<sup>[11, 12]</sup>. It is an important protective factor that can buffer the negative impact of stress on mental health<sup>[13]</sup>. Research indicates that a sense of meaning in life is itself a significant resource that promotes resilience, with some studies even suggesting an "upward spiral" relationship where they mutually reinforce each other<sup>[4]</sup>. Concurrently, self-efficacy has been identified as a core characteristic of highly resilient individuals<sup>[14, 15]</sup>. Those with high resilience possess stronger self-efficacy beliefs and can cope with challenges more effectively<sup>[15]</sup>.

Based on the above theories and empirical evidence, this study posits that the relationship between meaning in life and academic self-efficacy is not uniform across all contexts but may be moderated by an individual's level of resilience. Students with high resilience may be better at utilizing their sense of meaning to fend off academic stress, thereby more effectively consolidating and enhancing their academic self-efficacy. Conversely, for students with weaker resilience, even if they recognize the importance of their studies, their inability to cope effectively with setbacks may prevent the sense of meaning from being successfully converted into stable academic self-efficacy beliefs. Therefore, this study proposes the following hypotheses:

H1: Meaning in life will significantly and positively predict students' academic self-efficacy.

H2: Resilience will moderate the relationship between meaning in life and academic self-efficacy.

## 2. Methods

### 2.1 Participants

Using convenience sampling, 540 students from a university were selected as participants. Before the survey, the principles of voluntary participation and anonymity were explained. The questionnaire was distributed and collected uniformly via an online platform. A total of 540 questionnaires were collected, all of which were valid, resulting in a 100% effective response rate. Among the participants, 269 were male (49.8%) and 271 were female (50.2%); 94 were only children (17.4%), and 446 were non-only children (82.6%).

### 2.2 Research Tools

#### 2.2.1 Meaning in Life Questionnaire

The Meaning in Life Questionnaire (MLQ) developed by Steger et al. (2006) was used<sup>[16]</sup>. The scale consists of 10 items and includes two dimensions: "Presence of Meaning" and "Search for Meaning." This study focused on the "Presence of Meaning" dimension, which comprises 5 items (e.g., "My life has a clear sense of purpose"). A 7-point Likert scale was used, ranging from 1 (Absolutely Untrue) to 7 (Absolutely True), with higher scores indicating a stronger sense of meaning in life.

#### 2.2.2 Academic Self-Efficacy Scale for University Students

The Academic Self-Efficacy Scale, adapted from Pintrich's scale and revised by Liang Yusong, was used<sup>[17]</sup>. The scale contains 22 items and includes two dimensions: "Efficacy for Academic Ability" and "Efficacy for Academic Behavior" (e.g., "I am confident I can master the course content"). A 5-point Likert scale was used, from 1 (Completely Disagree) to 5 (Completely Agree), with higher scores indicating greater academic self-efficacy. The Cronbach's alpha for this scale in the current study was 0.917.

#### 2.2.3 Resilience Scale

The Connor-Davidson Resilience Scale (CD-RISC) developed by Connor and Davidson (2003) was used<sup>[18]</sup>. The scale has 25 items designed to assess an individual's ability to cope with stress or adversity (e.g., "I am able to adapt to change"). It uses a 5-point Likert scale, from 0 (Not true at all) to 4 (True nearly all the time), with higher scores indicating a higher level of resilience. The Cronbach's alpha for this scale in the current study was 0.719.

### 2.3 Data Analysis

SPSS 26.0 was used for descriptive statistics and correlation analysis. The PROCESS macro (Model 1) was used to test the moderation effect.

### 3.Results

*Statistics of basic demography variables and comparison of differences between main variables (N=540)*

|                  |                | <i>N</i> | Meaning in Life      | Academic self-efficacy | Psychological resilience |
|------------------|----------------|----------|----------------------|------------------------|--------------------------|
|                  |                |          | <i>M</i> ± <i>SD</i> | <i>M</i> ± <i>SD</i>   | <i>M</i> ± <i>SD</i>     |
| gender           | Man            | 269      | 47.684±10.288        | 73.323±15.589          | 89.022±13.883            |
|                  | Woman          | 271      | 47.447±10.040        | 72.089±14.519          | 87.229±14.873            |
|                  | <i>t</i>       |          | 0.272                | 0.953                  | 1.448                    |
| Family formation | Only-child     | 94       | 48.309±12.335        | 75.713±15.904          | 89.223±15.181            |
|                  | Non-only child | 446      | 47.408±9.643         | 72.070±14.817          | 87.890±14.240            |
|                  | <i>t</i>       |          | 0.666                | 2.139                  | 0.815                    |

Note: \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ ; “p” is the probability, reflecting the probability of an event.

Table 1 reveals that there were no significant differences ( $ps > 0.05$ ) in meaning in Life, academic self-efficacy, and psychological resilience based on gender and family formation. However, a significant difference ( $p < 0.01$ ) was found in meaning in Life based on whether the participants were only children or not. Non-only children scored significantly higher in meaning in Life compared to only children.

#### 3.1 Correlation Analysis of Variables

A Pearson correlation analysis was conducted on meaning in life, academic self-efficacy, and resilience. As shown in Table 2, meaning in life was significantly positively correlated with academic self-efficacy ( $r = 0.452$ ,  $p < 0.001$ ) and resilience ( $r = 0.339$ ,  $p < 0.001$ ). Academic self-efficacy was also significantly positively correlated with resilience ( $r = 0.484$ ,  $p < 0.001$ ). These results indicate a close relationship among the three variables, providing a basis for the subsequent moderation analysis.

*Table 2 Correlation analysis of main variables (N=540)*

|                             | M±SD          | 1       | 2       | 3 |
|-----------------------------|---------------|---------|---------|---|
| 1. Meaning in Life          | 47.565±10.155 | 1       |         |   |
| 2. Academic self-efficacy   | 72.704±15.060 | 0.452** | 1       |   |
| 3. Psychological resilience | 88.122±14.403 | 0.339** | 0.484** | 1 |

Note: \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ ; “p” is the probability, reflecting the probability of an event.

Table 2 displays the correlation analysis among key variables (N=540). Significant correlations were found between meaning in Life ( $M = 47.565 \pm 10.155$ ), academic self-efficacy ( $M = 72.704 \pm 16.060$ ), and psychological resilience ( $M = 88.122 \pm 14.403$ ). Meaning in Life were significantly positively correlated with psychological resilience ( $r = 0.339$ ,  $p < 0.001$ ), The higher the sense of meaning in an individual’s life, the greater their psychological resilience. Academic self-efficacy was significantly positively correlated with psychological resilience ( $r = 0.484$ ,  $p < 0.001$ ), suggesting that higher levels of psychological resilience may significantly improve academic self-efficacy. Meaning in Life showed a highly significant positive correlation with academic self-efficacy ( $r = 0.452$ ,  $p < 0.001$ ), confirming Hypothesis 1.

#### 3.2 The Moderating Role of Resilience in the Relationship Between Meaning in Life and Academic Self-Efficacy

A moderation analysis was conducted with academic self-efficacy as the dependent variable, meaning in life as the independent variable, and resilience as the moderator, after controlling for gender and only-child status. As shown in Table 3, meaning in life significantly and positively predicted academic self-efficacy ( $\beta = 0.331$ ,  $t = 15.378$ ,  $p < 0.001$ ), and resilience also significantly and positively predicted academic self-efficacy ( $\beta = 0.202$ ,  $t = 5.334$ ,  $p < 0.001$ ). Importantly, the interaction term between meaning in life and resilience also significantly predicted academic self-efficacy ( $B = -0.0023$ ,  $t = -2.484$ ,  $p < 0.05$ ), indicating a significant moderation effect of resilience. Both H1 and H2 were supported.

Table 3 The moderating effect of Psychological resilience on meaning in life and academic self-efficacy (N=540)

| Models and Variables                                 | Academic self-efficacy |           |            |          |             |          |
|--|------------------------|-----------|------------|----------|-------------|----------|
|  | Model 1                |           | Model 2    |          | Model 3     |          |
|  | $\beta$                | $t$       | $\beta$    | $t$      | $\beta$     | $t$      |
| 1. Meaning in Life                                   | 0.452                  | 11.741*** | 0.325      | 8.639*** | 0.836       | 4.562*** |
| 2. Psychological resilience                          |                        |           | 0.373      | 9.925*** | 0.765       | 5.372*** |
| 3. Meaning in Life $\times$ Psychological resilience |                        |           |            |          | -0.748      | -2.849** |
| $\Delta R^2$   | 0.202                  |           | 0.325      |          | 0.937       |          |
| $R^2$  | 0.204                  |           | 0.327      |          | 0.937       |          |
| $F$  | 137.856***             |           | 130.678*** |          | 2651.197*** |          |

Note: \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ ; “p” is the probability, reflecting the probability of an event.

Table 3 examines the moderating role of psychological resilience in the relationship between meaning in life and academic self-efficacy (N = 540). A hierarchical regression analysis was performed: Model 1 indicated that meaning in life significantly and positively predicted academic self-efficacy ( $\beta = 0.452$ ,  $t = 11.741^{***}$ ). In Model 2, the inclusion of psychological resilience revealed a significant main effect ( $\beta = 0.373$ ,  $t = 9.925^{***}$ ), while the predictive strength of meaning in life remained significant but decreased ( $\beta = 0.325$ ,  $t = 8.639^{***}$ ). Model 3 demonstrated a significant negative moderating effect of the interaction term (meaning in life  $\times$  psychological resilience) on academic self-efficacy ( $\beta = -0.748$ ,  $t = -2.849^{**}$ ). Specifically, higher psychological resilience attenuated the positive association between meaning in life and academic self-efficacy.

To further clarify the nature of the moderation, a simple slope analysis was performed. At a low level of resilience (M-1SD), meaning in life had a significant predictive effect on academic self-efficacy (simple slope = 0.261,  $t = 5.784$ ,  $p < 0.001$ ). At a high level of resilience (M+1SD), the predictive effect of meaning in life on academic self-efficacy remained significant but was weaker (simple slope = 0.142,  $t = 3.213$ ,  $p = 0.001$ ). This indicates that the positive impact of meaning in life on academic self-efficacy is more prominent among students with low resilience.

## 4. Discussion

This study investigated the impact of meaning in life on the academic self-efficacy of university students and examined the moderating role of resilience. The results showed that meaning in life significantly and positively predicted academic self-efficacy, and this relationship was moderated by resilience, which is consistent with the study’s hypotheses.

First, the study found that a sense of meaning in life is an important predictor of academic self-efficacy. This result supports previous research suggesting that imbuing academic pursuits with deeper meaning and purpose can effectively enhance students’ confidence in their academic abilities<sup>[6, 10]</sup>. When students view their education as a vital pathway to realizing their life’s values and achieving personal goals, they gain powerful intrinsic motivation. This profound understanding of “why I learn” helps students look beyond immediate challenges, see long-term rewards, and thus develop a firm belief that “I can succeed.”

The most significant finding of this study is the moderating role of resilience in the relationship between meaning in life and academic self-efficacy. Specifically, the positive effect of meaning in life on academic self-efficacy was more pronounced in students with low levels of resilience. This finding reveals a profound psychological mechanism: a sense of meaning in life may function as a psychological compensatory resource. For students who have lower resilience and are more susceptible to self-doubt and negative emotions when facing setbacks, a clear and firm sense of meaning acts as a “psychological anchor,” providing them with additional mental support and motivation to withstand pressure, thereby maintaining and enhancing their academic self-efficacy. In contrast, for students who are already highly resilient, they may already possess strong self-regulatory and emotional recovery skills, enabling them to build and maintain confidence through various channels.

Therefore, while a sense of meaning is still beneficial for them, its “additional” boosting effect is relatively less prominent. This finding is consistent with the protective-compensatory model of resilience, which posits that protective factors become more salient when individuals are in a high-risk state (e.g., low resilience).

## 5. Conclusion

This study draws the following conclusions: (1) A sense of meaning in life significantly and positively predicts the academic self-efficacy of university students. (2) Resilience plays a significant moderating role in the relationship between meaning in life and academic self-efficacy. The positive impact of meaning in life on academic self-efficacy is more significant among university students with low resilience compared to those with high resilience.

## 6. Limitations and Future Directions

This study has some limitations. First, its cross-sectional design cannot establish causal relationships or dynamic developmental processes among the variables. Future research could employ longitudinal or experimental designs (e.g., a meaning-in-life intervention) to explore the causal mechanisms more deeply. Second, the sample was drawn from a single institution, which may limit the generalizability of the findings. Future studies could expand the sample to include diverse populations to test the universality of the conclusions. Finally, this study relied solely on self-report questionnaires, which may be subject to biases such as social desirability. Future research could incorporate behavioral experiments or multi-source evaluations to enhance the objectivity and validity of the results.

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

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# The Relationship between International Market Entry Mode Choice and Performance of Cross-Border E-commerce Enterprises

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**Abstract:** Digital technologies have significantly transformed how international trade works; this created a new trend of companies that are now globally oriented, especially within the cross-border e-commerce (CBEC) industry. Businesses to these business, the proper selection an international market entry option is one of critical decision and has direct bearing on a firms profitability. This paper studies the complicated connections between various kinds of digital market entry methods and the performance of CBEC enterprises. In this study, the digital entry mode is divided into Third-party platform digital mode entry such as Amazon, Tmall Global and Proprietary self-built website entry and Social commerce-based entry. As a firm develops, its success or poor is seen as many things including sales growth, profitability, market share, brand recognition. Using a quantitative method, data was obtained through a survey of 285 CBEC firms. The one that was carried out to see the correlations and do multiple regressions shows difference results for each of these modes Findings showed that using 3rd party platforms was strongly connected with stronger short term financial performance, compared to building your own website which was connected with longer term market performance and brand equity. Social commerce appears as a kind of complement of great importance, improving the customer engagement and brand awareness thus contributing to performance. Further more, it is shown that the firms that adopt hybrid entry strategies, i.e., the ones that utilize more than one mode, outperform the sole strategy entry firms' ones. These findings have some theoretical worth in the digital internationalization literature and offer actual information that can help CBECs' managers when they start in different countries.

