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Research on Constructing Risk Communication Mechanism for Urban Rail Transit Integrating Grounded Theory and Analytic Hierarchy Process

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Abstract. Against the backdrop of escalating climate change, the effectiveness of risk communication for urban rail transit systems under extreme weather events such as rainstorms has emerged as a critical issue in urban resilience building. Focusing on the risk communication challenges faced by urban rail transit in rainstorm scenarios, this study systematically extracts eight categories of core factors through a three-level coding process based on grounded theory. Building on this, the Analytic Hierarchy Process (AHP) is employed to quantitatively assess the importance of each influencing factor. The theoretical model developed in this research not only enriches the research framework in related fields but also provides a theoretical foundation and practical guidance for optimizing risk communication mechanisms in urban rail transit under extreme climatic conditions.

Keywords: Urban Rail Transit, Rainstorm Disaster, Risk Communication, Grounded Theory, Analytic Hierarchy Process

1. Introduction

Against the backdrop of climate change, the frequency and intensity of extreme weather events have continued to rise, rendering urban rail transit systems particularly vulnerable to sudden-onset disasters such as heavy rainfall. Risk management, as a core strategy for addressing disaster risks in rail transit, encompasses the full spectrum of processes including risk identification, assessment, control, and monitoring. Within this process, risk communication plays a vital and irreplaceable role. An early definition provided by the U.S. National Research Council describes risk communication as a process embedded within the broader risk management framework, whereby information is shared and exchanged among multiple stakeholders to reduce uncertainty, enhance mutual understanding, and foster collaboration [1]. The Sendai Framework for Disaster Risk Reduction, issued by the United Nations, further emphasizes the central role of risk communication in strengthening resilience and reducing disaster risk. Effective communication is considered a fundamental component of disaster planning, emergency response, and post-disaster recovery efforts [2].

Empirical studies have shown that risk communication significantly improves public awareness and preparedness capacities in disaster scenarios, as evidenced by Bradley et al.'s systematic review

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[3]. The effectiveness of risk communication is influenced by several interrelated factors, including the accuracy of information, the credibility of the source, and the audience's perception of risk [4]. While emerging platforms such as social media have enhanced the speed and interactivity of information dissemination, they have also introduced challenges such as information overload and the proliferation of misinformation. Cross-national comparative studies further reveal that risk communication systems vary significantly across countries due to differences in legal foundations, institutional arrangements, and cultural contexts [5]. In the Chinese context, research has also indicated that effective risk communication contributes to enhancing the overall resilience of cities during disaster events [6].

In this study, grounded theory is employed to conduct a systematic analysis and coding of data related to risk communication in the context of heavy rainfall affecting urban rail transit systems. Through this qualitative approach, the study identifies key factors that influence the effectiveness of risk communication. Furthermore, the Analytic Hierarchy Process (AHP) is integrated to assess the relative importance and interrelationships among these factors. By combining qualitative insights with quantitative evaluation, this research aims to provide both a theoretical foundation and practical guidance for optimizing risk communication mechanisms within urban rail transit systems under climate-induced disaster scenarios.

2. Method

2.1. Grounded theory

Grounded theory is a qualitative research methodology characterized by its bottom-up approach to theory development. Its central premise is to generate theoretical constructs directly from empirical data by systematically analyzing and categorizing concepts derived from original materials in response to a specific research question. The methodological process of grounded theory typically involves four key stages: open coding, axial coding, selective coding, and theoretical saturation testing. Theoretical saturation is considered to be reached when no new categories emerge during continued data analysis. Ultimately, the process leads to the development of a theoretical framework structured around a core category, supported by axial categories as dimensions, and initial categories as indicators.

2.2. The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a semi-quantitative method that integrates qualitative judgment with quantitative analysis, thereby addressing some of the limitations inherent in purely quantitative approaches [7]. AHP is widely valued for its systematic structure, practical applicability, simplicity, and adaptability. It decomposes complex decision problems into a hierarchical structure comprising multiple interrelated elements, and considers both the relative importance and interdependencies among them. Through pairwise comparisons and consistency assessments, AHP enables the construction of a well-defined hierarchical model that supports robust decision-making.

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3. Identification of influencing factors of risk communication in rail transit under rainstorms based on grounded theory

3.1. Data sources

The data supporting this study mainly derive from relevant materials of rail transit systems' emergency responses in multiple Chinese cities under rainstorm scenarios. To ensure the research's pertinence, this paper focuses on collecting textual materials including accident bulletins, public reports, emergency information released by operational units, and authoritative news media reports. Meanwhile, it draws reference from multiple domestic and international official guidance documents and practical guidelines on disaster risk communication, such as emergency management policy documents, risk communication operation manuals, emergency communication guidelines, and urban flood management plans.

3.2. Open coding

The coding process in grounded theory consists of three levels. The first stage, open coding, involves identifying categories from the raw data and assigning conceptual labels to original statements.

3.3. Axial coding

Axial coding builds upon the outcomes of open coding by establishing connections among the identified categories. Its primary objective is to explore and construct relationships between different conceptual groupings, thereby revealing how various parts of the data are interrelated.

