

Systematic application and research of artificial intelligence technology in smart supervision of elevators

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Abstract

Purpose – The study aims to explore the transformation mechanism of artificial intelligence on elevator safety supervision and provide a theoretically cutting-edge and practically guiding governance plan for Ningbo and similar cities.

Design/methodology/approach – Based on the actual needs of Ningbo Municipal Market Supervision Bureau, this paper constructs a research system through literature review and case analysis, identifies key problems and proposes a four-dimensional AI supervision framework with technical application models and platform construction plans.

Findings – Four major supervision problems (“human-machine conflict”, “regulatory lag”, “early warning deficiency”, “data island”) are identified. A four-dimensional theoretical framework and technical application models for four scenarios (PHM, behavior recognition, voice emergency disposal, credit evaluation) are developed, with a three-stage platform construction plan and implementation solutions.

Originality/value – This study systematically constructs an AI-enabled closed-loop system for urban-level elevator lifecycle governance for the first time. We organically integrate independent technologies such as PHM, CV and NLP into a unified regulatory framework through the core carrier of “Digital Twin” and the computing paradigm of “Cloud-Edge Collaboration”, solving the key transition problem from “single-point intelligence” to “system intelligence”.

Keywords Elevator safety, Artificial intelligence, Smart supervision, Predictive maintenance, Digital twin, PHM

Paper type Research article

1. Introduction: profound transformation and digital intelligence opportunities in elevator safety supervision

1.1 Problem statement: increasingly severe safety supervision pressure and systematic challenges

Ningbo, an economic hub in the southern wing of the Yangtze River Delta and a modern international port city, has witnessed a rapid increase in high-rise and super high-rise buildings. The latest data from Ningbo Municipal Market Supervision Bureau show that by the end of 2024, the total number of elevators in use in the city exceeded 150,000, with an average annual growth rate of over 10% (Ningbo Municipal Bureau of Statistics, 2023; Ningbo Municipal Market Supervision Administration, 2024). While elevators have greatly facilitated citizens’ vertical mobility, they have also imposed increasing pressure on special equipment safety supervision departments. This pressure stems not only from the growing number of elevators but also from the inability of traditional supervision models to meet the requirements of the new era, resulting in structural contradictions, specifically the following four major systematic challenges (Ningbo Municipal Regulations on Elevator Safety Management, 2024).

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- C1. The “human–machine conflict” is worsening, making traditional supervision models unsustainable.

The number of inspectors is limited, while the number of elevators is growing rapidly. There are approximately 200 certified regulatory personnel for special equipment in Ningbo, with each responsible for supervising about 750 elevators, far exceeding the nationally recommended safety supervision ratio of 1:200. Manual supervision capacity cannot meet the increasing number of elevators, resulting in numerous regulatory blind spots. The traditional “manpower-intensive” supervision method is no longer applicable.

- C2. Supervision efficiency has a “ceiling”, and passive response leads to “regulatory lag”.

The current regular inspection system (generally once a year) can basically ensure safety, but it is essentially a periodic and sampling inspection that cannot monitor the operation of elevators between two inspections, especially sudden and gradually developing faults. Real-time continuous monitoring is not possible, resulting in a “time lag effect” in supervision. Generally, supervision intervenes passively after a fault or accident occurs, failing to “prevent problems before they occur”.

- C3. Risk early warning capability is insufficient, requiring crossing the gap from “prevention” to “prediction”.

Current supervision and maintenance methods are mostly still focused on “post-fault maintenance” or “fixed-time preventive maintenance”. With the application of IoT and cloud computing technologies, self-inspection functions for elevator faults have gradually become essential configurations. However, the supervision system has not yet effectively integrated the massive data generated by these intelligent monitoring methods, lacking effective early prediction and warning capabilities for potential risks that have not yet developed into obvious faults, such as initial component wear and control system parameter changes. This may lead to elevators “operating with faults”, posing risks to safety accidents. The number of fault alarms on the Ningbo Elevator IoT Platform reaches over 400,000 times annually, far exceeding the over 3,000 manual emergency responses, rendering manual supervision ineffective.

- C4. Data value is hidden in islands, lacking systematic support for decision-making.

Throughout the entire life cycle of elevators, from design, manufacturing, installation, use, maintenance, inspection to scrapping, there is a massive amount of structured and unstructured data. These data are scattered among manufacturers, users, maintenance companies, inspection institutions and supervision departments, forming “data islands”. Lacking unified data standards and efficient analysis tools, the huge potential value of these data in fault pattern analysis, maintenance quality evaluation, equipment retirement prediction and macro policy formulation has not been released and utilized.

1.2 Opportunities of the era: regulatory paradigm revolution driven by digital intelligence technology

Amid the predicament of traditional supervision models, technologies such as artificial intelligence (AI), Internet of Things (IoT) and big data provide historic opportunities for elevator safety supervision. Cases such as the digital transformation by Xinzailing Technology and the intelligent supervision platform of Wenshan Prefecture show that the deep integration of AI and IoT can construct an elevator “digital twin”, enabling the transformation of supervision from “experience-driven” to “data-driven”, and promoting fundamental shifts from “passive response” to “active early warning”, from “extensive management” to “precision governance” and from “government-only supervision” to “social collaborative governance” (Li *et al.*, 2022).