**Keywords:** CrossBorder E-commerce; Market Entry Mode; Firm Performance; Digital Platforms; Internationalization; Strategic Management

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## 1.Introduction

The 21st century has seen globalization accelerate at an unprecedented pace, not driven just by old economic and political forces, but also by the new force of the internet. Digitalization has torn down geographical barriers, reduced transaction costs, and produced a super-connected worldwide marketplace<sup>[1]</sup>. This landscape has become an increasingly powerful and fast-growing branch in International Business. This branch is called as CBEC. It gives businesses, even SMEs, the power to go around traditional intermediaries and get in touch with consumers all over the world on their own. This paradigm change means there's big possibilities as well as serious problems. One of the most important strategic decisions that an



CBEC firm must make is what international market entry mode to pursue. Traditional multinational enterprises must choose whether to export, license, engage in joint ventures, or run wholly-owned subsidiaries. CBEC firms follow different digital trails. All kinds are different from directly selling on established third-parties, such as Amazon, Alibaba, to create your own e-commerce website or rely on the huge social media networks. They have different implications for how resources are committed, risks are exposed, control is exerted and eventually how a firm's overall performance will be. On account of being practically relevant, not any more research has been carried out with relation to these digital entry modes in order to explore their connection to their performance results in the CBEC context. This paper tries to resolve such a gap by studying this relationship systematically. It attempts to answer the following questions: Modern CBEC firms tend to employ which common international markets entry modes? how does a given particular entry mode, or bunch of entry modes, connect with different facets of performance, the financial kind of performance, the market kind of performance? Based on the empirical data of some CBEC companies, this study attempts to make people understand what kind of trade off exists in strategy, and give some guidelines to managers who want to optimize its global footprint in digital era<sup>[2]</sup>.

## 2.Literature review and theoretical foundation

Theories of International Market Entry The literature on international business has provided some fundamental theories to help us understand what kinds of mode of entry companies should make into an international market. TCE argues that firms enter through an entry mode that minimizes the sum of production and transaction cost, with more asset specific and uncertain activities having higher favor for a hierarchical entry mode wholly owned subsidiary. Uppsala model which comes from the behavioural perspective describes that internationalization is a gradual learning process and commitment where companies gradually move into psychically closer markets before moving out further. Dunning's Eclectic Paradigm (OLI framework) puts forth a unified perspective, indicating that the choice of entry is influenced by factors such as ownership advantages (e.g., technology, brand), location advantages (e.g., market size, low labor cost) and internalization advantages (i.e., benefits of keeping activities within the company). But they offer really strong ways to explain stuff, but when it comes to using them for CBEC's digital world, we have to be careful. In addition, the Internet significantly shrinks the "psychic distance" which is at the heart of the Uppsala paradigm, permits more rapid entry into markets at a far lower capital outlay than traditional FDI, and changes the nature of transactions costs. Digital assets and capabilities such as data analysis and online brand reputation have become new ownership strengths, and a reevaluation of these old models is necessary given the existence of digitally-born worldwide firms<sup>[3]</sup>.

Digital entry modes in cross-border E-commerce Strategic alternatives for CBEC firms are essentially all digital. The first big mode is being entered through third parties. Platforms like Amazon, eBay, Tmall Global, Rakuten, these constitute as large digital marketplaces globally; they provide existing infrastructures, high user visits, payment facilities, and even sometimes logistical solutions (e.g. FBA). For new and resource-starved firms, this mode provides an inexpensive and fast way to enter foreign markets and circumvent the high cost and danger of creating a foothold from scratch. however, this convenience is traded off in exchange for heavy price war, huge platform commission, no control in branding and customer relationships and having to play by the rule of the platform and its algorithm. The second main mode is the self-built website. It includes having a fully dedicated, independent e-commerce store, so the company has full control over its own branding, the customer experience, data, and pricing. This mode will help us build up good brand equity over a longer period and create direct consumer loyalty. However, it demands considerable initial as well as continuing investments in technology, digital marketing, traffic sourcing (like SEO and PPC advertising), and creating a sense of trust with overseas shoppers, which is a slow and money-consuming undertaking. A third, now growing, one is social commerce. And it also means selling directly on Social Media, or driving traffic to another Sales Channel like on FB, Instagram, Tiktok, Pinterest. It has built communities and can interact directly with customers, using extremely targeted, data-based advertising. It's excellent at building brand awareness and desire, but it can be difficult and expensive to scale as a primary sale point and it's at the whims of the algorithms and policies of the social media giants. Lots of companies don't pick just one mode to use, but mix in two or even more to handle risk and make use of special benefits in every channel.

Firm performance in a digital context - Measuring how well a CBEC enterprise performs takes more than just looking at

traditional financial accounting. It also has to take into account other things as well. Though financial performance still is a measure of success, typically gauged by sales growth, profitability, and return on investment (ROI), it paints only half a picture. In the dynamic world of the digital economy, market-facing accomplishments are just as, if not more, important for long-term success. Market performance is thus an important second dimension. this would include the percent of the market in a specific country, how well known a brand is among international buyers, how inclined customers would be to be satisfied and the capability of acquiring and retaining a core of satisfied customers. As for CBEC companies, they cannot rely on strategies that generate instant sales without building a good brand reputation and customer base in today's globalized world. Say, a company can accomplish tremendous sales on a third-party platform by setting extremely low price but it wouldn't create any brand value, hence, vulnerable to others & platform rule. Contrary-wise, a company that invests in making website may face slow first growth of sales yet it will create a good brand name and also can get direct relation with customer which will give a path for more steady and good growth of business in coming days. Hence, any thorough analysis of how entry modes are related to performance must look at both of these things in order to grasp the accurate strategic tradeoffs.

### 3.Methodology

**Research Design & Sample** The research uses a quantitative methodology, cross-sectional research design to investigate the relationship between the choice of international market entry mode by firms and their performance<sup>[4]</sup>. The target group comprised of managers and senior executives who headed the cross-border e-commerce firms established in China, a global center for CBEC activity. A Structured Questionnaire was made as the major way to get the information. The survey was handed out electronically by means of diverse outlets such as professional networks inside LinkedIn, mailing lists belonging to e-commerce industry organizations, and discussion boards focused on CBEC entrepreneurs. Use a multi-pronged approach to guarantee a diverse and cross-industry representative sample of different-sized companies. The first batch contained a response number of 350: After removing responses that were incomplete or inconsistent (such as those from companies not doing any international sales), a final sample of 285 valid responses were kept for further analysis, a valid response rate of 81.4%. In terms of the profile of the sampled firms, as shown in Table 1, there is a broad representation of firm age, firm size, and primary product categories. This allows for a generalisable set of results.

*Table 1: Profile of Sampled Firms (N=285).*

| Characteristic               | Category                  | Frequency | Percentage (%) |
|------------------------------|---------------------------|-----------|----------------|
| Firm Age                     | < 3 years                 | 75        | 26.3           |
|                              | 3-5 years                 | 112       | 39.3           |
|                              | 6-10 years                | 68        | 23.9           |
|                              | > 10 years                | 30        | 10.5           |
| Firm Size (No. of Employees) | < 50 employees            | 121       | 42.5           |
|                              | 50-200 employees          | 95        | 33.3           |
|                              | > 200 employees           | 69        | 24.2           |
| Primary Product Category     | Electronics & Accessories | 88        | 30.9           |
|                              | Apparel, Shoes & Bags     | 96        | 33.7           |
|                              | Home Goods & Decor        | 55        | 19.3           |
|                              | Other                     | 46        | 16.1           |

**Measurement of Variables**—All constructs were measured with multi-item scales taken from established literature and response categories ranged from 1 (strongly disagree) to 7 (strongly agree) on 7 point Likert scale, unless noted otherwise  
**Independent variable Market entry mode:** To measure Market entry mode, I asked respondents to indicate how much weight their firm gives to each of the three main market entry modes for their international sales. We heavily relies on third-party

platform like Amazon, Tmall and etc for our international revenue, Our own website is also one of our main outlet for global sales. We also use social commerce which means we generate huge part of our sales from social media. The dependent variable, firm performance, was assessed according to two aspects. financial performance, 3 adapted items from prior studies that asked managers to assess their firm's performance against its main competitors over the last 3 years in terms of sales growth, profitability, and overall financial return. Market Performance was assessed with three items: Market Share Growth and Brand Recognition in key Foreign Markets and Customer Retention. Finally, add in controls so that we can account for other things which could make us do as well. included Firm Age in Years, Firm Size (ln of the number of employees) and industry (e.g., electronics and apparel dummy coded).

## 4.Results

**Descriptive Statistics and Correlation Analysis** This study started with an analysis of descriptive statistics and correlation between main variables: The means, standard deviations and correlation coefficients are given in table 2. The correlation matrix gives us an initial view of these linkages. As can be seen all three entry modes: Third-Party platform, self-buid website, social commerce all had positive correlation with both financial performance and market performance. Showing that all these 3 entry modes contributed somewhat towards achieving sucess. especially, the correlation between the Self-built website mode and the Market performance is  $r=0.58$ ,  $p<0.1$ , which has initial support for the hypothesis that it works for building brand and markets. Similarly, Third Party Platform mode is strongly related to Financial Performance ( $r=0.52$ ,  $p<0.01$ ). Firm Size, Firm Age and so on, there too are evident correlations with these performance measures, and therefore should be included in subsequent regressions as part of our analysis to determine the effect of each entry mode choice. Significant inter-correlations among the entry mode variables themselves also point to the fact that many firms are indeed using a blend rather than just one channel.

*Table 2: Means, Standard Deviations, and Correlation Matrix of Key Variables.*

| Variable        | Mean | S.D. | 1     | 2     | 3     | 4     | 5     | 6     | 7 |
|-----------------|------|------|-------|-------|-------|-------|-------|-------|---|
| 1. Firm Age     | -    | -    | 1     |       |       |       |       |       |   |
| 2. Firm Size    | -    | -    | .28** | 1     |       |       |       |       |   |
| 3.Platform Mode | 4.88 | 1.51 | .15*  | .21** | 1     |       |       |       |   |
| 4.Website Mode  | 4.12 | 1.65 | .31** | .29** | .41** | 1     |       |       |   |
| 5.Social Mode   | 3.95 | 1.72 | .18*  | .25** | .45** | .49** | 1     |       |   |
| 6.Fin.Perf.     | 4.65 | 1.33 | .22** | .26** | .52** | .46** | .41** | 1     |   |
| 7.Mkt. Perf.    | 4.51 | 1.40 | .29** | .33** | .44** | .58** | .51** | .65** | 1 |

Note: \*  $p < 0.05$ , \*\*  $p < 0.01$

**Hypotheses testing** In order to formally test out the hypothesis about how each entry mode is effecting each outcome there were 2 different multiple regressions run. One with financial performance as the dependent variable and one with market performance as the dependent variable results are shown in table 3 and table 4. In both models, the control variables (Firm Age, Firm Size, and Firm's Industry) were entered first, followed by the 3 entry mode variables. Model for both Financial Performance  $F=31.54$  and  $p<0.001$  and Market Performance  $F=45.21$  and  $p<0.001$  were very significant. R-squared indicates that the variables have explained the variance in performance.

*Table 3: Multiple Regression Results for Financial Performance.*

| Variable          | Model 1 (Controls) | Model 2 (Full Model) |
|-------------------|--------------------|----------------------|
| Control Variables |                    |                      |
| Firm Age          | 0.14*              | 0.08                 |
| Firm Size         | 0.21**             | 0.12*                |

| Variable                | Model 1 (Controls) | Model 2 (Full Model) |
|-------------------------|--------------------|----------------------|
| Industry Dummies        | Yes                | Yes                  |
| Entry Modes             |                    |                      |
| Third-Party Platform    |                    | 0.41***              |
| Self-Built Website      |                    | 0.19**               |
| Social Commerce         |                    | 0.11*                |
| Model Summary           |                    |                      |
| R <sup>2</sup>          | 0.11               | 0.38                 |
| Adjusted R <sup>2</sup> | 0.09               | 0.36                 |
| F-statistic             | 8.76***            | 31.54***             |

Note: \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ . Standardized Beta coefficients are reported.

As can be seen in table 4, the results for Market performance show something different. Self-Built Website shows up as the sturdiest predictor ( $\beta = 0.45$ ,  $p < 0.001$ ), giving solid support to the idea that it's better for constructing market presence and brand equity. The Social Commerce mode does have a large and relatively strong relationship with Market Performance ( $\beta = 0.25$ ,  $p < 0.01$ ), which shows how well it creates communities and increases brand popularity. Surprisingly, in this model, when facing the Third-Party Platform mode, although the impact on the market performance is still positive and significant ( $\beta=0.15, p<0.05$ ), it is far weaker than the impact on financial performance and compared with the other two modes in this model. It implies that although platforms are good at creating sales, they are not very good at being a mainstay in building long-term markets and brands, which fits the theory.

Table 4: Multiple Regression Results for Market Performance.

| Variable                | Model 1 (Controls) | Model 2 (Full Model) |
|-------------------------|--------------------|----------------------|
| Control Variables       |                    |                      |
| Firm Age                | 0.19**             | 0.10*                |
| Firm Size               | 0.25***            | 0.14**               |
| Industry Dummies        | Yes                | Yes                  |
| Entry Modes             |                    |                      |
| Third-Party Platform    |                    | 0.15*                |
| Self-Built Website      |                    | 0.45***              |
| Social Commerce         |                    | 0.25**               |
| Model Summary           |                    |                      |
| R <sup>2</sup>          | 0.16               | 0.49                 |
| Adjusted R <sup>2</sup> | 0.14               | 0.47                 |
| F-statistic             | 12.11***           | 45.21***             |

Note: \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ . Standardized Beta coefficients are reported.

## 5. Discussion

Interpretation of Findings The empirical results from this study shed light on the textured differences in impact each different digital entry mode has on the performance of cross-border e-commerce educational firms. The strong positive relationship between the use of third party platform and financial performance is logical and expected. They also give immediate access to a huge, existing pool of customers and a known transactional environment that lets businesses, especially new ones, rapidly produce revenue and create sales without the expensive costs of establishing a brand and getting traffic from the ground up. This mode hands

off the hard work of getting customers and building trust to the platform. But the milder hit on market success shows the underlying trade-off – it provides firms with more sales but means potentially losing out on the chance for a face-to-face connection with the customers and a distinct brand identity. They are usually just one of many vendors in a crowded, price-driven marketplace, making it hard to build the kind of loyalty and recognition that leads to strong market performance over time. On the contrary, the powerful pull in the website built by the self has a huge impact on the market, which illustrates the value of having control. They could run their own digital storefront, produce a special brand experience, speak out about what they stand for, and get hold of useful info about the people who buy from them. This D2C method is an investment in generating an asset - the brand and the buyers - which gives you more market share, greater brand recognition, and more loyal customers over time, although the money coming in might be slow at first. The major part played by social commerce in predicting both performance aspects and especially market performance proves how the field has been transformed from just a means of communication into a fundamental part of the e-commerce environment. It functions as a strong engine for forming a community, doing targeted marketing, and bringing in website traffic which boosts awareness about the brand and gives more fuel to the sales funnels of our own web-based sites and platform storefronts<sup>[5]</sup>.