3.4. Selective coding

Selective coding refines and integrates the major categories by identifying a central category that captures the essence of the research phenomenon. Based on the preceding open and axial coding stages, this study identified eight core categories: environment, human, infrastructure, knowledge, information, management, risk communication behaviors, and risk communication response strategies. Based on this, the final framework of influencing factors for risk communication in urban rail transit under heavy rainfall conditions was constructed, as illustrated in Figure 1.

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Figure 1: The framework of influencing factors for risk communication in urban rail transit

3.5. Theoretical saturation assessment

Theoretical saturation serves as a measure of the reliability and completeness of the conceptual model. In this study, the saturation test was conducted using 10 incident reports and 3 official guidelines or frameworks on risk communication. The coding process was extended using Nvivo 14 software to examine whether the currently identified influencing factors were sufficiently comprehensive. The results indicated that the categories and axial categories within the model were well-developed and conceptually robust.

4. Determination of weightings for influencing factors of risk communication based on Analytic Hierarchy Process

4.1. Construction of the hierarchical structure model

Based on the three-level coding results of the grounded theory model obtained in the previous text, a hierarchical structure model was constructed. The influencing factors of risk communication in rail transit rainstorm disasters were set as the top-level objective layer, which includes 8 first-level factor indicators.

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4.2. Calculation of weightings for influencing factors of risk communication

4.2.1. Construction of pairwise comparison judgment matrix

To determine the relative importance of the influencing factors, an expert panel was convened, and a structured questionnaire was administered. In order to reduce the cognitive complexity associated with comparing heterogeneous factors and to enhance the precision of the evaluation, the Analytic Hierarchy Process employs a pairwise comparison method. Experts assessed the relative importance of each factor in pairs using a standardized 1-9 scale. Let a_{ij} denote the comparative importance of factor i relative to factor j, and let n represent the total number of factors under a given criterion, which corresponds to the order of the judgment matrix. Accordingly, the pairwise comparison judgment matrix is constructed as follows:

$$A = (a_{ij})_{n\times n}, (i = 1,2,\cdots,n; j = 1,2\cdots,n) \tag{1}$$

A total of 100 respondents participated in the questionnaire survey, including rail transit company operators, safety officers, safety directors, passengers, etc. A total of 100 questionnaires were distributed, and 100 were recovered, among which 92 were valid, with a questionnaire validity rate of 92%.

4.2.2. Weight calculation

The factor weight refers to the relative importance of each factor to the upper-level factor. In this study, the arithmetic mean method was used to calculate the weights of factors at all levels. First, the judgment matrix was normalized by column, and the formula is as follows:

$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, (i = 1,2,\cdots,n; j = 1,2,\cdots,n) \tag{2}$$

The weight value of each factor can be obtained by calculating the average value of each row, with the formula as follows:

$$w_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij}, (i = 1,2,\cdots,n; j = 1,2,\cdots,n) \tag{3}$$

The summarized results of the weight calculation for the first-level index judgment matrix are presented in Table 1.

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Table 1: Summary of weight calculation results

Factors	Weight Coefficient
environment	0.035
human	0.078
infrastructure	0.084
knowledge	0.152
information	0.239
management	0.115
risk communication behaviors	0.129
risk communication response strategies	0.168

4.2.3. Consistency verification

To verify the scientific reliability of the scoring results and determine whether there are contradictions among them, a consistency check is required. The definition of the maximum eigenvalue needs to be introduced: The product of an n-order judgment matrix A and its eigenvector is equal to the matrix multiplied by a certain value λ_{max} , i.e., $AW = A\lambda_{max}$, where λ_{max} is the maximum eigenvalue. The approximate calculation formula for the maximum eigenvalue is as follows:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i} \tag{4}$$

The formula for calculating the Consistency Ratio (CR) of the judgment matrix is given as follows:

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{5}$$

RI represents the Random Consistency Index. For the 8-order matrix constructed in this study, the RI value is 1.41 according to the standard values of consistency indices. The Consistency Index (CI) is used to measure the degree of consistency within the judgment matrix. Its calculation is given by the following formula:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{6}$$

If the CR is less than 0.1, the consistency check is considered to be satisfied, indicating that the constructed judgment matrix is logically sound and the derived weight values are valid. The summary of the consistency check results is presented in Table 2. As shown in Table 2, all CR values are below the threshold of 0.1, confirming that the consistency requirements are met. Accordingly, the final calculated weights are reported in Table 1.

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Table 2: Consistency check results

Risk Factors	λ_{max}	CI	RI	CR	Consistency Test Result
A	8.263	0.0376	1.41	0.0267	pass

5. Conclusion

This study focuses on urban rail transit systems under heavy rainfall conditions and establishes an analytical framework for identifying the influencing factors of risk communication. By integrating grounded theory and the Analytic Hierarchy Process, the research systematically reveals the multidimensional and complex nature of risk communication from both theoretical and practical perspectives, while quantitatively assessing the relative importance of various factors. The findings indicate that the authority and clarity of information, the systematic planning of communication mechanisms, and the effective integration of knowledge are key determinants of communication effectiveness. Among the eight primary categories identified, information-related and strategic elements received the highest weights, underscoring the urgency of enhancing information infrastructure and institutional responsiveness. Furthermore, the study emphasizes that risk communication should be embedded within the routine operations and emergency management protocols of urban rail systems. The analytical model proposed herein offers valuable insights for advancing risk management in future urban transit contexts and holds strong potential for practical application and broader dissemination.

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