1.3 Review of domestic and international research status and advanced practices

Internationally, European and American countries started early in elevator predictive maintenance, with equipment manufacturers leading the efforts. Finland's Kone Group collects operational data from hundreds of thousands of elevators worldwide through its cloud platform, using AI algorithms for fault prediction, remote diagnostics and optimizing parts inventory and maintenance scheduling (Kone Group, 2020). Otis Elevator Company (2021) integrates real-time monitoring and data analysis functions on its IoT platform Otis ONE®, improving after-sales service efficiency (Otis Elevator Company, 2021). However, such practices mostly focus on single-brand equipment operation and maintenance, with few cases of government-led regional cross-brand intelligent supervision platforms, and relatively lagging management model innovation.

Domestically, cities represented by Shanghai, Shenzhen and Hangzhou have carried out smart elevator explorations: Shanghai Municipal Market Supervision Bureau (2022) implemented the "Smart Elevator" platform, which took the lead in large-scale application of IoT technology to improve rescue efficiency during entrapment incidents (Shanghai Municipal Market Supervision Administration, 2022); Standing Committee of Shenzhen Municipal People's Congress (2020) mandated IoT device installation in public place elevators through local legislation, laying a solid foundation for data collection (Shenzhen Municipal People's Congress Standing Committee, 2020); Hangzhou explored the linkage between elevator data and urban safety relying on the "City Brain". Currently, there are common problems of "emphasizing monitoring over prediction", "emphasizing equipment over behavior" and "emphasizing collection over mining" (Zhejiang Provincial People's Government, 2020). Most platforms remain in the stage of status monitoring and incident reporting, with AI predictive analysis applications just starting. Capabilities in full-life cycle supervision, active early warning and decision support urgently need improvement.

Based on Ningbo's actual situation and drawing lessons from domestic and international experiences, this study aims to construct a new smart supervision model of "perception interconnection-digital driven-intelligent judgment-efficient collaboration", not only realizing technical upgrading of special equipment supervision but also exploring the modernization path of urban public safety governance, forming replicable and promotable "Ningbo Experience".

1.3.1 Construction of a systematic theoretical framework for elevator AI smart supervision.

The elevator AI smart supervision system requires a comprehensive reshaping of technology, management, processes and concepts, with the core being the construction of a closed-loop adaptive system with data as blood and AI as the brain. This paper proposes a "four-dimensional integration" theoretical framework (as shown in Figure 1) to address core issues of data sources, processing, intelligent analysis and application value.

During elevator operation, various sensors in the Global Perception Layer (such as vibration, current and video sensors) collect raw data in real-time. These data are first sent to the Cloud-Edge Collaborative Computing Layer: high-real-time tasks (e.g. dangerous behavior recognition) are processed locally by edge gateways deployed at the elevator end; the remaining data are preprocessed and then uploaded to the cloud. At the AI Middle Platform Decision-Making Layer, the data aggregated in the cloud is input into different AI engines (such as PHM engines and CV engines) for in-depth analysis, generating structured insights (e.g. fault warnings, credit scores). Finally, these insights are transformed into specific services through the Business Smart Application Layer, such as pushing precise law enforcement work orders to supervisors, assigning predictive maintenance tasks to maintenance personnel or displaying elevator safety status to the public (State Administration for Market Regulation, 2023).

Core: Unified Data Resource Pool and Digital Twin.

This serves as the cornerstone of the entire system, aggregating all-dimensional data from the global perception layer and external systems to form a standardized, dynamically updated elevator holographic database. It constructs a high-fidelity "digital twin" for each physical

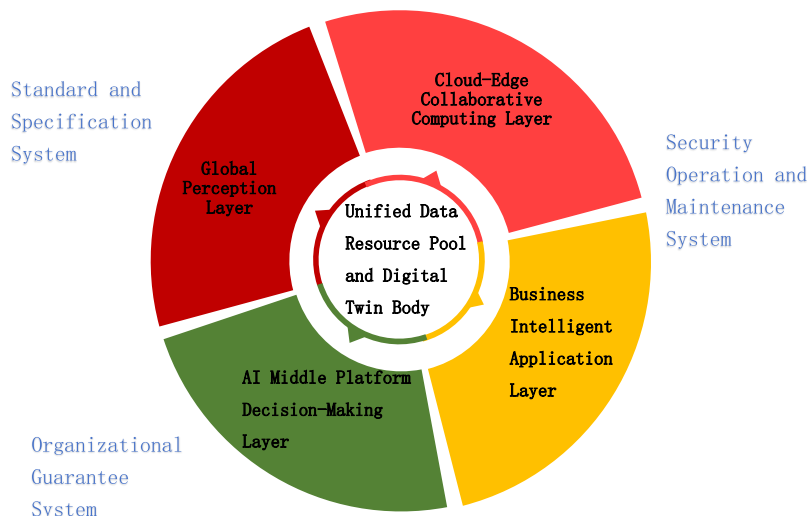


Figure 1. Theoretical framework diagram of elevator AI smart supervision system

elevator, functioning as a static data archive, a virtual mapping of real-time status, historical trajectory and future trends and a sandbox for precise supervision.

Inner Ring: Four-Dimensional Integrated Framework.