**Managerial and Theoretical implications** The findings of this research have many important implications in theory and practice. The paper provides theoretically, updates and contextualizes the classic theories in the digital era. In terms of entry modes literature. It shows that in the CBEC environment, the traditional trade off between risk, Control and Resource Commitment is still there but it takes a new form. The choice is not really between equitable or non-equitable – it's between platform-dependent or brand-owned. The results show that a dynamic, capabilities view appears to be more suitable for CBEC internationalisation where digital marketing, data analytics and online community management need to be developed for success. The results refute the assumption of a fixed entry mode strategy. The optimal entry mode can vary over the life cycle of a firm. For managers of CBEC firms, this means direct action. Firstly, there is really no best entry mode; instead it depends on the company's aim and resources. Startup needs some quick proof and some money coming in ? might want to start with a third-party platform. However, if a company has aspirations of a long-term vision to build a global brand, they have to invest in their own proprietary website. Second, it also really points to a hybrid and omnichannel strategy. Managers need to see the modes as additive rather than additive when it comes to entering a new market; they should see them as different parts of a larger market entry portfolio. Like, a company might use a third-party platform to start off by testing out the market and collecting revenue at the same time they were building out their own website and doing social commerce to send traffic to the business from both platforms. It lets a firm ride on a platform's traffic but still build a firm's own brand assets and mitigate the weaknesses of the traffic model and capitalise on the strengths of the asset model.

## 6. Conclusion

This study was about finding the important connection between picking a way to go into the global market and how well a company does in the quickly growing area where people buy things from other countries over the internet. Based on analyzing data from 285 firms, it is clear through these findings that the strategic choice of adopting third-party platform, developing its own website, and social commerce leads to different performance outcomes. **Key Findings:** There is a significant trade-off – third party platforms give rise to short term financial impact, self built websites are a better vehicle to achieve long term market performance and create brand equity. Social commerce has proven to be a crucial, collaborative, and supportive way of promoting an item in order to boost brand awareness and create a better connection with customers. In the end, this would improve your company's market performance. In the end, it seems a smart, mixed approach that mixes all these ways together just might work best.

This study gives great help to know about the internationalization in digital time. But it is not without flaw. The fact that the data are cross-sectional means that it is a snapshot at a point in time and does not take into account how the firm's entry mode strategy changes over the lifecycle of the firm. Also, self – reported perceptual data on performance has already been used widely in the study of strategic management, but objective financial data could also be used in future studies. The sample is good but comes from just one country, so later research might get some use out of cross-cultural work on finding if these study results apply to CBEC companies starting from different places with different cultures and rules. Future research could

also use a longitudinal approach to follow-up firms over the span of a few years, to see how firms change their entry mode portfolio and why; what the consequences are for their growth. And looking into the way things like digital literacy, supply chain capabilities, and how much competition there is in the target market could be moderating, that'd be an interesting thing to look into.

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no

## 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 Evaluation Mechanism of Artificial Intelligence-Enabled Education and Teaching Innovation in Colleges and Universities

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**Abstract:** The report of the 20th National Congress of the Communist Party of China first positioned ‘educational digitization’ as the core path to building a learning-oriented nation. The ‘China Education Modernization 2035’ plan further clarified that artificial intelligence is the key to achieving the organic integration of large-scale education and personalized cultivation. However, the traditional educational evaluation system suffers from static lag and insufficient adaptability, urgently requiring the reconstruction of evaluation mechanisms through artificial intelligence technology. Therefore, analyzing the role of artificial intelligence in empowering innovative evaluation mechanisms for higher education teaching and learning is of great significance. This article takes university students, teachers, and university administrators as the survey subjects and uses structural equation modeling to explore the innovative evaluation mechanisms of university education and teaching empowered by artificial intelligence. The research findings indicate that AI drives innovation in higher education evaluation mechanisms across six dimensions: learning outcomes, teaching processes, feedback on results, data privacy and security, acceptance, and social empowerment. Therefore, this paper suggests that the application of AI in higher education evaluation can be promoted by accelerating the construction of a national intelligent education evaluation standards system and advancing institutional evaluation innovation mechanisms, and provides relevant recommendations.

**Keywords:** Artificial Intelligence; Teaching and Learning in Higher Education; Innovation Evaluation; Structural Equation Modeling

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## 1.Introduction

The report of the 20th National Congress of the Communist Party of China emphasized the need to accelerate the digital transformation of education, build a modern education system for lifelong learning for all, and promote the development of a learning society and a learning nation. For education, artificial intelligence is not just a strategic issue, but a strategic and comprehensive issue that affects and even determines the high-quality development of education<sup>[1]</sup>. The document ‘China’s Education Modernization 2035’ highlights the advantages of new technologies such as artificial intelligence in transforming the role of teachers, explaining that artificial intelligence is key to achieving a combination of large-scale education and personalized training<sup>[2]</sup>. Artificial intelligence technology is reshaping the spatial boundaries and teaching activity processes

of education, opening up new horizons for innovative development in the education ecosystem. Empowering higher education evaluation with artificial intelligence is a key component of the important task of deepening the implementation of artificial intelligence empowerment initiatives, and it is also an urgent issue facing the deepening reform of higher education evaluation. How to use artificial intelligence to empower innovative evaluation standards for higher education teaching and learning, construct a scientific, efficient, and intelligent higher education evaluation system, and improve the quality and efficiency of higher education is of paramount importance<sup>[3]</sup>.

In March 2024, the Ministry of Education launched an initiative to empower education with artificial intelligence, aiming to use artificial intelligence to promote the integration of teaching and learning, improve the digital literacy and skills of the entire population, and regulate the scientific ethics of artificial intelligence use<sup>[4]</sup>. Deepening education evaluation reform is a key task and an important component of comprehensive education reform. It holds significant strategic importance for accelerating the modernization of education, building an education powerhouse, and providing education that satisfies the people. Therefore, based on existing research, this paper constructs an innovative evaluation system for artificial intelligence-enabled higher education teaching and attempts to analyze the mechanisms of artificial intelligence-enabled higher education teaching.

## 2. Literature Review

### 2.1 The Value of Artificial Intelligence in Empowering Higher Education Teaching

Some scholars believe that the integrated application of artificial intelligence in classroom teaching is the key to driving the evolution of education<sup>[4]</sup>. The application of artificial intelligence in university teaching can provide students with a highly personalized learning experience through precise personalized learning support, thereby promoting comprehensive improvement in students' knowledge acquisition, skill development, and cognitive abilities. Personalized learning can enhance classroom engagement and stimulate learning interest, thereby significantly improving students' learning interest and initiative, and effectively optimizing learning outcomes while promoting students' comprehensive development<sup>[7]</sup>. In terms of teaching effectiveness, artificial intelligence can help teachers identify student needs more accurately and improve the management and implementation of classroom teaching through the optimization of the teaching process.

Through intelligent tools and data analysis powered by artificial intelligence, teachers can monitor classroom learning dynamics in real time, accurately identify students' knowledge gaps, and implement dynamic adjustments to teaching content and methods based on data feedback, thereby optimizing teaching design to achieve precise and efficient teaching goals<sup>[8]</sup>. Scholar Zhang Yu believes that artificial intelligence technology reconstructs classroom teaching paradigms through data-driven mechanisms. On the one hand, it achieves the precise allocation of educational resources, and on the other hand, it promotes the intelligent upgrading and refined management of teaching management processes<sup>[4]</sup>. Through the smart education platform, school administrators can dynamically monitor classroom teaching plans in terms of progress, student engagement, teaching quality, and other aspects<sup>[9]</sup>.

At the societal level, the application of artificial intelligence in higher education not only meets society's demand for high-quality, innovative talent but also enhances societal competitiveness and sustainable development. Scholar Wu Zhongyuan conducted an in-depth analysis of the innovative evaluation concepts, subject diversification, technological innovation integration, and technological boundaries enabled by artificial intelligence. He found that the foundation of artificial intelligence-enabled higher education evaluation reform lies in enhancing the scientific rigor, fairness, personalization, and efficiency of educational evaluation, thereby driving the high-quality, inclusive development of higher education<sup>[10]</sup>.

### 2.2 The Need for Artificial Intelligence to Empower Innovative Evaluation of Higher Education Teaching and Learning

In the new era, the new development pattern requires high-level talent support. As an important platform for cultivating high-quality talent, the reform of the evaluation system in higher education is particularly important<sup>[10]</sup>. The traditional education evaluation system suffers from issues such as a single standard framework and static indicator design, making it difficult to adapt to the new requirements of the intelligent era for students' core competencies, such as information literacy, innovative

thinking, and critical thinking. This can lead to lagging evaluation mechanisms. A paradigm dominated by quantification lacks qualitative analysis dimensions, weakening the applicability and flexibility of evaluation and failing to meet the needs of personalized development and educational diversity for high-level talent<sup>[11]</sup>.

In the context of globalization, reforming higher education evaluation is one of the key means of enhancing a country's educational competitiveness. The application of artificial intelligence to higher education evaluation reform has also become a new focal point of technological competition among countries<sup>[11]</sup>. To ensure that students remain competitive in the age of artificial intelligence, American universities are adopting intelligent question banks and assessment systems to assist in teaching and introducing intelligent tutoring systems to improve learning outcomes and independent learning abilities<sup>[12]</sup>. Japanese universities focus on using AI to empower higher education by applying personalized learning evaluation systems that provide personalized learning recommendations and feedback based on students' learning data and behavioral characteristics<sup>[13]</sup>. The Singaporean government is rethinking the development model of AI-enabled higher education from the ground up and providing strong support for AI technology research and application through the establishment of innovation centers and scientific research platforms<sup>[14]</sup>. The experience of using artificial intelligence technology in higher education evaluation abroad provides reference and inspiration for China's higher education evaluation reform and the construction of a higher education evaluation system with Chinese characteristics and international standards.

### **2.3 The Content of Artificial Intelligence-Empowered Evaluation of Higher Education Teaching and Learning**

Artificial Intelligence Empowering Higher Education Evaluation Reform Based on the development needs of higher education in the new era, the application of artificial intelligence technology in higher education evaluation must establish a learner-centered approach, shift from knowledge transfer to ability cultivation, focus on the comprehensive development of students, integrate intelligent technology into educational objectives, cultivate AI literacy and digital citizenship literacy, develop AI application abilities, and enhance complex problem-solving abilities<sup>[10]</sup>. During the evaluation process, teachers transition from traditional evaluators to interpreters of evaluation results and providers of feedback. Artificial intelligence-enabled classroom teaching greatly enhances teachers' teaching effectiveness, helping them to more accurately identify students' needs, optimize teaching design, and improve the management and implementation quality of classroom teaching. Teachers can dynamically obtain classroom interaction data, identify students' weaknesses in certain knowledge points, and then flexibly adjust teaching content and strategies to achieve a more precise classroom teaching design<sup>[4]</sup>. Artificial intelligence technology can help build feedback systems and continuous improvement mechanisms. Based on assessment results and user feedback, educational evaluation programs can be regularly assessed and adjusted, evaluation indicator systems and methods can be optimized, intelligent evaluation tools and AI evaluation systems can be continuously optimized, evaluation models and algorithms can be adjusted, and the accuracy and reliability of evaluation systems can be improved<sup>[10]</sup>. In the process of higher education evaluation, the legitimate rights and interests of all evaluation entities should be respected and protected. An ethical review mechanism should be established to clarify the procedures and standards for ethical review. Privacy protection is an important aspect of AI-enabled evaluation. A sound data management system and privacy protection policy should be established to ensure data security and privacy. When collecting and using individual information, not only should their right to informed consent be fully respected, but the transparency of the evaluation process and results should also be maintained to enhance the credibility and satisfaction of the evaluation results<sup>[15]</sup>.

Artificial intelligence technology can autonomously establish course learning outcomes, describe evaluation weights, map learning outcomes to each evaluation method, and formulate learning activity plans and course schedules to achieve coordination between expected learning outcomes, teaching strategies, learning activities, and evaluation methods, thereby ensuring that students participate in meaningful learning experiences<sup>[16]</sup>. The ultimate goal of empowering higher education evaluation with artificial intelligence is to serve society. It is an inevitable trend in the modernization and high-quality development of education, which needs to meet society's demand for high-quality, innovative talent, and also provide support for society's sustainable development and competitiveness<sup>[4]</sup>.

### 3. Research Design

#### 3.1 Questionnaire Design

##### 3.1.1 Basic Information

This study aims to analyze the innovative evaluation of AI-enabled higher education teaching and learning from the perspectives of students, teachers, and school administrators. Therefore, based on the above analysis, this paper constructs evaluation indicators from six dimensions: learning outcomes, teaching process, feedback on results, data privacy and security, acceptance, and social empowerment. An evaluation innovation survey questionnaire is designed to understand the innovative evaluation mechanism of AI-enabled higher education teaching and learning. The questionnaire employs a five-point Likert scale for measurement and utilizes an integer allocation algorithm to ensure that the number of respondents for each option strictly aligns with the theoretical probability distribution.

##### 3.1.2 Evaluation Questions

The questionnaire items for evaluating innovation are designed as shown in Table 1. In terms of learning outcomes, there are three items: whether AI can identify learning difficulties, whether it can generate personalized evaluation reports, and whether it can integrate multidimensional data. In terms of the teaching process, there are three items: whether AI technology can objectively record teachers' teaching performance, whether it can generate real-time teaching feedback, and whether AI-assisted teaching evaluation reduces subjective bias, making the results more fair. In terms of feedback on results, the questionnaire is divided into three items: whether AI-generated evaluation reports are instructive, whether they effectively promote professional development, and whether they enhance overall educational quality; In terms of data privacy and security, there are three sub-items: whether AI systems can be trusted to collect personal data, whether there are clear regulatory mechanisms in place, and whether users can understand the purpose of personal data collection. In terms of acceptance, there are three sub-items: whether AI platforms are compatible with existing teaching platforms, whether users are willing to actively use AI evaluation functions, and whether related training can help users become proficient in using the evaluation system. In terms of social empowerment, it is also divided into three sub-questions: whether AI evaluation can help individuals understand the alignment between their own capabilities and societal needs, whether it can enhance the ability to address real-world societal issues, and whether it can promote educational equity.

