An Innovative Exploration of Post-Evacuation Assessment Systems

Xikun Li*
Beijing University of Civil Engineering and Architecture, Beijing, China
**Corresponding Author*

Abstract: With the development of society, public security events become more complex, and the innovation of the post-evacuation assessment system, as an important link in public security management, is particularly critical. This paper proposes an evacuation effect retrospective analysis method based on multi-source data, covering data sources such as surveillance video, cell phone signaling, social media, etc. It details how to integrate and analyze these data to obtain comprehensive evacuation effect information. Meanwhile, quantitative indicators of evacuation efficiency, such as the "golden escape time utilization rate", are established to provide precise measurement tools for evaluating the evacuation process. In addition, develop an AI-driven automatic optimization tool chain for evacuation scenarios, using its powerful computing and learning capabilities to achieve dynamic optimization of evacuation scenarios. These innovative directions aim to make up for the current research shortcoming of "focusing on the plan but not the assessment", form a management closed loop, and improve the specificity and effectiveness of the post-evacuation assessment system, so as to provide strong support for the development of more reasonable and efficient evacuation plans, enhance the ability to respond to emergencies, and safeguard the public's lives and property.

Keywords: Post-Evacuation Assessment; Multi-Source Data; Quantitative Metrics; AI Optimization; Public Safety

1. Introduction

Evacuation, as a key measure to deal with emergencies (e.g., fire, earthquake, terrorist attack, etc.), has as its main goal the rapid, safe, and orderly transfer of people in the danger zone to a safe area. Currently, most studies and practices focus on the development of evacuation plans and the organization and command of the evacuation process, while insufficient attention is paid to the post-evacuation evaluation process. However, an effective post-evacuation assessment system plays a crucial role in summarizing lessons learned, improving evacuation plans, enhancing emergency management, and improving public emergency awareness and self-rescue ability, etc. Cui [1] mentioned that plan evaluation is an important task in plan preparation and implementation. Therefore, studying the innovative direction of post-evacuation assessment system and constructing a scientific, comprehensive and efficient post-evacuation assessment mechanism is of far-reaching significance for safeguarding public safety and maintaining social stability.

2. Status and Problems of the Post-Evacuation Assessment System

2.1 Limited and Dispersed Sources of Assessment Data

Traditional post-evacuation assessment mainly relies on on-site observation records, statistical reports and a small number of questionnaires. These data often have problems such as small sampling range, incomplete information, and untimely access, which make it difficult to comprehensively and accurately reflect the various situations and behavioral characteristics of personnel during the evacuation process. For example, in large public places such as large shopping malls, stadiums and other emergencies, only relying on manual statistics on the number of people passing through the evacuation channel and the evacuation time, it is difficult to obtain detailed information such as the movement trajectory of the personnel in the venue, changes in the density of personnel in different

areas, and other detailed information, which makes it impossible to deeply analyze the congestion points in the process of evacuation, the reasons for the delay and other key factors.

2.2 Lack of Scientific and Systematic Assessment Indicators

The current post-evacuation assessment index system has not yet been unified and improved, and most of the assessment work focuses only on a few simple indicators such as evacuation time and number of evacuees, while neglecting the comprehensive consideration of multiple dimensions such as evacuation efficiency, safety and comfort. For example, there are obvious limitations when only using evacuation time to measure evacuation effectiveness: first, it is easy to cause the analytical model to ignore the quantitative assessment of safety elements such as personnel injury rate and group panic index; second, it is difficult to integrate the differentiated evacuation demand parameters of vulnerable populations, such as the elderly, children, and mobility-impaired people [2], which makes it difficult for the assessment conclusions to accurately reflect the comprehensive quality of evacuation processes. Ye [3] mentioned that the traditional method of fire evacuation simulation using FDS and Pathfinder does not consider the impact of fire on pedestrians, which will lead to errors in evacuation effects, reflecting the lack of systematic indicators for post-evacuation assessment.

