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A Summary of Research on Resilienc of Transportation

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ABSTRACT: In the context of today's social and ecological changes, extreme climate conditions and health emergencies pose a huge threat to urban development and people's lives and property worldwide. In response to this situation, the concept of enhancing urban "resilience" development is proposed. Transportation "resilience" is an important component of urban "resilience" and is of great significance to ensuring the smooth and orderly development of cities. Numerical analysis is a discipline that studies and analyzes numerical calculation methods and theories for solving mathematical problems with computers. It is widely used in various research fields and plays a fundamental role in scientific development. This paper mainly summarizes the current status of transportation "resilience" research at home and abroad from three aspects: transportation system resilience, transportation system resilience planning, and transportation system resilience assessment, as well as the application of numerical analysis related theories in the field of transportation "resilience" research. Literature analysis shows that numerical analysis is mainly used in two aspects in transportation "resilience" research: data initialization processing (including data acquisition and cleaning) and model solving.

Keywords: transportation; resilience; numerical analysis; review

I. INTRODUCTION

The transportation system plays an important role in urban development. The effective and stable operation of the transportation system is the foundation of urban development. However, with the intensification of urbanization and the large-scale population gathering, the natural ecology has been damaged to varying degrees, and various natural disasters and diseases have occurred frequently in society. According to the United Nations, a total of 7,348 natural disasters were recorded in the world in the first 20 years of the 20th century, far exceeding the 4,212 between 1980 and 1999; these more than 7,000 natural disasters caused 1.23 million deaths, brought economic losses of 2.97 trillion US dollars, and affected 4 billion people. Various new diseases have also emerged in the world, such as Ebola, monkeypox, and new coronavirus pneumonia. These have posed a major threat to human life, health, and property. In order to cope with various emergencies, experts and scholars have proposed to enhance the "resilience" of cities and have conducted research on related content.

"Resilience" has been extended from the concept of physics to ecological restoration, and gradually to the engineering problem of urban hardware construction to resist changes in the external environment, and has developed into the current concept of "resilient city" [1]. A resilient city refers to a city that can resist disasters and reduce disaster losses with its own capabilities under external interference, and rationally allocate resources through the autonomous regulation of the social system to avoid potential losses and cope with challenges and changes in the external environment. Resilient transportation is a component of a "resilient" city, which mainly refers to "transportation infrastructure that can predict and adapt to the changing natural environment, has high reliability and necessary redundancy, and can withstand and respond to emergencies and achieve rapid recovery." Current scholars' research on "resilient" transportation mainly focuses on three aspects, namely how to improve the "resilience" of transportation, transportation system resilience planning, and transportation "resilience" assessment.

Based on literature research, this paper analyzes the current perspectives, models, and solution methods of research on transportation "resilience" at home and abroad from the three aspects of transportation system resilience, transportation system resilience planning, and transportation system resilience assessment. In particular, the application of numerical analysis related theories in the field of transportation "resilience" research.

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II. TRANSPORT SYSTEM RESILIENCE

Early research on transportation resilience focused on the damage of engineering materials. It was not until 1990 that Karen C[3] and other scholars studied the impact of road closures caused by the Loma Prieta earthquake, which opened a new window for research on transportation system resilience. Improving transportation resilience requires predicting possible future departures and designing corresponding plans. In recent years, domestic scholars have combined some cutting-edge technologies in their research on "resilient" transportation. For example, Yang Hanwen and Ou Jinping [2] used the principle of least squares method and regression statistics to propose a general formula suitable for earthquake damage indicators of various types of infrastructure on highway trunk lines. This formula can be used to quickly evaluate the damage level of various types of infrastructure on highway trunk lines after an earthquake, providing an important basis for quickly evaluating the earthquake resilience of the entire highway trunk line after an earthquake; Huang Qian, Shangguan Su, Shi Hongfang [4] and other scholars studied the application of spatial information technology in "resilient" transportation; Ma Lingyong, Wang Zhenhao, Liang Jing and other scholars [5] based on the theory of resilient cities, explored the spatial resilience strategy of road traffic in Daqing City through iterative solution theory; Wang Jing [6] used the relevant theory of resilience to construct a resilience map, and used the iteration method and interpolation method to solve the theoretical composition equation, thereby realizing the application of resilience theory in transportation. With the development of "resilient" transportation, many experts and scholars have applied various methods and theories to the construction of "resilient" transportation. In model solving, it is necessary to use methods such as Lagrange interpolation and nonlinear equation iteration in numerical analysis to achieve model solving. Chen Shuwei [7] used binary particle swarm algorithm and breadth-first search algorithm to reduce the number of iterations in his research on the resilience of air traffic networks in order to optimize the solution of air network models.