Composed of four interconnected, progressive concentric rings, sequentially from data input to value output:

- (1) The Global Perception Layer (“nerve endings”) is responsible for multi-dimensional data collection; the Cloud-Edge Collaborative Computing Layer (“peripheral nerves and primary centers”) processes data; the AI Middle Platform Decision-Making Layer (“cerebral cortex”) analyzes data and generates intelligence and the Business Smart Application Layer (“effector organs”) outputs value.

Outer Layer: Guarantee System.

It includes a standard specification system (ensuring interconnection and quality), a security operation and maintenance system (guaranteeing system stability and data security) and an organizational guarantee system (providing management, talent and institutional support), laying a solid foundation for the sustainable operation of the entire smart supervision system.

The following elaborates on each core dimension in detail:

1.4 Dimension 1: global intelligent perception layer (“nerve endings” of the system)

As the data source of the system, the Global Perception Layer realizes full-dimensional collection of elevator “body” status through deploying multiple types of high-precision sensors. Its coverage breadth and precision directly determine the accuracy of intelligent applications.

Mechanical System Perception:

Traction system: Deploy vibration acceleration sensors (monitoring bearing wear, alignment deviation), temperature sensors (motor overheating warning); guide rail installation verticality and vibration sensors; wire rope configuration with magnetic flux leakage/visual broken wire detection and tension sensors for real-time monitoring.

Door system: Car doors and landing doors are equipped with LiDAR/TOF sensors to monitor door opening/closing speed, obstacle distance and door lock closing status.

Electrical System Perception:

Control cabinet is installed with current, voltage, power factor sensors to collect inverter waveform data, analyze harmonic content and load changes to diagnose motor and inverter fault risks; monitor safety circuit node on-off status and resistance changes.

Safety circuit: Check the on-off status and resistance value changes of each node in the safety circuit.

Operation Status Perception:

Operation status perception uses car top incremental encoders or machine vision floor scanning devices to accurately measure operating speed, acceleration/deceleration curves and leveling precision (vertical deviation from floor), providing key indicators for evaluating ride comfort and operational stability.

Environment and Behavior Perception:

Inside the car: Deploy high-definition cameras supporting AI edge computing (dedicated for behavior recognition, non-continuous recording), microphone arrays (for voice interaction and abnormal sound capture), passive infrared sensors (occupant detection) and high-precision weighing sensors (anti-overload).

Outside landing doors: Install cameras to monitor waiting order and identify abnormal situations such as prolonged door blocking.

1.5 Dimension 2: cloud-edge collaborative computing layer (“peripheral nerves and primary centers” of the system)

When traditional supervision models face difficulties, core technologies of the Fourth Industrial Revolution such as AI, IoT, big data and cloud computing are becoming increasingly mature. They have entered various fields of social governance with unprecedented breadth and depth, bringing historic opportunities to solve the challenges of elevator safety supervision. Some pioneering regions in China, such as Xinzailing Technology’s digital transformation to enhance elevator safety and Wenshan Prefecture Market Supervision Bureau’s implementation of information-based supervision throughout the entire lifecycle of elevators through an intelligent supervision platform, have demonstrated the effectiveness of technology in playing its role ([Shanghai Municipal Market Supervision Administration, 2022](#); [Shenzhen Municipal People’s Congress Standing Committee, 2020](#)).

AI, especially its branches such as machine learning, deep learning, computer vision and natural language processing, has endowed machines with the capabilities of “perception, cognition, prediction and decision-making”. The deep integration of AI and IoT technologies can build a “digital twin” for each elevator, which real-time maps the operating status of physical entities in virtual space. This enables the transformation of elevator safety supervision from an “experience-driven” to a “data-driven” model, with three fundamental shifts at its core: from “passive response” to “active early warning”, from “extensive management” to “precision governance” and from “government-only supervision” to “social collaborative governance”.

1.6 Dimension 3: AI middle platform decision-making layer (“cerebral cortex” of the system)

As the intelligent core of the system, the AI Middle Platform Decision-Making Layer takes data from the cloud-edge collaboration layer as input, conducts in-depth mining through modular AI algorithm models and outputs structured insights and decision recommendations ([Wang, 2004](#)).

Predictive maintenance engine: Integrates time series analysis
Predictive maintenance engine: Integrates time series analysis and machine learning algorithms (LSTM, XGBoost,

1D-CNN, etc.) to realize health assessment of key components, early fault diagnosis and remaining useful life (RUL) prediction (Li and Wang, 2020; Xu *et al.*, 2021).

Computer vision engine: Integrates object detection (YOLOv7, Faster R-CNN), behavior recognition (SlowFast network) and privacy-protected face recognition models, responsible for video stream analysis, unsafe behavior recognition and passenger flow statistics (He *et al.*, 2017).

Natural Language Processing Engine: Integrates Automatic Speech Recognition (ASR), Text-to-Speech (TTS) and Dialogue Management (DM) models, enabling intelligent voice interaction inside the car, understanding passenger intentions, multi-turn conversations and emotional comfort.

Big Data Analysis Engine: Integrates tools such as association rule mining methods (e.g. Apriori algorithm), clustering analysis methods (e.g. K-means) and knowledge graph construction and reasoning, to identify fault correlation patterns from macro data, evaluate maintenance quality, simulate policy effects and provide quantitative basis for industry governance.