2.3 Lack of Effective Assessment Tools and Technical Instruments

In the post-evacuation assessment process, there is a lack of specialized and efficient assessment tools and technical means for data processing, analysis and simulation. This makes the assessment work often rely on manual empirical judgment and simple statistical analysis, and it is difficult to conduct in-depth mining and accurate interpretation of the complex evacuation process and a large amount of data. For example, manual frame-by-frame analysis of evacuation images recorded in surveillance video is inefficient and prone to omissions, while existing video analysis software often suffers from low recognition accuracy and limited analysis capabilities when dealing with large-scale crowd evacuation scenes, and cannot provide strong technical support for post-evacuation assessment.

3. Innovative Directions for Post-Evacuation Assessment Systems

3.1 Lack of Scientific and Systematic Assessment Indicators

3.1.1 Data sources and integration

(1) Surveillance video: By reasonably arranging multiple cameras in the evacuation place, it is possible to record in real time the behavior, location, moving direction and other information of the personnel in the process of evacuation. Deep mining and analysis of the surveillance video can obtain parameters such as the flow of personnel, flow rate, queue length, degree of congestion, and so on. For example, after an evacuation event in a subway station, viewing the surveillance video of the various exits in the station hall and on the platform can determine the efficiency of evacuating personnel from different exits and analyze whether congestion exists.

(2) Cell phone signaling data: Cell phone users will interact with nearby base stations for signals in the power-on state, thus generating cell phone signaling data. This data contains the user's location information, movement trajectory, and communication time. The cell phone signaling data can be used to track the large-scale movement of people during evacuation, and to understand the changes in the distribution of people in different areas and the choice of evacuation paths. For example, at a large outdoor event, cell phone signaling can be used to analyze the evacuation paths and time required for evacuating people from the various entrances to the safe area, as well as whether there is an excessive gathering of people or a lack of evacuation.

(3) Social media data: After an evacuation event, on-site personnel often post text, pictures, videos and other relevant information on social media platforms. These social media data can serve as an important supplement to the evacuation effect assessment, reflecting the public's subjective feelings, opinions and suggestions about the evacuation process. For example, by analyzing popular topics and user comments related to evacuation events on social platforms such as Weibo and Tik Tok, it is possible to understand the public's

evaluation of the evacuation organization, information dissemination, and on-site order, so as to identify potential problems and directions for improvement. Wen [4] emphasize that social media data have a unique advantage in obtaining feedback from the public on their evacuation experience, and that they are able to quickly and extensively collect the public's It can quickly and widely collect the public's real thoughts and feelings, which provides a strong basis for optimizing the evacuation work from the perspective of humanistic care.

The integration of the above multi-source data requires the establishment of a unified data format and interface standards, the use of data fusion algorithms to temporally and spatially match and fuse data from different sources to form a complete data set of the evacuation process, which provides a rich data base for subsequent analysis.

3.1.2 Retrospective analysis methods

(1) Personnel Behavior Pattern Recognition: Based on multi-source data, machine learning and data mining algorithms are used to identify and classify the behavior patterns of personnel during evacuation. For example, by analyzing the movements and postures of the personnel in the surveillance video and the changes in the movement speed in the cell phone signaling data, different behavioral patterns such as normal walking, running, stopping, turning back, etc., can be identified, and then analyze the differences in the evacuation efficiency and safety of the personnel under the different behavioral patterns, and find out the behavioral factors that may lead to evacuation delays or dangers.

(2) Evacuation path analysis and optimization: Combining the path selection information provided in the cell phone signaling data and social media data, as well as the actual movement trajectories of the personnel in the monitoring video, the evacuation path is analyzed in detail. It evaluates the capacity of each evacuation path, the location of congestion points, and the reasons for delays, and identifies the optimal evacuation paths and problematic paths. At the same time, based on the analysis results, we propose evacuation path optimization suggestions, such as adjusting the width of the evacuation channel, increasing the evacuation indicator signs, and opening new evacuation entrances, in order to improve the efficiency and safety of the evacuation process.