Table 1: Questionnaire Design and Items

| Variable                  | Number | Question   |
|---------------------------|--------|--|
| Learning outcomes         | C1     | Capturing learning difficulties                    |
|                           | C2     | Personalized evaluation report                     |
|                           | C3     | Integrate multidimensional data                    |
| Teaching process          | C4     | Teacher performance                                |
|                           | C5     | Real-time teaching feedback                        |
|                           | C6     | Fair evaluation results                            |
| Feedback on results       | C7     | The evaluation report is instructive.              |
|                           | C8     | Effectively promote professional development       |
|                           | C9     | Improving overall educational quality              |
| Data privacy and security | C10    | The trust evaluation system collects personal data |
|                           | C11    | Clarify regulatory mechanisms                      |
|                           | C12    | Knowing how your data is used                      |
| Acceptance                | C13    | Compatible with existing teaching platforms        |
|                           | C14    | willing to use proactively                         |
|                           | C15    | Related technical training                         |

| Variable           | Number | Question                              |
|--------------------|--------|---------------------------------------|
| Social empowerment | C16    | Individual abilities and social needs |
|                    | C17    | Technology + Social Problem Solving   |
|                    | C18    | Promoting educational equity          |

### 3.2 Research Methods

To explore the evaluation mechanism for innovation in higher education enabled by artificial intelligence, this study conducted a survey using a questionnaire. The questionnaire included six dimensions: learning outcomes, teaching process, feedback on results, data privacy and security, acceptance, and social empowerment. Each dimension had three items, totaling 18 items. To enhance the accuracy and authenticity of this survey, the respondents were current students, faculty members, and administrative staff at higher education institutions. The survey was distributed in June 2025, with a total of 1,321 questionnaires distributed and 1,218 formally returned. After internal logical checks, 94 questionnaires were excluded, leaving 1,124 valid questionnaires, with a validity rate of 92.28%. SPSS software was used for reliability and validity analysis of the questionnaires, and AMOS software was used to construct the relevant structural equation model.

## 4. Research Findings

### 4.1 Validity and Reliability Analysis

Reliability and validity analysis were conducted using SPSS 27.0, and Cronbach's Alpha was used to assess the internal consistency of the survey questionnaire's research variables, as shown in Table 2. The Cronbach's Alpha coefficient for the survey questionnaire was 0.713, which is greater than 0.7, indicating that the data reliability is suitable for further analysis. Validity analysis reflects whether the scale effectively measures the intended content<sup>[17]</sup>. As shown in Table 3, the KMO value of the survey questionnaire was 0.853, and the Bartlett's sphericity test value was 0.000, which was statistically significant at the 0.05 level. This indicates that the questionnaire data is highly suitable for information extraction and can be used for further research analysis.

Table 2: Cronbach's Reliability Analysis

| Cronbach's Alpha | number of items |
|------------------|-----------------|
| 0.713            | 18              |

Table 3: KMO and Bartlett's Test

| Indicator                     | Indicator Value |
|-------------------------------|-----------------|
| KMO sampling adequacy measure | 0.853           |
| Approximate Chi-square        | 1480.616        |
| Degree of Freedom             | 153             |
| Significance                  | 0.000           |

### 4.2 Structural Equation Model

#### 4.2.1 Initial Model

The initial structural equation model was constructed using AMOS software, as shown in Figure 1. In Figure 1, the ellipses represent latent variables, the rectangles represent observed variables, and the circles represent the residuals of each variable. The coefficients in the model were estimated using the maximum likelihood estimation algorithm<sup>[16]</sup>.

Before conducting path analysis, it is necessary to test the model for goodness of fit. This paper selects the chi-square degree of freedom ratio, root mean square error of approximation (RMSEA), goodness of fit index (GFI), incremental fit index (IFI), Tucker-Lewis index (TLI), and comparative fit index (CFI) as goodness of fit indicators, as shown in Table 4.

Figure 1: Initial Structural Equation Model

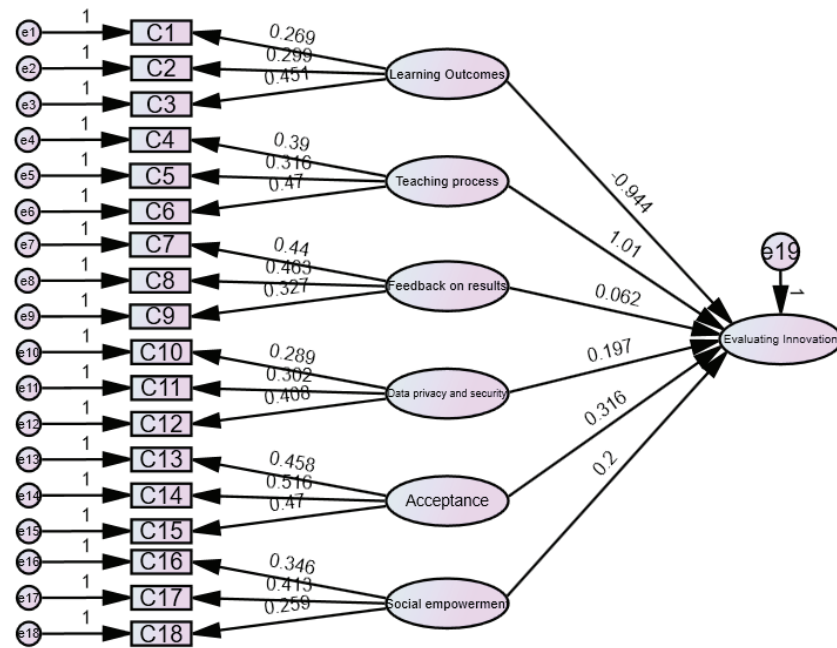


Table 4: Initial Model Goodness-of-Fit Test

| Indicator       | $\chi^2/d_f$ | GFI   | IFI   | TLI   | CFI   | RMSEA       |
|-----------------|--------------|-------|-------|-------|-------|-------------|
| Requirements    | <3           | >0.9  | >0.9  | >0.9  | >0.9  | <0.05       |
| Indicator Value | 1.208        | 0.986 | 0.981 | 0.976 | 0.981 | 0.004~0.021 |

According to Table 4, the chi-square degree of freedom ratio of the initial model is 1.208, which is less than 3. The goodness-of-fit index is 0.986, meeting the research standard of being greater than 0.9. The incremental goodness-of-fit index is 0.981. The Tucker-Lewis index is 0.976, and the comparative fit index is 0.981, both of which are greater than 0.9. The approximate root mean square error ranges from 0.004 to 0.021, which is less than 0.05, indicating that the initial model meets the goodness-of-fit requirements.

#### 4.2.2 Model correction

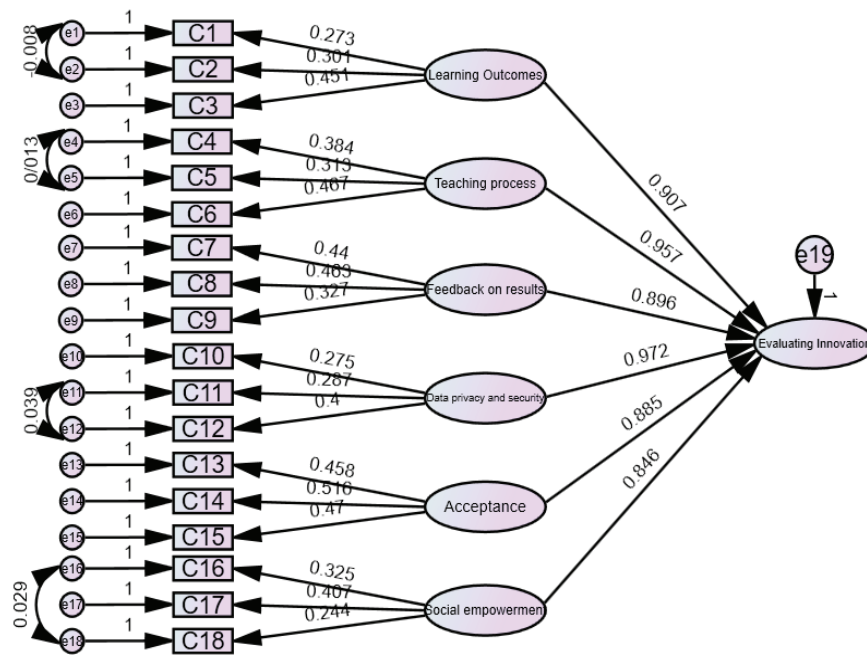
Based on practical experience, the accuracy of AI diagnostic results is a prerequisite for generating personalized reports, so items C1 and C2 are related; AI data collection is the basis for generating feedback reports. If AI records are considered to be biased, the validity of the feedback results will be questioned, so items C4 and C5 are related. Users' trust in AI's collection of personal information is a prerequisite for algorithm transparency. If users are concerned about data breaches, it may undermine the effectiveness of regulatory mechanisms. Therefore, items C10 and C11 are interrelated. Item C16 represents the conversion of individual capabilities, while item C18 represents system fairness. These belong to different levels of social empowerment but share the common goal of promoting social fairness, thereby influencing each other. Therefore, the error terms of the above related items were set as related relationships, and the model was revised accordingly. The revised model is shown in Figure 2. IFI, TLI, and CFI meet the requirements, and all fitting indicators meet the standards, as shown in Table 5.

Table 5: Fitting Test of the Corrected Model

| Indicator       | $\chi^2/d_f$ | GFI   | IFI   | TLI   | CFI   | RMSEA       |
|-----------------|--------------|-------|-------|-------|-------|-------------|
| Requirements    | <3           | >0.9  | >0.9  | >0.9  | >0.9  | <0.05       |
| Indicator Value | 1.173        | 0.984 | 0.984 | 0.980 | 0.984 | 0.003~0.020 |



Figure 2: Revised Structural Equation Model



#### 4.2.3 Model Results Analysis

The evaluation of AI-empowered innovation in higher education teaching is influenced by many factors. This paper constructs evaluation indicators based on relevant literature and uses a structural equation model to reflect the evaluation mechanism of AI-empowered innovation in higher education teaching. The results are shown in Table 6. The path relationships between learning outcomes, teaching process, feedback on results, data privacy and security, acceptance, and social empowerment are all significant, and all hypotheses are valid.

Table 6: Factor Loadings of the Revised Structural Equation Model

|     |    |                     | Estimate | S.E.  | C.R.  | P   |
|-----|----|---------------------|----------|-------|-------|-----|
| C1  | <— | Learning Outcomes   | 1.000    | -     | -     | -   |
| C2  | <— | Learning Outcomes   | 1.098    | 0.201 | 0.000 | *** |
| C3  | <— | Learning Outcomes   | 1.623    | 0.258 | 0.000 | *** |
| C4  | <— | Teaching process    | 1.000    | -     | -     | -   |
| C5  | <— | Teaching process    | 0.859    | 0.123 | 0.000 | *** |
| C6  | <— | Teaching process    | 1.245    | 0.145 | 0.000 | *** |
| C7  | <— | Feedback on results | 1.000    | -     | -     | -   |
| C8  | <— | Feedback on results | 1.057    | 0.118 | 0.000 | *** |
| C9  | <— | Feedback on results | 0.633    | 0.087 | 0.000 | *** |
| C10 | <— | Data privacy        | 1.000    | -     | -     | -   |
| C11 | <— | Data privacy        | 1.023    | 0.177 | 0.000 | *** |
| C12 | <— | Data privacy        | 1.449    | 0.225 | 0.000 | *** |
| C13 | <— | Acceptance          | 1.000    | -     | -     | -   |
| C14 | <— | Acceptance          | 1.186    | 0.120 | 0.000 | *** |
| C15 | <— | Acceptance          | 1.110    | 0.117 | 0.000 | *** |
| C16 | <— | Social empowerment  | 1.000    | -     | -     | -   |

|            |    |                     | <b>Estimate</b> | <b>S.E.</b> | <b>C.R.</b> | <b>P</b> |
|------------|----|---------------------|-----------------|-------------|-------------|----------|
| C17        | <— | Social empowerment  | 1.247           | 0.189       | 0.000       | ***      |
| C18        | <— | Social empowerment  | 0.662           | 0.129       | 0.000       | ***      |
| Evaluating | <— | Learning Outcomes   | 1.000           | -           | -           | -        |
| Evaluating | <— | Teaching process    | 1.456           | 0.245       | 0.000       | ***      |
| Evaluating | <— | Feedback on results | 1.510           | 0.247       | 0.000       | ***      |
| Evaluating | <— | Data privacy        | 1.091           | 0.208       | 0.000       | ***      |
| Evaluating | <— | Acceptance          | 1.463           | 0.237       | 0.000       | ***      |
| Evaluating | <— | Social empowerment  | 1.076           | 0.199       | 0.000       | ***      |

Note: \*\*\* indicates  $P < 0.001$ .

As shown in the figure above and the revised structural equation model, the standardized path coefficients for learning outcomes, teaching process, feedback on results, data privacy and security, acceptance, and social empowerment are 0.907, 0.957, 0.896, 0.972, 0.885, and 0.846, respectively. This indicates that these six indicators drive innovation in the evaluation of higher education teaching and learning enabled by artificial intelligence.

Among the observed variables of learning outcomes, the factor loading coefficient of artificial intelligence in integrating multidimensional data is 0.451, which is higher than the other two items, indicating that it has a significant impact on the evaluation of learning outcomes. Promoting the use of artificial intelligence to integrate multidimensional data can provide an analytical basis for identifying learning difficulties and generating personalized reports, thereby achieving the goals outlined in the ‘Overall Plan for Deepening the Reform of Education Evaluation in the New Era’ to improve outcome evaluation, strengthen process evaluation, explore value-added evaluation, and improve comprehensive evaluation.