1.7 Dimension 4: business smart application layer (“effector organs” of the system)

As the ultimate embodiment of the system’s value, the Business Smart Application Layer transforms the outputs of the AI decision-making layer into specific application services for governments, enterprises and the public, realizing the implementation of regulatory effectiveness.

For Government Supervision:

Dynamic Four-Color Map of Elevator Safety Risks: Based on the results of AI risk assessment models, visually display risk levels (red, yellow, blue, green) on GIS maps to achieve “overview at a glance”.

Precision Law Enforcement and Intelligent Dispatch System: Automatically generate inspection instructions based on risk levels, accurately push to supervision personnel via mobile terminals and improve law enforcement efficiency.

Credit Evaluation and Publicity Platform for Maintenance Units: Dynamically generate “health” portraits and credit ratings of maintenance enterprises, make them public and form a market-oriented survival-of-the-fittest mechanism.

For Enterprise Side (Maintenance/Property/Manufacturing):

Intelligent Maintenance Work Order System: Automatically receive early warning work orders generated by the AI predictive maintenance engine, push them to maintenance personnel via mobile App, supporting full-process online management of order acceptance, navigation, execution, recording and feedback.

Remote Diagnosis and Expert Support System: When on-site maintenance personnel encounter difficult problems, use devices like AR glasses to conduct audio-visual calls with back-end experts, share first-person perspective and obtain real-time remote guidance to improve first-time repair rate.

For Public Side:

“Zheliban”/WeChat Mini Program Integration: Citizens can query elevator safety status, inspection information and fault history of buildings, support one-click alarm and real-time viewing of entrapment rescue progress.

Civilized Elevator Riding Publicity and Interaction System: On the elevator car screen, AI recognizes riding behaviors (e.g. when children are detected) and automatically pushes corresponding safety publicity animations or reminders, achieving precise and scenario-based safety education.

The four dimensions are closely linked with the central data resource pool and digital twin, forming a complete closed-loop of data collection-transmission-processing-analysis-decision application. Through application feedback, model strategies are continuously optimized, ultimately realizing real-time, precise, automated and intelligent elevator safety supervision.

2. In-depth analysis of core application scenarios of AI technology in elevator smart supervision

The theoretical framework provides a planning foundation for smart supervision, and the in-depth application of AI in specific scenarios is key to value realization. This chapter focuses on four core scenarios, analyzing their technical mechanisms, implementation paths and transformative value.

2.1 Elevator fault prediction and health management based on AI and PHM

The core of AI improving elevator safety is to promote the maintenance strategy from fixed-cycle “preventive maintenance” to condition-based “predictive maintenance”, and ultimately evolve to dynamically optimized “proactive maintenance”, achieving the optimal balance between safety and economy.

For multi-source heterogeneous data fusion and feature engineering, this study adopts a layered fusion strategy. On the edge side, signal-level fusion is performed on homologous high-frequency data (such as three-axis vibration signals) from the same subsystem (e.g. traction machine), and time-frequency domain features are extracted through wavelet packet decomposition. On the cloud side, feature-level fusion is conducted on feature vectors from different subsystems (e.g. traction machine vibration features, motor current harmonic features, ambient temperature) to construct a unified equipment health status vector. For different components, we select differentiated fusion algorithms: for bearing wear with strong temporal characteristics, an LSTM network is used to learn its degradation trajectory; for transient current anomalies in the door machine system, 1D-CNN is employed to capture local mutation patterns.

2.1.1 Multi-source heterogeneous data fusion: cornerstone of accurate prediction. The system integrates multi-dimensional data such as mechanical, electrical, operational and environmental data, including high-frequency sensor data, operational parameters, historical maintenance records and external environmental data, forming a unified equipment health view. Figure 2 shows the application of PHM Technology in elevator systems.

Process: Data collection → Edge-side preprocessing and feature extraction → Cloud data fusion and advanced feature engineering → Historical data training to establish health baselines → Real-time data stream anomaly detection and fault prediction → Generate maintenance recommendations (type, priority, duration) → Maintenance effect feedback to optimize models.

2.1.2 Feature engineering and algorithm selection: key to model success. Feature engineering and algorithm selection are crucial for the model, requiring differentiated design for elevator subsystems.

Traction machine bearings use LSTM/GRU models for wear prediction; door systems detect current anomalies via 1D-CNN; wire rope health assessment combines magnetic flux leakage data and images, using Random Forest/XGBoost to evaluate safety levels.

2.1.3 Fault evolution and remaining useful life prediction: highest level of PHM. RUL prediction integrates current vibration features with historical degradation data, using particle filtering or deep learning survival analysis models to predict future fault probability

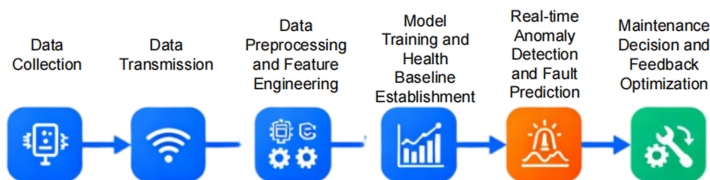


Figure 2. Elevator PHM technology flowchart

distribution and confidence intervals of bearings, promoting maintenance decision-making from “condition-based maintenance” to “predictive proactive planning”.