(3) Evacuation time distribution analysis: through the extraction and analysis of the evacuation start time, the time nodes of each evacuation stage, and the final evacuation completion time in the multi-source data, the distribution law of the evacuation time is studied. For example, by analyzing the differences in evacuation time between different regions and different people, the key time nodes and bottleneck links in the evacuation process can be identified to provide a basis for the development of a reasonable evacuation plan and optimization of the evacuation process. Liu [5] studied the characteristics of the distribution of the evacuation time in depth, and through the analysis of the fitting of the actual data, it provides a scientific method for accurately grasping the law of the evacuation time, which can help to carry out the evacuation time management and optimization more purposefully time management and optimization.

3.2 Establishment of Quantitative Indicators of Evacuation Efficiency

3.2.1 Utilization of prime escape time

(1) Definition and calculation method: The golden escape time refers to the best time window in which people can safely evacuate to a safe area after an emergency, usually determined according to the speed of development of the disaster, the degree of danger of the place and other factors. Golden escape time utilization rate can be defined as the ratio of the actual effective evacuation time (from the time of evacuation instructions to the time when all the personnel arrive at the safe area) to the golden escape time. Its calculation formula is:

$$\alpha = \frac{t_1}{t_2} \times 100\% \quad (1)$$

α --- Golden escape time utilization rate

t_1 ---Actual effective evacuation time

t_2 ---Golden Escape Time

(2) Significance and application: This indicator can visually reflect the efficiency and urgency of the evacuation process. Higher utilization rate of golden escape time indicates that the evacuation process is more rapid and efficient,

which can complete the evacuation of people within a limited time and reduce the risk of casualties; while lower utilization rate means that there is a delay in evacuation, which needs to be further analyzed and improved. For example, in the fire evacuation of high-rise buildings, if the utilization rate of the golden escape time is lower than a certain threshold (e.g., 80%), it means that there are problems in the evacuation plan or the organization process, such as the evacuation channel is not smooth, the evacuation of people guided in a timely manner, and so on, and it is necessary to take targeted measures to optimize the measures. Zhang[6] introduced the escape time indicator when analyzing a number of fire evacuation cases, and through the indicator can determine the escape ability of people during escape, providing a clear direction for the development of subsequent improvement measures.

3.2.2 Growth rate of evacuees per unit of time

(1)Definition and calculation method: The growth rate of the number of evacuees per unit of time refers to the ratio of the increase in the number of evacuees in each time unit to the number of evacuees in the previous time unit during the evacuation process. Its calculation formula is:

$$\beta = \frac{a_1 - a_0}{a_0} \times 100\% \tag{2}$$

β ---Growth rate of the number of evacuees per unit of time

a_1 ---Number of evacuees for the current time unit

a_0 ---Number of evacuees from previous time unit

(2) Significance and application: This indicator can reflect the acceleration or deceleration trend of the evacuation process. In the early stage of evacuation, it is usually expected that the growth rate of the number of evacuees per unit of time is high so as to evacuate people as soon as possible; while in the late stage of evacuation, the growth rate gradually decreases and tends to stabilize. By analyzing the change curve of the growth rate of the number of evacuees per unit of time, it is possible to find out the congestion, stagnation and other abnormalities in the evacuation process in a timely manner, and provide a basis for adjusting the evacuation strategy and deploying emergency resources. For example, in the evacuation of a large stadium, if the growth rate of the number of evacuees per unit of time suddenly drops sharply, it may indicate that a certain exit or channel is congested, and it is necessary to take immediate measures to ease the flow.