Among the observed variables in the teaching process, the factor loading coefficient for whether artificial intelligence can ensure fairness in evaluation results is 0.467, which is higher than the other two factors, indicating that it has a significant impact on the evaluation of the teaching process. Teaching performance and real-time feedback can be optimized through algorithms, but issues with the fairness of evaluation results can lead to systemic trust crises. The ‘Overall Plan for Deepening the Reform of Educational Evaluation in the New Era’ explicitly requires that we ‘adhere to scientific effectiveness, improve result-based evaluation, strengthen process-based evaluation, and establish a comprehensive evaluation system.’ Fairness is the bottom-line standard for ‘scientific and effective’ evaluation.

Among the observed variables in the feedback results, the factor loadings for whether the evaluation report is instructive and whether it can effectively promote professional development are 0.44 and 0.463, respectively, indicating that they have a high impact on the feedback results. Together, they constitute the substantive vehicle for educational evaluation to empower teaching reform: an instructive evaluation report can ensure the conversion efficiency of evaluation results, while promoting professional development can achieve improvements in educational quality.

Among the observed variables related to data privacy and security, the factor loading coefficient for awareness of data usage is 0.4, which is higher than the other two items, indicating that it has a significant impact on the evaluation of data privacy and security. Educational data contains highly sensitive information, and awareness of the purpose of such data is fundamental to data privacy and security. Without transparency regarding the purpose of data usage, users’ trust may turn into passive compliance.

Among the observed variables of acceptance, the factor loadings of the three items were 0.458, 0.516, and 0.47, respectively. The factor loading of willingness to actively use was relatively high, indicating that it had a greater impact on acceptance. Willingness to actively use is a direct reflection of users’ ultimate behavioral intention to adopt the technology, while compatibility and related training are only external moderating variables. Promoting active willingness can achieve the sustainability of educational innovation behavior.

Among the observed variables of social empowerment, the factor loading coefficient of ‘technology + social problem solving’ is 0.407, indicating that it has a high impact on social empowerment. ‘technology + social problem solving’ requires the collaborative participation of the government, enterprises, communities, and individuals to ensure that resources are accurately matched to social needs, build public trust, and stimulate social participation.

## 5. Conclusions and Recommendations

### 5.1 Conclusions

This paper aims to explore the innovative evaluation mechanisms for higher education teaching and learning enabled by artificial intelligence. Through a literature review, the paper analyzes the innovative evaluation mechanisms for higher education teaching and learning enabled by AI, identifies relevant evaluation indicators, and designs an AI-enabled higher education teaching and learning evaluation innovation survey questionnaire. Using data from current students, faculty members, and administrative staff at relevant universities as the sample, the paper analyzes the innovative evaluation mechanisms for higher education teaching and learning enabled by AI. Through structural equation modeling, it was confirmed that six dimensions—learning outcomes, teaching processes, feedback on results, data privacy and security, acceptance, and social empowerment—significantly drive the innovation of the evaluation system. Among these, the integration of multi-dimensional data is the core foundation for optimizing learning diagnostics, while the fairness of evaluation results and the transparency of data usage are the foundation of trust in teaching reforms and the key to privacy protection. After refining the model, the error correlations between learning diagnosis and personalized reports, data collection and feedback generation, and privacy trust and regulatory mechanisms validated the dynamic interconnectivity of the innovative evaluation mechanism. Among these, in terms of social empowerment, the ability to combine ‘technology with social problem-solving’ is the key link between individual development and societal needs. It is hoped that the findings of this study can provide insights for the innovative evaluation mechanism of AI-empowered higher education teaching and learning.

### 5.2 Policy Recommendations

First, accelerate the construction of a national intelligent education evaluation standard system. Based on the characteristics of artificial intelligence, establish a basic framework for evaluating educational artificial intelligence, with a focus on multi-dimensional data integration mechanisms to ensure the comprehensiveness of the model. In terms of model algorithms, establish relevant systems for algorithm transparency, publicly disclose the parameter logic of evaluation models to increase user trust, and have third-party institutions regularly test the fairness of the model. Central government special funds can be used to deploy lightweight evaluation systems in resource-poor areas, thereby addressing resource barriers that affect educational equity.

Second, promote innovation in university evaluation mechanisms. Based on feedback data on educational quality, optimize existing university evaluation models to build dynamic and accurate evaluation models; establish a verification mechanism for models, allowing universities to combine student peer evaluation data with AI analysis results to adjust the evaluation system, thereby preventing excessive quantification of the evaluation system; Universities can actively encourage teachers to participate in training and practical operations of artificial intelligence evaluation tools, cultivating their ability to interpret artificial intelligence reports. This can be transformed into teaching improvement strategies. In terms of data security, university teachers should take the lead in maintaining data security to enhance students’ and parents’ trust in the system. Universities can also convert students’ ability evaluation results into relevant credits and link them with industry certification systems to increase social benefits.

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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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# Career Uncertainty and Employment Anxiety Faced by Arabic Language Undergraduates in the Face of Big Data

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**Abstract:** Employment anxiety is a psychological issue commonly found among contemporary college students, with manifestations that transcend disciplinary boundaries, encompassing a dual-dimensional structure of cognitive expectations and somatic symptoms, and posing threats to social stability and human resource development. Research indicates that individual psychological factors (psychological resilience, career sense of mission, cognitive bias), social environment (social support, employment guidance, social media use), and external events (pandemic, market uncertainty) collectively shape the mechanism of anxiety formation. Among these, career uncertainty as a core predictor exacerbates anxiety through pathways that reduce tolerance for uncertainty, trigger chain reactions of fear and depression, and weaken sense of control, while career planning and social support can buffer these effects.

For Arabic language major students facing unique challenges in the big data era, it is recommended to establish a three-tier intervention system: at the social level, expand “language+technology” composite positions and establish information platforms; at the school level, reform curriculum systems (integrating data analysis), implement comprehensive career planning and specialized psychological interventions; at the individual level, master cross-domain skills, explore interest-career connections and enhance psychological resilience. Multi-dimensional linkage can transform uncertainty into opportunities for cross-domain development.

**Keywords:** Employment Anxiety; Career Uncertainty; Arabic Language Major; Big Data Era

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## 1.Introduction

Employment anxiety, as a psychological issue widely prevalent among contemporary college students, has become a research hotspot in global higher education. Against the backdrop of China’s rapid social transformation and economic structure upgrading, the continuous expansion of college graduates and intensified job market competition have caused employment anxiety to exhibit characteristics of high incidence and complexity (Wang et al., 2025; Zheng et al., 2022). Empirical research shows that the prevalence of employment anxiety among Chinese college students transcends disciplinary boundaries: it is significantly present among art education and music majors (Zhang et al., 2023; Ya et al., 2024), science and engineering students also face employment confidence crises triggered by the pandemic (Zheng et al., 2022), and it even extends to hotel service workers (Chela-Alvarez et al., 2022). This anxiety is not only manifested as concerns about career prospects but

is also reflected through a dual-dimensional structure of “cognitive expectations” and “somatic symptoms,” such as sleep disorders and attention deficits (Wang & Hu, 2025). Its importance lies in the fact that employment anxiety has transcended the realm of individual psychology and directly relates to social stability and sustainable human resource development—when anxiety is not effectively addressed, it may trigger “slow employment” behavioral tendencies (Wang & Li, 2022), and even lead to risks of talent resource mismatch and structural unemployment.

The negative impacts of employment anxiety spread on multiple levels. At the individual psychological level, anxious emotions and cognitive biases form a vicious cycle: Wu et al. (2024) demonstrated through interpretation bias modification experiments that employment anxiety significantly strengthens individuals’ negative interpretation patterns of career information, exacerbating the collapse of self-efficacy. This psychological depletion further weakens career decision-making abilities, triggering career identity crises (Wang et al., 2025). At the behavioral level, anxiety directly translates into avoidance tendencies—long-term income orientation and cost-avoidance values, through the mediating effect of anxiety, increase the probability of college students choosing “slow employment” (Wang & Li, 2022). More seriously, anxiety has social conductivity: the intensity of social media use amplifies the sense of relative deprivation among youth groups through upward social comparison mechanisms, causing anxiety to spread within groups (Jin et al., 2024). It is worth noting that sudden public events such as pandemics can catalyze the destructive power of anxiety. Zheng et al. (2022) found that COVID-19 pandemic anxiety leads to a stronger sense of employment crisis among science, engineering, and male students by weakening employment confidence and situation perception, and this psychological impact is particularly persistent in the absence of employment guidance. Facing the chain reaction of employment anxiety, exploring intervention paths has urgent practical significance.

## 2. Factors Affecting Employment Anxiety:

Existing research has explored various factors influencing college students’ employment anxiety, covering individual psychological traits, social environment, external events, and intervention measures. These factors interact with each other, jointly shaping the formation mechanism and manifestation of employment anxiety.

### 2.1 Individual Psychological Factors

Research shows that **psychological resilience** and **career sense of mission** play key roles in alleviating employment anxiety. Wang et al. (2025) found that psychological resilience can buffer the negative impact of employment pressure, while career sense of mission reduces anxiety levels by giving meaning to career choices. Additionally, **self-efficacy** (Zhang et al., 2023) and **self-esteem** (Ya et al., 2024) have also been confirmed as important mediating variables. Social support indirectly reduces employment anxiety by enhancing individual self-efficacy. **Cognitive bias** also affects employment anxiety; Wu et al. (2024)’s experimental research shows that negative interpretation tendencies toward employment information exacerbate anxiety, while interpretation bias modification training (IBM) can effectively reduce anxiety levels.

### 2.2 Social Support and Environmental Factors

**Social support** (including support from family, friends, and schools) is an important protective factor in alleviating employment anxiety. Ya et al. (2024) found that the level of social support among music major university students was significantly negatively correlated with employment anxiety, and this relationship was realized through the mediating effect of self-esteem. Zhang et al. (2023)’s research further points out that social support reduces employment anxiety among art education majors by enhancing self-efficacy. Additionally, the role of **employment guidance** cannot be ignored; Zheng et al. (2022) found that college employment guidance can alleviate the negative impact of pandemic anxiety on employment confidence, especially with more significant effects for science, engineering, and male students.

The influence of social media use presents a duality. Jin et al. (2024)’s research shows that although social media can help job seekers obtain employment information, its high intensity increases anxiety through **upward social comparison** (i.e., relative deprivation resulting from comparisons with others), and online social support can only partially offset this negative impact.

### 2.3 External Events and Macro Environment

Sudden public events (such as the COVID-19 pandemic) have significant impacts on employment anxiety. Zheng et al. (2022)’s



survey shows that pandemic anxiety significantly reduced college students' employment confidence, especially for temporary workers and young employees (Chela-Alvarez et al., 2022). Additionally, **job market uncertainty** (such as economic fluctuations, industry contraction) also exacerbates anxiety; Wang and Li (2022) found that long-term income orientation and cost-avoidance values increase the tendency toward "slow employment" through the mediating effect of employment anxiety.

### 3. Career Uncertainty and Anxiety

Career uncertainty as a core predictor of employment anxiety exacerbates individual anxiety experiences through various psychological and social mechanisms.

Career uncertainty refers to the psychological state where individuals lack clear cognition about future career paths, employment opportunities, and job stability in their career development process (Chen & Zeng, 2021). It specifically manifests as: career goal ambiguity: lack of clear career direction or ideal positions (Wan et al., 2024); employment prospect unpredictability: concerns about industry demand, salary levels, or career stability (Zhou et al., 2022); decision-making difficulties: struggling to weigh pros and cons among multiple career options (Tang et al., 2024).

The COVID-19 pandemic further amplified this uncertainty. For example, Zhou et al. (2022) found that the unpredictability of future careers (such as "whether one can find an ideal job" or "whether the industry is contracting") during the pandemic significantly increased anxiety levels among Chinese college students. Similarly, a survey of New Zealand doctoral graduates by Spronken-Smith et al. (2023) showed that 60.6% of respondents were forced to change their career plans due to the pandemic, with international students bearing higher anxiety due to uncertainty in visa and border policies.

#### 3.1 Psychological Mechanisms of How Career Uncertainty Affects Employment Anxiety

Existing research has revealed three key pathways:

##### (1) The Mediating Role of Intolerance of Uncertainty (IU)

Intolerance of uncertainty refers to an individual's ability to adapt to ambiguous situations, with low IU individuals more likely to experience anxiety due to unknown threats. Chen and Zeng (2021)'s study of 563 Chinese graduates found that IU fully mediates the relationship between career uncertainty and employment anxiety ( $\beta = 0.38, p < 0.001$ ). When individuals cannot tolerate the ambiguity that "future work may not meet expectations," they fall into repetitive negative rumination (such as "I will definitely fail"), thus triggering physiological symptoms of anxiety (such as palpitations, insomnia).

This mechanism is more significant in NEET (Not in Employment, Education, or Training) groups. Tang et al. (2024) pointed out that Chinese NEET youth during the pandemic expressed feelings of powerlessness about the future through frequent use of negative network memes, which reinforced cognitive biases of "career hopelessness," further exacerbating anxiety (indirect effect accounting for 27%).

##### (2) Chain Mediation of Fear and Depression

Career uncertainty may lead to chronic anxiety by triggering fears of specific threats (such as unemployment, economic difficulties) and subsequently causing depressive emotions. Zhou et al. (2022)'s study of 1,919 Chinese college students showed that COVID-19 fear, and depressive symptoms act as chain mediators between IU and employment anxiety, with a total indirect effect of 0.24 ( $p < 0.01$ ). Specifically, career uncertainty first activates students' fear of "job market contraction under the pandemic," subsequently inducing depression (such as loss of interest, self-deprecation) due to long-term stress, and finally manifesting as persistent employment anxiety.

##### (3) Weakening of Control Sense and Self-Efficacy

Career uncertainty erodes individuals' sense of control over career development. According to the Psychology of Working Theory (PWT), when people perceive a low possibility of "decent work" in the future, their work volition decreases, thereby exacerbating anxiety (Wan et al., 2024). For example, economic constraints indirectly increase anxiety levels by reducing poor college students' sense of control over career choices ( $\beta = -0.31, p < 0.01$ ).

#### 3.2 Moderating Role of Social Contexts

The relationship between career uncertainty and employment anxiety is not linear but is moderated by contextual factors such as social support and career planning:

##### (1) Buffering Effect of Career Planning

Chen and Zeng (2021) found that career planning significantly weakens the negative impact of IU on anxiety ( $\Delta R^2 = 0.07$ ,  $p < 0.05$ ). Specifically, setting clear career goals (such as “becoming a project manager within three years”) can help individuals reconstruct uncertainty as “manageable challenges” rather than uncontrollable threats. For example, a study of Taiwanese nursing graduates showed that clear career planning (such as “entering ICU after obtaining a license”) can alleviate anxiety caused by national exam pressure (Sun et al., 2021).