2.1.4 Application value enhancement and economic benefit analysis. Application Value: Reduce fault downtime by over 50% (especially in high-load scenarios such as office buildings and hospitals); transform maintenance mode from “regular on-site visits” to “on-demand service”, improve per capita management efficiency and reduce full-life cycle costs by 15%–20%; provide technical support for “on-demand maintenance” policies, realizing supervision transformation from “one-size-fits-all” to “elevator-specific measures” (Li and Wang, 2020).

2.2 Intelligent recognition of elevator riding behavior and active safety intervention based on computer vision

This application expands supervision scope from “equipment” to “human-behavior-environment”, realizing unified safety management and active intervention of “human-machine-environment”, reflecting the initiative and refinement of smart supervision.

2.2.1 Evolution of high-precision object detection and recognition models. Adopt object detection models for real-time object recognition; distinguish dangerous behaviors through spatiotemporal networks; use unsupervised learning models to detect rare abnormal behaviors and improve generalization ability (Feichtenhofer *et al.*, 2019).

2.2.2 Multi-modal fusion and behavior understanding. Fuse audio and sensor data, and improve behavior understanding accuracy while reducing false alarm rates through cross-modal models (He *et al.*, 2017).

2.2.3 Privacy protection-by-design principles. Privacy protection adopts design principles of edge computing priority, data minimization and desensitization processing (Jia *et al.*, 2023; People’s Republic of China Cybersecurity Law, 2017; People’s Republic of China Data Security Law, 2021; People’s Republic of China Personal Information Protection Law, 2021). Figure 3 presents the privacy protection process for visual analysis based on edge computing.

Process: Camera video stream → Real-time analysis by edge AI gateway (in-memory processing without storage) → Local saving of short clips when security events are triggered → Automated desensitization (face blurring) → Encrypted upload to supervision platform → Generate alarm work order → Scheduled cleaning of local data.

In the edge AI gateway, we have integrated lightweight face detection and blurring algorithms. Once a security event is triggered (such as electric vehicles entering elevators), the system will immediately call this module. Based on the improved MobileNetV2 architecture, this module detects face regions in real-time in the memory buffer of the video stream and performs irreversible pixel perturbation processing using a Gaussian blur kernel ($\sigma = 5$). Only the processed video segments are allowed to be encrypted and uploaded, and the original video

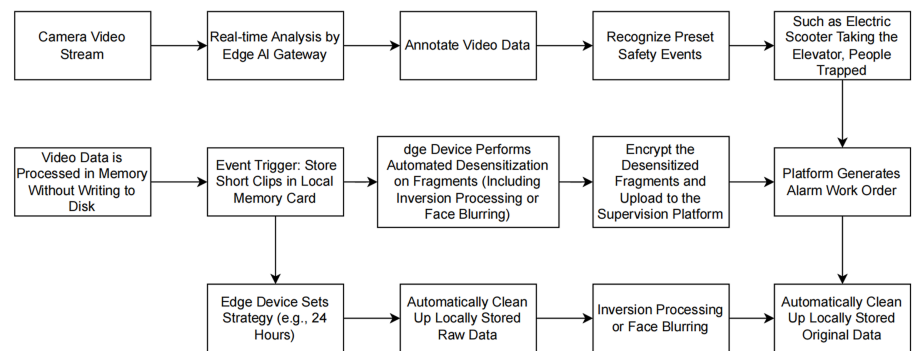


Figure 3. Privacy protection process for visual analysis based on edge computing

stream is discarded in the memory immediately to ensure that “raw data does not leave the device”.

Our privacy protection design strictly adheres to the Personal Information Protection Law and the Cybersecurity Law. In addition to technical measures such as “Edge Computing Priority” and “Data Minimization”, we have established a three-level authorized access mechanism: ordinary members of the public can only view the overall safety status of elevators; property management and maintenance units can access non-sensitive operational data of the elevators under their jurisdiction; only regulatory authorities can apply for temporary decryption to view desensitized videos of specific time periods when handling safety accidents. All data access activities are recorded in complete audit logs.

2.2.4 Application scenario expansion and social governance extension. Application Scenarios: Electric vehicle management adopts “technical prevention + human prevention” mode; entrapment recognition integrates multi-modal data to reduce false alarm rates; record uncivilized behaviors to assist community management (Li, 2019).

2.3 Intelligent voice interaction and humanized emergency response

This application aims to improve emergency response efficiency and passenger experience, reflecting the humanistic care of smart supervision.

- (1) Multi-turn Dialogue and Context Understanding: Achieve intent understanding and coherent interaction through NLU and DST technologies.
- (2) Emotion Recognition and Differentiated Response: Analyze voice features to judge emotional states and dynamically adjust dialogue strategies.
- (3) Information Linkage and Visualized Comfort: The voice system links with the car display screen to synchronously play rescue route animations or countdown bars, alleviating passenger anxiety through audio-visual integration.
- (4) Application Deepening and System Integration: The voice system is deeply integrated with the city-wide “96,333” emergency platform to realize full-process intelligence including automatic alarm, intelligent comfort, rescue progress synchronization and satisfaction follow-up, improving platform response efficiency; optimize comfort scripts and rescue processes through desensitized voice data analysis to provide case support for training.

2.4 Big data-driven regulatory decision-making and industry credit evaluation

This is the macro manifestation of the value of AI smart supervision, from solving small issues of individual elevators to optimizing medium-level management of the entire elevator industry and major decisions in urban public safety governance.