3.2.3 Evacuation route utilization

(1)Definition and calculation method: evacuation channel utilization rate is defined as the evacuation process, the number of evacuees actually passing through the evacuation channel and the channel design capacity (the maximum number of people who can pass through the channel in a unit of time) of the ratio. Its calculation formula is:

$$\gamma = \frac{x}{y} \times 100\% \tag{3}$$

γ ---Evacuation route utilization rate

x ---Number of people actually passing through the evacuation route

y ---Evacuation route design capacity

(2) Significance and application: This indicator is used to assess the efficiency and rationality of the utilization of evacuation routes. Reasonable distribution of the utilization rate of evacuation channels can ensure that the channels give full play to their roles and avoid the situation where some channels are overcrowded while others are idle. For example, in shopping mall evacuation, if the utilization rate of a certain evacuation channel is much higher than that of other channels, it indicates that there are problems with the channel settings or guide signs, and it is necessary to optimize and adjust the layout of the channel, such as adjusting the width of the channel and increasing the evacuation indicator signs, etc., in order to improve the overall evacuation efficiency. Zhong[7] analyzed the cross-floor escape routes of high-rise building fires, and found that a good evacuation channel design could improve the evacuation channel channel utilization rate, significantly reducing the safety risk in the evacuation process, which strongly proves the important guiding value of this indicator for the optimization of evacuation channel.

3.3 AI-Driven Toolchain Development for Automatic Optimization of Evacuation Scenarios

3.3.1 Data-driven evacuation modeling

(1) Model training data preparation: collect a

large amount of historical evacuation event data, including evacuation data under different types of places (e.g., schools, hospitals, factories, public places, etc.), different disaster scenarios (fires, earthquakes, floods, etc.), and different crowd characteristics (age, gender, physical condition, etc.). These data can be obtained from governmental departments, emergency rescue agencies, scientific research units, etc., and can also be supplemented by simulated evacuation drills and virtual scenario generation, etc. Cuesta [8, 9] emphasized the importance of rich and diverse evacuation data for constructing accurate and reliable evacuation models, and proposed a set of effective data acquisition and preprocessing methods to ensure that the data quality and availability can meet the requirements of model training.

(2) Application of machine learning algorithms: deep learning algorithms are used to train the collected data and construct a data-driven evacuation model. The model is able to learn the influence laws of different factors on the evacuation process, and predicts the evacuation behavior and evacuation results of personnel in a given scenario. For example, by training the model, it can predict the evacuation flow and evacuation time at different exits in case of a fire in a specific factory floor, providing data support for the development of evacuation plans.

3.3.2 Design of optimization algorithms for evacuation scenarios

(1) Multi-objective optimization algorithm: The optimization of evacuation plan involves multiple objectives, such as the shortest evacuation time, the smallest casualties and the lowest evacuation cost. Therefore, the design of evacuation plan optimization tools based on multi-objective optimization algorithms can comprehensively consider the interrelationships and trade-offs between the various objectives, and generate the optimal evacuation plan. For example, in the optimization of school evacuation plan, it is necessary to ensure that students are evacuated to the safe area in the shortest time, but also to consider avoiding accidents such as stampede during the evacuation process, and at the same time to minimize the workload of the teacher's guidance during the evacuation process and other cost factors.

(2) Real-time dynamic adjustment algorithm: In the actual evacuation process, the situation may change at any time, such as the emergence of new sources of danger, obstruction of evacuation routes, etc. Therefore, real-time dynamic adjustment algorithms are developed so that the evacuation plan can be quickly adjusted and optimized based on real-time monitoring data. For example, during an earthquake evacuation, if an evacuation channel is impassable due to the collapse of a building, the system is able to immediately re-plan the evacuation path based on the real-time data, and guide people to choose other safe channels for evacuation.

3.3.3 Tool-chain integration and visualization

(1) Tool-chain Integration: Integrate the tools for building evacuation models, optimization algorithms, data processing, simulation, etc. to form a complete AI-driven tool chain for automatic optimization of evacuation scenarios. The tool-chain can realize the automated process from inputting evacuation scenario parameters (e.g., place layout, personnel distribution, disaster type, etc.) to outputting the optimal evacuation plan, which improves the efficiency and specificity of evacuation plan formulation.