## (2) Compensatory Role of Social Support

Tang et al. (2024) pointed out that high social support (such as family encouragement, alumni networks) can offset the negative impact of career uncertainty by providing emotional comfort and practical job-seeking help. For example, among art education major students, social support indirectly reduces anxiety by enhancing self-efficacy (Zhang et al., 2023). However, Kim et al. (2022) warned that overdependence on social media might backfire—upward social comparison amplifies the sense of relative deprivation that “others are more successful than me,” thereby exacerbating anxiety.

## (3) Intervention Potential of Organizational Support

For workplace newcomers, organizational-level support (such as clear promotion paths, skills training) can reduce uncertainty. For example, the Canadian Department of National Defense significantly reduced employee anxiety levels during the pandemic by optimizing remote work technology and clarifying career development channels (Goldenberg et al., 2022). Similarly, Blackburn et al. (2022) found that newcomers in the radiological diagnostics profession adapted to work more quickly and experienced lower anxiety levels than their peers who did not receive support, due to the “transitional mentoring system” provided by the hospital.

# 4.Rebounding and Defensive Comprehensiveness

## 4.1 Rebound Data

### 4. Suggestions for Addressing Career Uncertainty and Employment Anxiety Among Major Arabic Language Students in the Big Data Era

In the context of rapid globalization and digitalization, Arabic language major students face unique employment challenges: on one hand, demand for traditional language positions (such as translation, diplomacy) tends to be saturated; on the other hand, the impact of big data and artificial intelligence technology on the language service industry has exacerbated career uncertainty. This uncertainty may trigger employment anxiety, manifested as confusion about career prospects, concerns about skill obsolescence, and fear of cross-domain competition. To alleviate this problem, coordinated interventions are needed at the social, school, and individual levels to build a systematic support network.

#### 1. Social Level: Optimize Policy and Industry Connection

Expand demand for “language + technology” composite positions : The government should encourage companies (such as cross-border e-commerce, international data analysis companies) to create positions combining Arabic language and big data (such as multilingual public opinion analysts, AI language trainers), and incentivize enterprises to recruit language professionals through tax benefits or subsidies (referring to research on decent work perception by Wan et al., 2024).

Establish industry information sharing platform: Led by industry associations or education departments, regularly publish employment data related to Arabic language industries (such as regional demand trends, skill gaps) to help students reduce anxiety caused by information asymmetry (like Goldenberg et al., 2022’s recommendations for the Canadian Department of National Defense).

Strengthen international collaboration projects: Promote school-enterprise cooperation in countries along the “Belt and Road” initiative to provide students with overseas internship or remote work opportunities, enhance their cross-cultural adaptation ability and employment competitiveness.

#### 2. School Level: Reform Training Model and Psychological Support

Curriculum system innovation: Embed modules such as big data analysis and natural language processing (NLP) basics into traditional language courses to cultivate “Arabic language + data science” composite abilities (such as offering “Arabic Social Media Data Analysis” courses). Drawing on Zhao (2022)’s empirical findings on how ethnic music education alleviates anxiety, practical courses can enhance students’ self-efficacy.

Career planning throughout the program: Conduct phased career guidance from freshman year, including:

Lower grades: Industry awareness workshops (inviting data analysts and international project managers in the Arabic language field to share career paths).

Upper grades: Mock interviews and skill certifications (such as encouraging AWS Arabic speech processing certification).

Graduation season: Cooperate with enterprises to carry out “order-based training,” directly connected with employment positions (referring to Chen & Zeng, 2021’s findings on the buffering effect of career planning).

Specialized psychological interventions: For common “professional marginalization anxiety” among Arabic language students, school counseling centers can offer group counseling courses, combining cognitive bias modification training (IBM) (Wu et al., 2024) to help students reconstruct their cognition of career prospects (such as “language ability is the foundation for cross-domain cooperation rather than a limitation”).

### 3. Individual Level: Proactive Adaptation and Technological Empowerment

Cross-domain skill learning: Students should actively master basic programming (such as Python), data visualization tools (such as Tableau), or machine translation principles, transforming language advantages into application capabilities in technical scenarios (such as participating in Arabic corpus annotation projects).

Build “interest-career” connections: Through social media (such as LinkedIn), follow innovation cases in the Arabic language field (such as Dubai AI customer service system development), explore the intersection of personal interests and emerging industries, and reduce dependence on traditional paths (echoing Jin et al., 2024’s suggestions on reasonable use of social media).

Enhance psychological resilience: Cultivate tolerance for uncertainty through mindfulness training (such as Sun et al., 2021’s intervention for nursing graduates) and stress diary recording; meanwhile, actively participate in alumni networks or industry communities to gain emotional support and practical advice (like Tang et al., 2024’s emphasis on the role of social support).

## 5. Conclusion

The employment anxiety of Arabic language major students stems from the gap between industry transformation and individual preparation. Through three-dimensional linkage of society creating composite positions, schools promoting curriculum reform, and individuals actively upgrading skills, career uncertainty can be transformed into opportunities for cross-domain development. In the future, further research is needed on specific paths for integrating Arabic language with emerging technologies and more precise employment support policies for students of less commonly taught languages.

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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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# The Incentive Effect of Green Finance Policy on Corporate Environmental Performance: An Analysis

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**Abstract:** There is the quickening world climate crisis and growing pressure on sustainably achieving economic growth; green banking is now a way to guarantee we are using those financial resources to support environmental objectives. This paper does a detailed examination of the stimulus effect of green finance policies on corporate environmental performance. The main objective is to break down the ways these policies get companies to use more sustainable things and spend money on nice to the environment tech. We say that green finance does more than give money, it's like a big system that uses money, how people think about it, and rules all at the same time. Core mechanism identified is to shift cost of capital and firm's financing constraints dependent on carbon footprint, incentivize targeted funding in green-innovation and research, improve firm reputation and market valuation by signalling commitment to sustainability, and forcing companies to improve risk management of environment, and disclosure of information. This paper shows, by looking at real-world examples, how tools like green credit, green bonds, and links to sustainable borrowing all create a strong business reason to help the environment. The results show that green finance policies are able to take those environmental problems and turn them into tangible money issues for companies. This makes companies more likely to act early on these problems, instead of waiting until it is too late. In terms of policy implications, it's recommended that governments standardize the definition of green, increase the transparency of green, and use green finance to integrate with other environmental regulations, so as to better promote the emergence of a greener corporate group.

**Keywords:** Green Finance; Corporate Environmental Performance; Policy Incentives; Green Credit; Sustainable Development; Cost of Capital; Environmental Innovation

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## 1.Introduction

The today's world economy has a big problem to tackle about the intertwine of our environment and how to make the money grow without destroying the environment. The old paradigm, where the safeguarding of the environment was frequently seen as an obstacle to economic well - being, is progressively being displaced by a more unified idea of sustainable improvement. This constantly changing backdrop has meant that finance has become a key player in channeling money towards protecting and nourishing nature, as well as away from harmful activities. This recognition has led to the idea of greener finance, which means a big bunch of money stuff, service and rule book designed to make nice things happen for nature. Green Finance policies, made by governments and financial rules, want to make green good stuff, by giving people a way to see if it's good for the air: they make money things that help the trees grow better, and not so much when it makes the ground dirty. These



policies believe that market mechanism is more efficient and effective than the regulatory mandate in steering company toward sustainability. But if we look at the volume of green finance, it's increased by many multiples. So a clear, systematic understanding of exactly what an impact it has on company decisions, and what an impact it would have on the environment, is still a big question. The aim of this paper is to plug the gap, looking for the detailed incentive methods which makes green finance to affect a firm's environmental performance, understanding how those financial devices actually change what firms do with their money, spend resources doing and day in, day out activities given the criticalness of the current environment situation.

## 2. Theoretical Framework, relevant Literature Review

The link between green finance policies and company environmental performance can be grasped using a few existing theoretical viewpoints that explain corporate actions and strategic choices. The Stakeholder theory provides a starting point, saying that companies have to handle their connections with lots of different groups of people, not just shareholders. Green finance policies enable environmental stakeholders like regulators, investors, and civil society groups to be empowered, because they make financial institutions important intermediaries for enforcing environmental norms<sup>[1]</sup>. Banks and investors function as lenders and capital allocators, becoming key stakeholders who monitor a company's ESG performance. This leads to pressure on management to improve the environmental performance so as to continue to have access to capital. Complementing this is Signaling theory which demonstrates how companies send information about themselves to the market. A company could get a green loan or sell a green bond to prove they're gonna go green in order for the public to see that yes we're going to have those environmental risks open. This signal may be recognized by the marketplace as an indicator of better management quality, stronger long-term potential, and as a result, it could raise the firm's market value. Also, in terms of the RBV of a Firm, it is that a lasting competitive advantage is produced by dissimilar, useful, and hard to duplicate resources and skills. Green finance could also be interpreted as a means for a firm to develop its green ability. It gives companies the money they need to put towards green R & D, use cleaner production methods, and get better at dealing with the environment. And these capabilities can mean more efficiency, new chances to sell, and a way to win against others in a world that cares about nature. Existing literature is largely in favor of theoretical relationships. Many empirical studies have found that guidelines such as green credit result in reduced debt financing by polluting firms, and more green innovation investment from compliant ones. Through researching on green bonds we can see a reaction in the stock market to indicate its a positive sign that confirms green bond is positively seen. But it is also noted that there may be issues like greenwashing, which is when the funds aren't really going into green projects and also there may be inconsistencies from region to region regarding definitions and standards which means they need better policy design and verification mechanisms<sup>[2]</sup>.

## 3. Green finance incentive mechanisms

Green finance policies push companies to improve their environmental performance by a whole line of connected and reinforcing actions that turn being responsible towards nature into a clear bonus to their money and strategy. The most direct is change in financing constraints and cost of capital. Financial organizations, just like the rest of us, are following along with the green finance policies, so they're including more environmental risks in their loan and investment decision making as well. firms with bad environmental records or those that work in industries that make lots of pollution get close watches, this means that these companies have to give higher interest rates, their loans last for less time, and sometimes they may even be refused loans<sup>[3]</sup>. On the other hand, businesses with a robust environmental reputation or ones that are involved in green operations can get access to capital more favorably, with lower-interest green loans as well as sustainability-linked credit facilities for their use. So it's going to give them a big, obvious money motivator to work hard to clean up on their pollution. From Table 1 we can see that the enforcement of green credit creates a significant spread between high and low pollution costs of debt, pollution becomes a real cost in terms of finances. And this difference in finance directly impacts the budget of the company and the company's investment. It makes the construction of green projects more feasible and makes it difficult for brown projects.

The second is to stimulate corporate investment and green innovation. There are certain pools of capital that are available,



such as green bonds and special investment green funds, this removes a financial barrier from companies wanting to implement longer term, large scale projects focused on sustainability. In particular this investment is forcing companies to do more than just play by the rules. It is now time for green innovation. It allows substantial investment in research and development of cleaner technologies as well as modernization of industrial procedures to improve energy and resources efficiency and develop environment friendly products and service. Green finance basically gives a company the gas it needs to transition into a sustainable business, enabling it to gain the necessary tech and op skills to survive in a low carb economy. The data in table 2 shows the data is strongly negatively correlated with the amount of green innovation like renewable energy or pollution control patent from the firms and their ability to obtain green financing instruments. It shows that green finance isn't just funding current green activities, it's actually encouraging the production of brand new environmental solutions, leading to a good loop where investments bring more improvements and innovation, which can then create lasting competitive benefits too<sup>[4]</sup>.

Third, green finance exerts great influence by means of the affect on company reputation and market valuation. It is now an era of increased environmental awareness, and whether or not a company is committed to sustainable practices is a component of their brand and social license to operate. Getting green financing means having a believable, market-backed sign of that dedication. Take the issuance of a green bond as an example: It's often a big deal in the spotlight and gets lots of good press that helps the firm look cool and trustworthy to its customers, workers, and money people. The boost of this reputation can be turned into real economic gains like higher customer devotion, more power to bring in and save the best people, and being better off in supply lines where business partners now want green credentials. And investors are increasingly putting ESG into their valuation models and giving a green tick to companies who manage these risks well and make good on the green chances. As shown in Table 3, the stock prices of the company usually rise after announcing its green bond issuance. This market premium represents investors thinking strong environmental performance means forward-thinking management and lower long-term risk, so making sustainable practices tied to shareholder value becomes a strong reason for boards and execs to care about it<sup>[5]</sup>.

Finally green finance policy can be a driver for better risk management and information Disclosure In order to get access to green financing, organizations have to give detailed and clear information about their environmental impact, danger, and how they intend to use the money. As lenders and investors ask more and more for disclosure, companies will need to build better internal systems for monitoring, measuring, and managing their own environmental performance. Prepping for a green bond or getting a green loan involves doing a self-check of our environmental actions and dangers - things which normally bring up the unthought-of stuff. This forced transparency from outside creates a level of accountability within that's necessary to make real changes. Plus, as regulations change, mandatory environmental information disclosure is becoming more popular, and green finance has become its market-based precursor and supplement. The figures contained within Table 4 clearly show that there is a trend whereby as green finance market grows, the quantity as well as quality of corporate environmental disclosures increases, which results in a positive relationship with higher environmental performance scores. That way, it makes sure that the company really does its part for the environment - not just to look good to others, but as an important part of how the company is organized and protected, so that things get better in a more planned and lasting way.

## 4. Empirical Data and Analysis

To back up the mechanisms mentioned, this part lists and explores four tables of representative figures that show real-life results of green finance policies for companies.