- (1) Technical Mechanism and Model Construction
Construction of Elevator Risk Knowledge Graph: With “elevator” as the central node, associate entities such as manufacturers and maintenance/use units, integrate multi-dimensional attributes, analyze risk propagation paths through graph neural networks and identify common defects.
- (2) Risk Prediction and Credit Evaluation Model
Integrate equipment features to generate dynamic fault probability scores; construct a multi-dimensional evaluation system for maintenance units and calculate credit scores.

Elevator Safety Risk “Four-Color Map”: Red (high risk) - 24-h on-site inspection and rectification; Yellow (relatively high risk) - Remote verification within one week; Blue

(general risk) – Routine inspection; Green (low risk) – Included in “on-demand maintenance” pilot.

Credit Supervision of Maintenance Units: Generate and publicly release credit scores and rankings; link with policies; compile industry white papers to support standard formulation and training.

Policy Simulation and Effect Evaluation: Construct Agent-Based Modeling (ABM) or system dynamics models (Forrester, 1961) to simulate changes in safety levels, social costs and industry structure 5–10 years after the implementation of policies such as “on-demand maintenance” and “old elevator renewal subsidies”, providing a low-cost “policy laboratory” to support scientific decision-making.

The evaluation system shown in Table 1 is adopted.

3. Practical path and blueprint planning for constructing the Ningbo-characteristic “Yongti Intelligent Management” platform

Relying on Ningbo’s manufacturing foundation and smart city construction, and following the principles of “holistic intelligent governance, iterative evolution, market-oriented and government-guided”, promote the construction of the “Yongti Intelligent Management” integrated platform in three phases.

3.1 Phase 1: foundation and demonstration period (2025–2026) – standard leadership, pilot breakthroughs

Core Goal: Complete top-level design and legislative preparation, break through key standards, build representative demonstration projects, verify the feasibility of technical paths and initially form social consensus.

Key Tasks and Key Performance Indicators (KPIs):

(1) Top-Level Design and Legislative Guarantee:

Measures: Issue the Guiding Opinions on the Construction of Ningbo’s Elevator Smart Supervision System and supporting measures, launch revision research on the Ningbo Elevator Safety Regulations and clarify IoT configuration requirements and legal basis for data sharing.

KPI: Issue the Guiding Opinions in Q2 2026; complete the preliminary draft of the Regulations revision in Q4 2026.

Table 1. Credit evaluation system table

Evaluation dimension	Specific indicator	Weight	Data source	Scoring rule
Response efficiency	Average time for trapped person rescue	30%	Regulatory platform alarm records	<30 min: 5 points; 30–60 min: 3 points; >60 min: 1 point
Maintenance quality	AI prediction fault hit rate	25%	PHM engine output vs maintenance records	Hit rate >90%: 5 points; 80%–90%: 4 points. . .
Operational standards	Electronic maintenance order completion rate	20%	Maintenance app upload records	Completion rate 100%: 5 points; 1 point deducted for every 10% decrease
Historical credit	Previous annual rating	15%	Platform historical data	Grade A: 5 points, Grade B: 4 points, Grade C: 3 points, Grade D: 1 point
User evaluation	Owner satisfaction score	10%	“Zheliban” mini program feedback	Average score ≥ 4.5 : 5 points. . .

(2) Standard Specification First:

Measures: Formulate the Local Standard for Data Collection and Interface of Ningbo Elevator IoT and the Measures for Classification Management of Data Security in Elevator Smart Supervision Platform. This standard will clearly specify which data items IoT devices of all elevators sold and installed in Ningbo must open, which communication protocols and data formats to adopt, and propose a “Standard + Platform + Ecosystem” trinity model to solve data silos and promotion issues.

KPI: Release the data interface specification in Q2 2025; release the safety management measures in Q3 2026.

(3) Infrastructure and Platform Construction:

Measures: Develop the “Yongti Intelligent Management” cloud platform V1.0 (supporting access of 10,000 elevator terminals, data storage and analysis and alarm management), and complete the model selection and security evaluation of edge computing IoT gateways.

KPI: Complete the development of platform V1.0 in Q4 2024; complete the finalization of IoT gateways in Q1 2025.

(4) Demonstration Project Construction:

Measures: Select old elevators over 10 years old (approximately 14,000 units) to carry out IoT retrofitting demonstrations and explore a collaborative promotion model involving multiple subjects.

KPI: By the end of 2025, the demonstration project will cover at least 14,000 elevators, with the predictive maintenance model precision exceeding 80% and the active entrapment detection rate reaching 95%.

Supporting Measures: Establish a special working group led by municipal leaders, with the office located in the Municipal Market Supervision Bureau, and set up an initial municipal financial guidance fund of 40 million yuan.

KPI Verification Method: The indicator of “Predictive Maintenance Model Accuracy Exceeds 80%” will be verified retrospectively using 14,000 elevators deployed in demonstration projects. We will utilize historical maintenance records from the past year as true labels, compare the prediction results of the AI model with them, calculate Precision and Recall and the F1-Score must reach above 0.8. The indicator of “Active Trapped Person Detection Rate Reaches 95%” will be subjected to stress testing through simulated trapped person scenarios (conducted by third-party institutions), and the proportion of successful identification and alarm times by the system will be counted.