(2) Visualization display interface design: develop an intuitive and friendly visualization display interface to display the optimization process and results of the evacuation plan to the user in the form of graphs, charts, animations and so on. For example, through the 3D visualization technology to show the movement trajectory of the personnel in the evacuation process, changes in the density of personnel in various regions, the use of evacuation channels, etc., so that emergency management personnel and decision makers can clearly understand the details and effects of the evacuation plan, to facilitate decision-making and command.

4. Implementation Steps and Safeguards for Innovative Directions

4.1 Affiliations

4.1.1 Data collection and organization phase

Determine the collection channels and equipment for multi-source data, such as installing high-definition surveillance cameras at key locations, deploying cell phone signaling collection base stations, and establishing data-sharing interfaces with social

media platforms. Conduct preliminary organization and cleaning of the collected data, remove noisy data and invalid data, and establish a data warehouse to provide a high-quality data base for subsequent analysis and modeling.

4.1.2 Stage of construction of assessment methodology and indicator system

In-depth research on the retrospective analysis method of evacuation effect, development of corresponding data analysis algorithms and software tools, fusion processing and in-depth mining of multi-source data, extraction of personnel behavioral patterns, evacuation paths, time distribution and other key information. Establish a scientific and reasonable quantitative index system for evacuation efficiency, clarify the definition, calculation method and evaluation standard of each index, and verify and optimize the index system through expert consultation and field research.

4.1.3 AI-driven evacuation scenario optimization tool chain development phase

Collect and organize a large amount of evacuation training data, select appropriate machine learning algorithms for evacuation model training and optimization, and improve the accuracy and generalization ability of the model. Design and implement evacuation scheme optimization algorithms, combine multi-objective optimization and real-time dynamic adjustment techniques, develop an automatic evacuation scheme optimization tool chain, and conduct internal testing and debugging to ensure the stability and reliability of the tool chain.

4.1.4 Pilot application and replication phase

Select some representative places (e.g. schools, shopping malls, factories, etc.) for pilot application of post-evacuation assessment system innovations, collection of pilot data, and practical validation and evaluation of the assessment methodology, indicator system and tool chain.

Based on the results of the pilot application, lessons learned will be summarized and the innovative system will be further refined and improved, and then gradually promoted and applied on a wider scale to raise the level of public security emergency management.

4.2 Safeguards

4.2.1 Organizational safeguards

Establish a leading group and expert team for the innovation of post-evacuation assessment system composed of government emergency management agencies, scientific research units, relevant enterprises and other parties, responsible for the overall planning, organization and implementation of the project, technical guidance and supervision and evaluation. Clarify the division of responsibilities among departments and units, strengthen collaboration and cooperation, and establish an efficient communication and coordination mechanism to ensure the smooth implementation of the innovation work. Feng[10] analyzed the current technical challenges and development trends of the innovation of post-evacuation assessment system, and put forward measures such as policy guidance and improvement of spatial facilities, to provide a solid organization for the smooth implementation of the innovation work.

4.2.2 Technical safeguards

Increase scientific research investment in innovative research on post-evacuation assessment systems and encourage universities, research institutions and enterprises to carry out research and development and innovation in related technologies, so as to provide sufficient technical support for project implementation.

4.2.3 Financial security

Seek financial support from the government to set up a special fund for post-evacuation assessment system innovation, which will be used for the purchase of data collection equipment, technology research and development, pilot applications and other work. At the same time, it has actively guided the participation of social capital, broadened funding channels through cooperation with relevant enterprises and project bidding, etc., to ensure that the innovation work is guaranteed with stable funding.

4.2.4 Talent Cultivation and Training Guarantees

Strengthen the training of professionals related to post-evacuation assessment, set up relevant specialized courses and training programs in colleges and vocational schools, and cultivate a group of composite talents with knowledge and skills in multi-source data analysis, AI technology, and emergency management.