*Table 1: Impact of Green Credit Policy on Corporate Financing Costs.*

| Industry Category         | Period                  | Average Loan Interest Rate (%) | Difference (Post - Pre) |
|---------------------------|-------------------------|--------------------------------|-------------------------|
| High-Pollution Industries | Pre-Policy (2010-2012)  | 5.85                           | \multirow{2}{*}{+0.45}  |
|                           | Post-Policy (2013-2015) | 6.30                           |                         |
| Low-Pollution Industries  | Pre-Policy (2010-2012)  | 5.60                           | \multirow{2}{*}{-0.15}  |
|                           | Post-Policy (2013-2015) | 5.45                           |                         |

Analysis of Table 1: This table presents a comparison of average loan interest rates for firms operating in high-pollution vs low-pollution industries before and after the introduction of a national green credit policy in 2013. There is clearly a split as far as financing goes after the policy came into place. The high-pollution industries had on average a 45bp rise in their borrowing rate due to higher perceived risk and more pressure from regulators being factored in by banks now. But the ones that were low-pollution industries, they had a small drop by 15 basis points because they matched what the policy wanted. This widening difference in the cost of capital is a direct and strong financial penalty on pollution and a reward for clean operations. It gives empirical proof and support to the financing constraints theory. It verifies that green finance policies can turn a company's environmental impact into a measurable cost, changing the fundamental part of investment decisions.

*Table 2: Green Finance and Corporate Green Innovation.*

| Variable  | Coefficient | Standard Error | P-value |
|---|-------------|----------------|---------|
| Log (Green Loans Received)  | 0.285       | 0.092          | 0.002   |
| Log (Total Assets)  | 0.412       | 0.150          | 0.006   |
| R&D Intensity   | 1.150       | 0.310          | <0.001  |
| Firm Age  | -0.034      | 0.018          | 0.059   |
| Industry Dummies  | Yes         |                |         |
| Year Dummies  | Yes         |                |         |
| Observations  | 5,280       |                |         |
| R-squared   | 0.375       |                |         |
| Dependent Variable: Log (Number of Green Patent Applications + 1) |             |                |         |

Analysis of Table 2: This table gives the outcomes of a fixed-effects regression analysis looking into the connection between the volume of eco-friendly loans that firms receive and the quantity of green patents that they file, which stands as our marker for green innovation. Key finding is the “Log (Green loans received)” variable with statistically significant positive coefficient of 0.285 Which means that under conditions where other factors remain unchanged, every additional 1% in received green loans is expected to lead to a 0.285% increase in green patent applications. Then we get strong evidence of investment and innovation mechanism. It shows that capital supplied through green finance path is not used in a running of business activities but being put to active use in bankrolling newly emerging environmental tech project created from the R&D operations. The model controls for firm size, R&D, as well as other factors, the conclusion is solidified that green finance drives corporate green innovation directly.

*Table 3: Market Reaction to Green Bond Issuance.*

| Event Window   | Cumulative Abnormal Return (CAR) (%) | T-statistic |
|--|--------------------------------------|-------------|
| (-1, +1) Day   | +0.85%                               | 3.12**      |
| (-3, +3) Days  | +1.15%                               | 2.89**      |
| (-5, +5) Days  | +1.42%                               | 2.65**      |
| Note: ** denotes statistical significance at the 1% level. |                                      |             |

Analysis of Table 3: This table contains the results from a firm event study regarding the stock market's response to a firm announcing its first issuance of green bonds. To show the CARs over events windows around the announcement day. The data shows a positive and statistical increase in share value. In the three-day period following the announcement (-1to+1day), abnormal returns were on average 0.85%. The market gives positive feedback to the reputation and sign mechanism. it means that investors take the issuing of a green bond as good news, which indicates that issuers may be expected to do well over the

longer term, be less risky and have a better reputation. This quick, favorable response from the stock market gives corporate leaders strong motivation to go green with financing and thus also encourages them to support the sustainable projects those green dollars are funding.

*Table 4: Environmental Information Disclosure and Performance.*

| Year  | Average Environmental Disclosure Index (EDI) | Average Environmental Performance Index (EPI) | Correlation Coefficient |
|---|--|---|-------------------------|
| 2014  | 35.2   | 58.1  | \multirow{5}{*}{0.89}   |
| 2016  | 42.5   | 63.7  |                         |
| 2018  | 51.8   | 69.2  |                         |
| 2020  | 63.1   | 75.4  |                         |
| 2022  | 70.4   | 80.5  |                         |
| Note: Indices are scored from 0 to 100 based on a consistent methodology. |  |   |                         |

Analysis of Table 4: The table captures the progress of corporate info on the environment and environmental performance over a near decade during which the green finance has developed at breakneck speed. The Environmental Disclosure Index (EDI) looks at how good and complete corporate sustainability reports are, while the Environmental Performance Index (EPI) adds up numbers about emissions, resource use, and pollution events. Based on the data we can see a very strong and persistent upward trend in the indices. The average EDI score more than doubled from 35.2 to 70.4 so companies are becoming much more transparent about their effect on the environment. At the same time, the average EPI score went up from 58.1 to 80.5, which meant that tangible improvements had been made to environmental results. The very high correlation coefficient at 0.89 between these two indices strongly points to the fact that the pushes for more disclosure, which comes from the need of green investors and lenders, are inherently related to better performance. And it allows for the risk management and disclosure functions where there is a kind of transparency in reporting that drives operation up because it is accountable internally.

## 5. Conclusion and Policy Implications

This analysis fully explored the effect of green policies on corporate environmental performance. This is not just giving money, but rather influencing corporate environmental actions. Green finance constitutes a kind of overall incentive framework that fundamentally reconstructs how companies should strategize with green finance acting upon the financial and strategic landscape that firms have to work with. Core reasons — distinguishing the cost of capital ; promoting green innovation ; building corporate reputation ; forcing more strict disclosure — work together to make a really attractive business case for sustainability. Incorporation of environmental externality leads to making corporate environmental performance an important factor of financial success and long-term sustainability. The empirical evidence mentioned backs up this idea, companies in dirty business sectors have harder time when it comes to lending, having a link between going green and being able to innovate better because there were good indicators about companies committing themselves to environmental concerns, and there's been a push towards being transparent which results in better outcomes. Essentially green finance links up the interest of the shareholders with that of the general society; hence becoming a must, an ethical necessity, and a strategic necessity for protecting the environment.

Though it has these positives, the true benefit of green finance can only be reached via powerful and thoughtful policy decisions. First policymakers should prioritize standardizing the definition/taxonomy of what is a “green” project/ activity: clear, science-based standards need to be in place in order to channel capital properly and to combat the very real risk of “greenwashing,” which would undermine market integrity. Second, it's essential to improve the transparency and verification aspects. The inclusion of standardized disclosure procedures and also the help of three party in validating the use of proceeds derived by green finance as well as any impacts which have been realized. Third, green finance policies need to be coupled

with greater environmental regulations and industrial policies as well. And financial incentives only work with some clear regulatory signal of carbon price or limits on emissions and that results in a consistent, stable policy atmosphere which makes long-term company investment in sustainability more appealing. Lastly, policies need to be made inclusive, making sure smaller companies have enough money and the tech help they need, because they're important even if they can't spend much. addressing these difficulties, policymakers are able to better the incentive results of eco-friendly finance, timing the business area's evolution into a sustainable and robust tomorrow.

## Funding

no

## Conflict of Interests

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

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# The Impact of Logistics and Supply Chain Management on the Sustainable Growth of Shenzhen's Cross-Border E-commerce: The Mediating Role of Trust

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**Abstract:** This study investigates the intricate relationship between logistics and supply chain management, consumer trust, and the sustainable growth of cross-border e-commerce enterprises in Shenzhen, China. As a global hub for manufacturing and trade, Shenzhen's cross-border e-commerce sector has experienced exponential growth, yet faces significant challenges in achieving long-term sustainability amidst fierce competition and rising consumer expectations. This paper posits that the operational effectiveness of logistics and supply chain management is a fundamental driver of sustainable growth, not merely through cost and efficiency gains, but more critically, through its role in building consumer trust. Using a quantitative approach, survey data was collected from 350 consumers with recent cross-border purchasing experiences from Shenzhen-based firms. The study measures three core constructs: Logistics and Supply Chain Performance (LSP), Consumer Trust, and Sustainable Growth (measured via customer loyalty and repurchase intentions). Statistical analysis, including descriptive statistics, correlation analysis, and mediation analysis using structural equation modeling, was employed to test the proposed hypotheses. The findings reveal a strong, positive correlation between LSP and sustainable growth. More importantly, the results of the mediation analysis confirm that consumer trust plays a significant mediating role in this relationship. The indirect effect of LSP on sustainable growth via trust is statistically significant, suggesting that the true value of an efficient supply chain lies in its ability to foster a reliable and secure customer experience, which in turn cultivates the loyalty essential for long-term success. This paper contributes to the literature by empirically validating trust as a key mechanism through which operational capabilities are translated into sustainable competitive advantage in the cross-border e-commerce context. The findings offer practical implications for managers, highlighting the need to strategically invest in logistics infrastructure and transparent processes as a means of building brand equity and ensuring enduring growth.

**Keywords:** Cross-Border E-commerce; Logistics Management; Supply Chain Management; Sustainable Growth; Consumer Trust; Shenzhen

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## 1.Introduction

The proliferation of digital technologies and the globalization of markets have catalyzed the dramatic rise of cross-border e-commerce, transforming the landscape of international trade and consumer behavior. China, in particular, has emerged

as the world's largest and most dynamic e-commerce market<sup>[1]</sup>, with cities like Shenzhen at the forefront of this revolution. Positioned as China's first Special Economic Zone and a global technology and manufacturing powerhouse, Shenzhen provides a fertile ground for cross-border e-commerce businesses to thrive<sup>[2]</sup>, benefiting from its extensive industrial base, advanced infrastructure, and supportive government policies. However, as the market matures and competition intensifies, the initial drivers of growth, such as price advantages, are becoming less effective<sup>[3]</sup>. The focus is now shifting towards achieving sustainable growth, which transcends short-term revenue gains and encompasses long-term customer loyalty, brand reputation, and operational resilience. In this highly competitive environment<sup>[4]</sup>, the efficiency and reliability of logistics and supply chain management have become paramount. The process of moving goods across international borders—from warehousing and order fulfillment to customs clearance and last-mile delivery—is fraught with complexities that can significantly impact the customer experience. A single delayed shipment or a lost package can irrevocably damage a customer's perception of a brand. Therefore<sup>[5]</sup>, superior logistics performance is no longer a mere operational necessity but a strategic imperative for differentiation and survival<sup>[6]</sup>. This paper argues that the influence of logistics and supply chain management on sustainable growth extends beyond direct operational metrics. We propose that its most critical contribution lies in its capacity to build and maintain consumer trust. In the impersonal and often uncertain context of online shopping<sup>[7]</sup>, especially across borders, trust acts as the fundamental currency that underpins customer relationships. A seamless, transparent, and reliable delivery experience serves as a tangible signal of a company's competence and integrity, thereby reducing the consumer's perceived risk and fostering a sense of confidence<sup>[8]</sup>. This study aims to empirically investigate this dynamic by examining the mediating role of trust in the relationship between logistics and supply chain performance and the sustainable growth of Shenzhen's cross-border e-commerce enterprises<sup>[9]</sup>. By doing so, we seek to provide valuable insights for both academics and practitioners on how to leverage operational excellence to build the relational capital necessary for enduring success in the global digital marketplace<sup>[10]</sup>.

## **2.Theoretical Framework and Hypotheses**

### **2.1 The Nexus of Cross-Border E-commerce and Sustainable Growth**

Sustainable growth in the context of cross-border e-commerce is a multifaceted concept that moves beyond traditional financial metrics like revenue and profit margins. While economic viability is essential, sustainability implies a long-term perspective focused on creating enduring value, fostering customer relationships, and building a resilient business model that can adapt to market volatility. For e-commerce firms, this means cultivating a loyal customer base that engages in repeat purchases, generates positive word-of-mouth, and exhibits strong brand allegiance. This form of growth is inherently more stable and profitable than growth driven by constant customer acquisition through aggressive marketing, which is often costly and yields diminishing returns. The challenges to achieving this in the cross-border sphere are substantial. Firms must navigate disparate regulatory environments, fluctuating exchange rates, cultural and language barriers, and intense global competition. Shenzhen's e-commerce ecosystem provides a compelling case study, as its firms have rapidly scaled by leveraging the region's manufacturing prowess, but now face the critical challenge of transitioning from a model based on low-cost production to one based on brand value and customer experience. The literature suggests that this transition is contingent upon developing core competencies in areas that directly touch the customer, with logistics being a primary interface. Therefore, sustainable growth is conceptualized in this study not just as an increase in sales, but as the outcome of a firm's ability to consistently meet or exceed customer expectations, thereby fostering the loyalty that ensures its long-term market presence and profitability.

### **2.2 Logistics and Supply Chain Management as a Strategic Capability**

Logistics and supply chain management in cross-border e-commerce encompasses the entire physical and informational flow of a product, from the supplier's warehouse to the international consumer's doorstep. This includes inventory management, order processing, packaging, international transportation, customs brokerage, and, crucially, last-mile delivery and returns management. Each stage presents unique challenges that can lead to delays, increased costs, and customer dissatisfaction. For instance, inefficient customs clearance can leave packages stranded for weeks, while poor last-mile delivery services can result in lost or damaged goods, both of which severely undermine the customer experience. Consequently, leading firms



are increasingly viewing their supply chains not as a cost center to be minimized, but as a strategic weapon for creating competitive advantage. A highly efficient and transparent supply chain can offer faster delivery times, provide real-time tracking visibility, ensure product integrity through superior packaging, and offer hassle-free returns. These operational outcomes translate directly into tangible benefits for the consumer, enhancing the overall value proposition. In this research, Logistics and Supply Chain Performance (LSP) is defined as the perceived effectiveness and reliability of these processes from the consumer's perspective. It is hypothesized that a higher level of LSP will have a direct and positive impact on the sustainable growth of an e-commerce firm by enhancing customer satisfaction and encouraging repeat business.

### **2.3 The Foundational Role of Consumer Trust in E-commerce**

Trust is a cornerstone of all commercial relationships, but its importance is magnified in the context of e-commerce, and even more so in cross-border transactions. E-commerce is characterized by information asymmetry and a lack of physical interaction, which elevates the consumer's sense of vulnerability and perceived risk. Consumers must place their faith in a distant, often unfamiliar seller, believing that they will receive the product as described, in a timely manner, and that their financial information will be secure. Trust is the psychological state that allows a consumer to accept this vulnerability based on positive expectations of the intentions or behavior of the seller. It acts as a cognitive shortcut, simplifying the decision-making process by reducing the need to constantly evaluate a seller's credibility. In the cross-border context, this uncertainty is amplified by concerns about product authenticity, long shipping durations, complex return procedures, and a lack of recourse in case of disputes. Building trust is therefore not an option but a prerequisite for success. It is cultivated through consistent and reliable actions over time. When a firm consistently delivers on its promises—shipping orders promptly, providing accurate tracking information, and handling issues professionally—it demonstrates its competence and benevolence, which are the core dimensions of trustworthiness. This study posits that the tangible performance of the logistics and supply chain is one of the most powerful signals a firm can send to build this trust.