3.2 Phase 2: integration and promotion period (2026–2027) – global perception, platform empowerment

Core Goal: Achieve full IoT coverage of elevators in key public places, put the platform’s core AI capabilities into production and application, complete the online reconstruction of business processes and ensure the effective operation of the credit supervision system.

Key Tasks and KPIs:

(1) IoT perception expansion:

Mandatory Requirement: The revised Regulations or government decree shall clarify that all newly installed elevators in the city comply with Ningbo’s IoT interface standards.

Existing Elevator Renovation: Complete intelligent transformation of 75,000 existing elevators in public places such as subways and stations.

KPI: By the end of 2027, the overall IoT coverage rate of elevators in the city shall reach 60%, and the coverage rate in public places shall exceed 90%.

(2) Platform capability upgrade and data integration:

Measures: Construct Platform AI Middle Platform V2.0 (core model accuracy rate for predictive maintenance >85%), connect cross-departmental data interfaces of provincial special equipment platforms and city brain, to realize collaborative disposal of safety incidents.

KPI: Achieve data interconnection with all the above core systems by Q1 2025, and complete the launch of AI Middle Platform by 2026.

(3) Business process reengineering and online closed-loop:

Measures: Promote the “Yongti Intelligent Management Maintenance App” to realize full-process online closed-loop including AI early warning and intelligent dispatching, establish a credit evaluation system for maintenance units and release it quarterly.

KPI: By the end of 2024, over 98% of maintenance enterprises in the city will use this App, the electronization rate of maintenance records will reach 99% and release the city-wide maintenance unit credit star rankings twice.

Supporting Measures: Explore market-oriented promotion models such as “insurance + service”, encourage insurance companies to provide premium discounts for elevators connected to the platform and incorporate elevator smart supervision work into the “Safe Ningbo” construction assessment system of each district (county, city).

3.3 Phase 3: Ecological Innovation period (2028 and beyond) – intelligent symbiosis, value spillover

Core Goal: Smart supervision becomes the new normal in the industry, forming an active local industrial cluster, spawning new business models using elevator data and realizing value spillover.

Key Tasks and KPIs:

(1) Supervision model consolidation and deepening:

Measures: Mainstream the “on-demand maintenance” model city-wide, optimize traditional regular inspection cycles and compile the “Ningbo Elevator Safety and Development Annual White Paper”.

(2) Industrial Ecosystem Cultivation: Cultivate 1–3 domestically leading elevator IoT and AI enterprises, establish the “Ningbo Elevator Digital Intelligent Safety Industry Alliance”; KPI: Form an enterprise cluster with national service capabilities, with industry alliance units ≥15. 3. Business Model Innovation: Mature the “elevator insurance + service” model (rates linked to AI safety ratings), explore value-added applications of elevator data; KPI: “Insurance + service” covers ≥50,000 elevators by 2028, launch 1–2 data value-added pilots; “on-demand maintenance” coverage rate ≥50% by 2028, release annual industry white paper.

Supporting measures: Establish a municipal-level “Elevator Digital Intelligent Safety Industry Innovation Fund” to explore the path of authorized operation of public data.

4. Challenges and systematic countermeasures in the promotion process

The promotion of any major systematic project will not always be smooth sailing. The construction and promotion of the “Yongti Intelligent Management” platform also face severe challenges in technology, management, finance and talent. Only by facing these challenges and planning systematic solutions in advance can the project’s success be ensured.

4.1 In-depth analysis of key challenges

Challenge 1: Data Security, Privacy Protection and Compliance Risks – A Triple Integrated Challenge.

Elevator operation data, geographical location information and video data collected by the platform are vulnerable to cyber-attacks. Data leakage or abuse will violate privacy and endanger public safety. It is necessary to strictly follow laws and regulations such as the Cybersecurity Law and Data Security Law, meet Level Protection 2.0 standards, resulting in high complexity of compliance review and technical guarantee.

Challenge 2: Technical Instability in “Rare Cases” and Poor Model Performance.

Large-scale deployment of AI models in real environments faces “long-tail problems” (such as rare electric vehicle models, difficulty in recognizing dialect commands) and “model drift” (performance degradation due to equipment aging), requiring continuous learning and adaptive optimization capabilities.

Challenge 3: High Initial Investment and Lack of Sustainable Business Model.

Initial investments in hardware transformation, network leasing and platform development require hundreds of millions of yuan. Relying solely on financial subsidies or enterprise undertaking is unsustainable, so it is necessary to build a cost-sharing mechanism benefiting multiple parties including government, property, maintenance and insurance.

Challenge 4: Talent Gap, Insufficient Capabilities and Difficult Organizational Transformation.

Supervision and maintenance personnel have insufficient adaptability to data tools and intelligent work orders, with great resistance to capacity transformation; cross-departmental collaboration faces invisible resistance from power and interest adjustments.

4.2 Systematic countermeasures for challenges

(1) Systematic and Integrated Countermeasure System

To address these challenges, a systematic solution throughout the project’s full life cycle is needed, rather than piecemeal responses.

(2) Strengthen Top-Level Design and Fortify Safety and Compliance Lines

Organizational Guarantee: Upgrade the special working group to the permanent “Ningbo Municipal Office for Elevator Smart Supervision and Development” to coordinate and supervise standards; Legal Advance: Accelerate the revision of the “Ningbo Elevator Safety Regulations” to clarify IoT configuration, data responsibilities and safety management; Technical Protection: Adopt end-to-end encryption, differential privacy, federated learning and other technologies and complete Level 3 Security Protection filing and evaluation.