5. Summary

The innovation of the post-evacuation assessment system is of great significance for enhancing the public safety guarantee capability. Through the retrospective analysis method of evacuation effect based on multi-source data, it can comprehensively and accurately obtain all kinds of information in the evacuation process; the establishment of quantitative indicators of evacuation efficiency provides a scientific measurement tool for evaluating the evacuation process; and the AI-driven automatic optimization tool-chain of the evacuation plan can realize the dynamic optimization and intelligent adjustment of the evacuation plan. These innovative directions complement and promote each other, and can effectively make up for the shortcomings of the current evacuation research that focuses on planning but not on evaluation, forming a complete management closed loop and promoting the scientific, standardized and intelligent development of evacuation work. In the implementation process, it is necessary to take scientific and reasonable steps and effective safeguards to ensure that the innovative results can be applied and play a practical benefit, making a positive contribution to the protection of people's lives and property safety and social stability.

In future research and practice, innovation in the post-evacuation assessment system will continue to deepen and expand as technology continues to develop and social needs change. For example, we will further explore the application of Internet of Things technology and blockchain technology in post-evacuation assessment to improve the authenticity and security of data; strengthen cross-sector and cross-region post-evacuation assessment synergies and cooperation to realize resource sharing and complementary advantages; and focus on the evacuation needs of special populations to develop more targeted assessment methods and tools. All of these will be important directions in the innovation of the post-evacuation assessment system, which will help to continuously improve China's emergency response capacity and level of response to all types of emergencies.

References

[1] Cui H. An Evaluation Model for Fire Fighting and Emergency Evacuation Plan. IOP Conference Series: Earth and Environmental Science, 2021, 760(1).

[2] SHINOZAKI M, SEKIZAWA A, KOBAYASHI K, et al. International Comparative Analysis on Regulatory Provisions and Codes of Fire Evacuation Safety for Physically Challenged People. Bulletin of Japan Association for Fire Science and Engineering, 2016, 66(2): 21-30.

[3] Chenghao Y, Yuechan L, Chao S. Risk Assessment of Pedestrian Evacuation under the Influence of Fire Products. Discrete Dynamics in Nature and Society Discrete Dynamics in Nature and Society, 2020, 2020.

[4] Zhiqiang W, Fei W, Meiting Z & Feng H. Fire Emergencies and Information Disclosure in the New Media Era. Fire Science and Technology, 2023, 42 (07): 1000-1004.

[5] Ling L, Yuanyuan Z. Optimization of Safety Evacuation in Middle School Teaching Buildings. Value Engineering, 2025, 44(14): 82-84.

[6] Xiaochun Z, Shaoming T, Jiangang Z, et al. Experimentalesign of Uantitative Valuation of MergencyScape Bility under lrtual lre Cenario, 2024, 43(06): 179-183+208. DOI: 10.19927/j.cnki.syyt. 2024.06.035.

[7] Dongjie Z. Design of Fire Escapes Across the Floors in High-rise Buildings. Journal of Hubei University of Technology, 2014, 29(04): 79-81.

[8] Cuesta A, Alvear D, Abreu O, et al. A Method to Assess the Accuracy of Pseudo-Random Number Sampling Methods from Evacuation Datasets. Fire Technology, 2018, 54(3): 649-668.

[9] Junbo L. Research on emergency evacuation risk analysis and path optimization methods for passenger ships in fire incidents. Shandong Jiaotong University, 2024. DOI: 10.27864/d.cnki. gsjtd.2024.000110.

[10] Guangyuan F, Jingxiang Z, Mengyuan M, et al. Evacuation Capability Assessment and Optimization Strategies of Urban Civil Defense Projects from the Angle of Perceptual Differentiation: A Case Study of Xinjiekou Area, Nanjing/Guangyuan F. Planners, 2025, 41(03): 58-65.