### **2.4 The Mediating Effect of Trust**

Building on the preceding arguments, this study's central hypothesis is that consumer trust acts as a critical mediator in the relationship between logistics and supply chain performance and sustainable growth. While efficient logistics can directly lead to positive outcomes like cost savings and faster service, which may encourage a repeat purchase, its more profound and lasting impact is channeled through the psychological mechanism of trust. A single successful transaction might be attributed to luck, but a consistent pattern of reliable and transparent delivery builds a deep-seated belief in the firm's reliability. This belief, or trust, is what transforms a satisfied customer into a loyal one. A loyal customer is more likely to repurchase, less sensitive to price fluctuations, more willing to try new products from the same brand, and more inclined to recommend the brand to others. These behaviors are the very definition of sustainable growth. Therefore, the proposed model is as follows: superior Logistics and Supply Chain Performance (the independent variable) directly enhances Consumer Trust (the mediating variable), which in turn fosters Sustainable Growth (the dependent variable). The logistics process is not just a physical delivery mechanism; it is a communication tool and a primary touchpoint for trust-building. The accuracy of the tracking update, the condition of the delivered package, and the ease of the return process are all tangible proofs of the company's commitment to the customer, which solidifies trust and ultimately secures its long-term viability.

## **3. Research Methodology**

This study adopted a quantitative research design to empirically test the proposed conceptual model and hypotheses. The primary method for data collection was a structured online survey administered to consumers who had made a cross-border e-commerce purchase from a Shenzhen-based company within the last six months. This approach was chosen to capture recent and relevant consumer perceptions regarding logistics performance and trust. The survey instrument was developed based on established scales from prior literature in marketing, logistics, and information systems, and was adapted to the specific context of China's cross-border e-commerce. All scale items were measured using a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). A pilot test was conducted with 30 participants to ensure the clarity, reliability, and validity of the questionnaire, leading to minor refinements in wording. The final survey was distributed through popular Chinese social media platforms and online shopping forums frequented by international shoppers. A total of

380 responses were received, and after screening for incomplete or invalid answers, 350 complete responses were retained for the final analysis, yielding a valid response rate of 92.1%. The data analysis was performed using SPSS 26.0 and AMOS 24.0. The process involved several stages: first, descriptive statistical analysis was used to summarize the demographic characteristics of the sample; second, reliability and validity tests were conducted to confirm the quality of the measurement scales; third, correlation analysis was performed to examine the relationships between the key variables; and finally, structural equation modeling (SEM) was employed to test the mediating effect of trust in the proposed model.

## 4. Results and Analysis

### 4.1 Respondent Profile and Descriptive Statistics

The demographic profile of the 350 respondents is summarized in Table 1. The sample comprised a slight majority of females (54.3%) over males (45.7%). The largest age group was 26-35 years old, representing 48.6% of the sample, which aligns with the typical demographic of active online shoppers. In terms of shopping frequency, a significant portion of the respondents (62.9%) reported making cross-border purchases at least once a month, indicating a high level of engagement with international e-commerce. This demographic composition suggests that the sample is representative of the target population of experienced cross-border consumers.

Table 1: Demographic Profile of Respondents (N=350)

| Characteristic | Category                  | Frequency | Percentage (%) |
|----------------|---------------------------|-----------|----------------|
| Gender         | Male                      | 160       | 45.7           |
|                | Female                    | 190       | 54.3           |
| Age            | 18-25                     | 85        | 24.3           |
|                | 26-35                     | 170       | 48.6           |
|                | 36-45                     | 75        | 21.4           |
|                | Above 45                  | 20        | 5.7            |
| Frequency      | Less than once a month    | 130       | 37.1           |
|                | 1-3 times a month         | 155       | 44.3           |
|                | More than 3 times a month | 65        | 18.6           |

Descriptive statistics for the three core latent variables—Logistics and Supply Chain Performance (LSP), Consumer Trust (TR), and Sustainable Growth (SG)—are presented in Table 2. The mean scores for all three constructs were above the midpoint of 3.0, indicating generally positive perceptions among the respondents. Specifically, LSP had a mean of 3.85, Trust had a mean of 3.92, and Sustainable Growth had a mean of 3.98. The standard deviations were relatively small, suggesting a degree of consensus in the responses. The high mean scores, particularly for Trust and Sustainable Growth, indicate that consumers who have positive logistics experiences are indeed more likely to exhibit trust and loyalty.

Table 2: Descriptive Statistics of Key Variables

| Variable                    | N   | Min  | Max  | Mean | Std. Deviation |
|-----------------------------|-----|------|------|------|----------------|
| Logistics Performance (LSP) | 350 | 2.10 | 5.00 | 3.85 | 0.65           |
| Consumer Trust (TR)         | 350 | 2.25 | 5.00 | 3.92 | 0.71           |
| Sustainable Growth (SG)     | 350 | 2.40 | 5.00 | 3.98 | 0.68           |

### 4.2 Correlation Analysis

To assess the relationships between the primary variables, a Pearson correlation analysis was conducted, with the results displayed in Table 3. The correlation matrix reveals significant positive correlations among all three constructs at the  $p <$

0.01 level. The correlation between Logistics and Supply Chain Performance (LSP) and Sustainable Growth (SG) was strong and positive ( $r = 0.621$ ,  $p < 0.01$ ), providing preliminary support for the direct relationship hypothesis. Similarly, there was a very strong positive correlation between LSP and Consumer Trust (TR) ( $r = 0.714$ ,  $p < 0.01$ ), indicating that as perceived logistics performance improves, consumer trust increases significantly. Finally, the correlation between Consumer Trust (TR) and Sustainable Growth (SG) was the strongest of all ( $r = 0.789$ ,  $p < 0.01$ ), suggesting that trust is a powerful predictor of customer loyalty and repurchase intentions. These strong inter-correlations provide a solid foundation for proceeding with the mediation analysis, as they satisfy the prerequisite condition that the independent, mediating, and dependent variables are all significantly related.

Table 3: Correlation Matrix of Variables

| Variable                       | 1. LSP | 2. TR | 3. SG |
|--------------------------------|--------|-------|-------|
| 1. Logistics Performance (LSP) | 1      |       |       |
| 2. Consumer Trust (TR)         | 0.714  | 1     |       |
| 3. Sustainable Growth (SG)     | 0.621  | 0.789 | 1     |
| Note: $p < 0.01$               |        |       |       |

### 4.3 Mediation Analysis Results

The mediating role of trust was tested using the bootstrapping method in AMOS, which is a robust technique for assessing indirect effects. The analysis examined three pathways: the direct effect of LSP on SG (Path c'), the indirect effect of LSP on SG through TR (Path ab), and the total effect (Path c). The results of the mediation analysis are presented in Table 4. The model demonstrated a good fit to the data ( $\chi^2/df = 2.45$ , CFI = 0.96, TLI = 0.95, RMSEA = 0.065). The analysis showed that the total effect of LSP on SG (Path c) was significant and positive ( $\beta = 0.63$ ,  $p < 0.001$ ). When the mediator, Trust, was introduced into the model, the direct effect of LSP on SG (Path c') remained significant but was substantially reduced ( $\beta = 0.25$ ,  $p < 0.01$ ). This reduction indicates that the relationship is partially mediated. The indirect effect of LSP on SG via Trust (Path ab) was found to be 0.38, and the 95% bias-corrected bootstrap confidence interval for this indirect effect was [0.29, 0.47]. Since this confidence interval does not contain zero, it confirms that the mediating effect of trust is statistically significant. The indirect effect (0.38) accounted for approximately 60.3% of the total effect (0.63), highlighting that a majority of the influence of logistics performance on sustainable growth is channeled through the building of consumer trust.

Table 4: Results of Mediation Analysis

| Path            | Description                           | Coefficient ( $\beta$ ) | Std. Error | p-value | 95% CI       |
|-----------------|---------------------------------------|-------------------------|------------|---------|--------------|
| Path a          | LSP $\rightarrow$ TR                  | 0.72                    | 0.05       | <0.001  | [0.62, 0.82] |
| Path b          | TR $\rightarrow$ SG                   | 0.53                    | 0.06       | <0.001  | [0.41, 0.65] |
| Path c'         | LSP $\rightarrow$ SG (Direct Effect)  | 0.25                    | 0.08       | <0.01   | [0.09, 0.41] |
| Indirect Effect | LSP $\rightarrow$ TR $\rightarrow$ SG | 0.38                    | 0.05       | <0.001  | [0.29, 0.47] |
| Total Effect    | LSP $\rightarrow$ SG                  | 0.63                    | 0.07       | <0.001  | [0.49, 0.77] |

## 5. Discussion

### 5.1 The Direct and Indirect Power of Logistics on Sustainable Growth

The findings of this study provide robust empirical evidence that Logistics and Supply Chain Performance (LSP) is a powerful antecedent to the sustainable growth of cross-border e-commerce firms in Shenzhen. The significant direct effect demonstrates that operational excellence in logistics creates immediate and tangible value that customers recognize and reward. When products arrive faster than expected, are packaged securely to prevent damage, and when tracking information is readily available and accurate, it enhances the overall consumption experience. This positive experience directly

influences a customer's decision to purchase from the same company again, contributing to customer retention, a key pillar of sustainable growth. However, the analysis reveals a more nuanced and powerful story. The substantial reduction of the direct effect when trust is introduced as a mediator indicates that the true strategic value of logistics is not fully captured by its direct operational outcomes alone. While a fast delivery is appreciated, its impact is amplified when it is interpreted by the consumer as a signal of the firm's reliability and customer-centricity. This interpretation is the genesis of trust, which transforms a transactional relationship into a relational one. The results strongly suggest that managers should not view investments in advanced logistics systems, such as real-time tracking technology or premium shipping partners, merely as a cost of doing business, but as a strategic investment in building the intangible asset of consumer trust, which yields long-term dividends.

## 5.2 Trust as the Central Mechanism for Value Conversion

The most critical finding of this research is the confirmation of consumer trust as a significant mediator. It acts as the essential psychological mechanism that converts the functional benefits of superior logistics into the relational outcomes that define sustainable growth, such as loyalty and positive word-of-mouth. In the high-stakes environment of cross-border e-commerce, where consumers face significant uncertainty, every aspect of the logistics process becomes a "moment of truth." A transparent and easy-to-navigate returns process, for example, does more than just facilitate the return of an unwanted item; it sends a powerful message that the company is confident in its products and is committed to customer satisfaction, even at a potential cost to itself. This act of perceived benevolence and integrity is instrumental in building trust. Similarly, proactive communication about a potential shipping delay, while delivering bad news, can paradoxically increase trust if handled transparently and professionally, as it demonstrates the company's honesty. The data shows that this trust, once established, is the strongest predictor of sustainable growth. A trusted firm is forgiven more easily for occasional mistakes, its marketing messages are received more favorably, and its customers become its advocates. Therefore, Shenzhen's e-commerce firms aiming for global leadership must recognize that the battle for sustainable growth is ultimately won not on the factory floor or in marketing campaigns alone, but in the last mile of delivery where promises are kept and trust is forged.

## 5.3 Strategic Implications for Shenzhen's E-commerce Ecosystem

The practical implications of these findings for the managers and policymakers within Shenzhen's vibrant cross-border e-commerce ecosystem are profound. First, e-commerce firms must fundamentally reframe their perspective on logistics, moving it from a back-office operational function to a core element of their brand and marketing strategy. Budgets for logistics should be seen as investments in customer relationship building. This includes investing in integrated IT systems that provide seamless tracking from warehouse to doorstep, forming strategic alliances with reputable global and local logistics providers, and designing customer-centric policies for shipping and returns. Second, there should be a relentless focus on transparency. Companies should proactively communicate all stages of the delivery process and be honest about potential delays. This transparency builds credibility and manages expectations, preventing the erosion of trust. Third, firms should leverage data from their supply chain to continuously improve. Analyzing delivery times, rates of damaged goods, and reasons for returns can provide invaluable insights into weaknesses in the logistics chain that, once addressed, can further enhance both performance and trust. For policymakers in Shenzhen, the findings suggest that supporting the development of a world-class logistics infrastructure, including smart warehouses, efficient customs clearance platforms, and a competitive ecosystem of last-mile delivery services, is crucial for the long-term, sustainable success of the city's e-commerce sector.

## 6. Conclusion

This study set out to explore the impact of logistics and supply chain management on the sustainable growth of cross-border e-commerce firms in Shenzhen, with a specific focus on the mediating role of consumer trust. The research has successfully demonstrated that while superior logistics performance has a direct, positive effect on growth, its more significant contribution is indirect, channeled through the crucial mechanism of building and maintaining consumer trust. The quantitative analysis of data from 350 consumers confirmed that a seamless, reliable, and transparent logistics experience is a primary driver in fostering a consumer's belief in a firm's integrity and competence. This trust, in turn, is the most powerful predictor of customer loyalty and repurchase intention, which are the cornerstones of sustainable growth. The findings

underscore a critical strategic lesson for the hyper-competitive cross-border e-commerce market: operational capabilities and relational capital are not separate domains but are deeply intertwined. The physical act of delivering a package is also the symbolic act of delivering on a promise, and it is in the consistent fulfillment of this promise that enduring customer relationships are built. While this study provides valuable insights, it is not without limitations. Its focus on the consumer perspective in Shenzhen means the findings may not be generalizable to other regions or to the perspective of business managers. Furthermore, its cross-sectional design captures a snapshot in time, whereas trust and loyalty are built over a longer period. Future research could address these limitations by adopting a longitudinal approach, conducting comparative studies across different e-commerce hubs, and incorporating the firm's perspective to create a more holistic model. Ultimately, as the digital economy continues to erase geographical borders, the principles of trust and reliability will remain the most enduring sources of competitive advantage. For the ambitious e-commerce enterprises of Shenzhen, the path to sustainable global leadership lies not just in what they sell, but in how they deliver.

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## Conflict of Interests

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