(3) Innovative Investment and Business Model: Adopt a hybrid model of “government-guided fund + market financing”, with initial government funds supporting basic research and demonstration projects, and social capital introduced for operation in the mid-to-late stage; Explore the “beneficiary-pays” mechanism by incorporating IoT costs into maintenance funds or insurance products; Implement “credit pledge”

allowing high-quality maintenance enterprises to apply for low-interest loans based on platform credit, forming a virtuous cycle.

The “Beneficiary-Pays” mechanism is specifically manifested as follows: (1) Property management side: Incorporate the annual service fee of IoT devices into property public revenue expenditure, as it can significantly reduce accident risks and maintenance costs; (2) Insurance side: Cooperate with insurance companies to launch “Smart Elevator Insurance”, offering a 10%–15% premium discount for elevators connected to the platform, with insurance companies benefiting from reduced claim ratios; (3) Government side: Initially leverage social capital through financial guidance funds, and later achieve self-sustaining operation of the platform by providing data value-added services (such as precision marketing and spare parts prediction) to maintenance enterprises.

- (4) Industry-Research-Application Collaboration: Jointly establish the “Ningbo Key Laboratory of Elevator Digital Intelligent Safety” with universities and research institutes to tackle long-tail problems and model optimization technologies; Establish a ModelOps system for full-lifecycle AI model management; Host the “Yongti Intelligent Management” Algorithm Challenge to attract global teams to solve practical problems.
- (5) Talent and Organizational Empowerment: Conduct training for “Digital Elites” (supervision personnel) and “Digital Craftsmen” (maintenance personnel); Introduce AI and big data talents, and jointly launch targeted training classes on “Intelligent Special Equipment Management” with universities; Resolve transformation resistance through publicity and case sharing to cultivate a digital culture.

5. Future outlook: towards a new ecosystem of comprehensive intelligent elevator safety governance

Continuous breakthroughs in core technologies and expanding application scenarios will drive elevator AI smart supervision to develop toward greater breadth, intelligence and collaboration in the future, ultimately evolving into a new ecosystem characterized by self-optimization, multi-stakeholder participation and value symbiosis.

With the maturity of large model technologies (such as Qwen-Max, GPT-4o), the future “Elevator Safety Expert System” will no longer be limited to preset rules. It can understand unstructured maintenance logs, passenger complaint texts and combine the real-time status of digital twins to perform causal reasoning. For example, when receiving a complaint of “elevator abnormal noise”, the system can automatically correlate the vibration spectrum data of that period, locate possible fault sources (such as loose guide rails or wear of traction wheels) and provide maintenance personnel with graphically illustrated diagnostic reports. This has been initially verified in Alibaba Group’s City Brain project.

5.1 Evolution of technology and architecture

5G-A/6G and integrated communication-sensing technologies will provide low-latency transmission for seamless monitoring of elevator operation status; General large models will upgrade to “Elevator Safety Expert Systems”, with maintenance robots enabling physical space operations; Deep digital twins will evolve into “agent twins” supporting virtual fault reproduction and emergency drills.

5.2 Evolution of governance models

Governance models will evolve towards multi-governance: public participation in safety supervision, industry associations developing advanced group standards and insurance

companies offering diversified products; Systems will adaptively adjust regulatory resource allocation and dynamically optimize early warning thresholds to achieve intelligent self-optimization.

6. Conclusion

This study systematically constructs an AI-enabled closed-loop system for urban-level elevator lifecycle governance for the first time. We organically integrate independent technologies such as PHM, CV and NLP into a unified regulatory framework through the core carrier of “Digital Twin” and the computing paradigm of “Cloud-Edge Collaboration”, solving the key transition problem from “single-point intelligence” to “system intelligence”.

Elevator safety is a crucial component of urban public safety, and its governance modernization is vital to urban efficiency and citizen well-being. Based on Ningbo’s regulatory practices, this paper demonstrates the core role of AI in transforming elevator supervision from traditional manual models to digital, intelligent and smart paradigms.

The constructed “Comprehensive Perception-Cloud-Edge Collaboration-Intelligent Decision-Smart Application” four-dimensional integrated theoretical framework provides systematic top-level design for elevator smart supervision; In-depth analysis of four core scenarios (PHM, riding behavior recognition, intelligent voice interaction and big data credit evaluation) reveals the mechanism and potential of AI reshaping the entire supervision chain; The three-phase implementation blueprint (“Foundation Demonstration, Integration Promotion, Ecological Innovation”) and systematic countermeasures form a practical “Ningbo Solution” rooted in Ningbo and applicable nationwide.

Ningbo’s elevator AI smart supervision is not merely a technological application or business innovation but a systematic social governance project. It requires applying the “Whole-of-Government” concept to break down barriers, balancing technological innovation with compliance and public interests with commercial value, advancing with strategic vision and iterative courage.

By promoting the implementation of “Yongti Intelligent Management”, Ningbo will solve regulatory challenges, fortify safety lines, cultivate emerging industries and build professional teams, providing a replicable “Ningbo Model” for the modernization of national special equipment safety governance, collectively moving towards a future of “knowable, predictable, preventable and controllable” elevator safety.

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