The development of various fields in the world today is closely linked to digitalization and intelligence, and so is "resilient" transportation. Starting from smart transportation, we can strengthen the "resilience" of transportation, improve the adaptability of transportation and cities, and promote the construction of smart cities. Numerical analysis is a discipline that studies and analyzes the numerical calculation methods and theories of using computers to solve mathematical calculation problems. In the research related to the "resilience" of transportation, it is often used to solve the relevant models by computer. Based on the theory of resilience, Wang Fang, Hu Wenying and Gao Chenge applied KD calculation to analyze river systems, explore the linear elements of transportation networks, and study the coupling evolution of transportation and cities, proposing a new direction for the study of "resilience" in transportation. In the study of the "resilience" of subway network energy supply, H. A. Gabbar, A. M. Othman and J. Chang[8] proposed a resilient network design, and constructed a mathematical model of the resilient network with the help of interpolation calculation, so as to ensure the energy supply under normal and special conditions, and thus improve the resilience of subways in cities.

In the study of transportation system resilience, numerical analysis theory is mainly used in three areas: basic data acquisition and model solution. The basic data specification mainly involves methods such as dichotomy and condition number in numerical analysis, while iterative calculation, interpolation calculation and decomposition calculation in numerical analysis are widely used in model solution.

III. TRANSPORTATION SYSTEM RESILIENCE PLANNING

Given the unpredictable changes in the external environment, many scholars consider "resilience" as an important planning factor when studying transportation planning and urban planning. Wang Huan, Zhang Peng, and Yin Niyang [10] studied urban development and utilization from the perspective of resilience; Cai Yunnan and Wen Zhaopeng [11] proposed a study on urban "resilience" climate in response to climate change; and Wang Xinhao [12] proposed that urban "resilience" research is a future development direction.

As an integral part of a city, transportation planning and design are often combined with urban planning. “Resilient” transportation is also the key to building a “resilient” city. “Resilient” transportation construction requires adjusting the role of public transportation and the government to fully guarantee the operation of the transportation system in the event of natural disasters and pandemics [1]. In the study of “resilient” transportation planning, Wu Jing, Yan Qingqing, and Jiao Tianshuai [13] proposed to build an “urban transportation cluster” and establish an effective interconnection mechanism to reduce the spread of accidents caused by emergencies. In addition, they proposed to establish a three-dimensional transportation network with a

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complete infrastructure structure and three-dimensional connection in the urban area, forming a comprehensive three-dimensional transportation network with different service levels to ensure the short-term operation of transportation in emergencies. These strategies are undoubtedly effective in dealing with emergencies and provide a new direction for the construction of "resilient" transportation. In response to the outbreak of pandemic diseases, especially the new coronavirus pneumonia, Yu Xiaochun and Zhang Jing [14] proposed that "resilient" transportation planning requires diversity and modular development; Zhang Haohong and Huang Feimei [15] proposed that comprehensive transportation planning should be people-oriented, improve transportation "resilience", and connect with "resilient" urban construction in the context of national space; Zheng Baoli, Yang Tao, and Chen Mingtao [16] proposed that in order to respond to public health emergencies, it is necessary to advocate the construction of resilient cities, strengthen the diversity of urban transportation supply, optimize the urban logistics and transportation system, and pay attention to the construction of urban smart transportation.

The resilience planning of transportation systems is mainly analyzed from a qualitative perspective, and there are few areas where numerical analysis methods need to be applied.

IV. ASSESSMENT OF THE RESILIENCE OF THE TRANSPORTATION SYSTEM

With the development of research related to transportation resilience, the industry has a certain theoretical and technical foundation for increasing the research related to transportation system resilience. How to evaluate the current urban and transportation resilience also shows research significance. Many scholars and experts have conducted research on transportation resilience. Among them, regarding the assessment of rail transit resilience, Z. Xu, S. S. Chopra and H. Lee et al. [25] selected five different rail transit networks and evaluated the resilience of rail transit from the four recovery cycle stages of preparation, stability, recovery and adaptation through graph theory and network theory based on the flow network model; Lv Biao, Gao Ziqiang, Guan Xinyi et al. [18]proposed an urban road network resilience assessment model based on daily traffic distribution to effectively evaluate the performance of the road network under major disturbance events, providing a scientific model for the evaluation of road network resilience; the methods, theories and model solving algorithms involved in the research on transportation system resilience assessment are summarized as shown in Table 1.

Table 1 Summary of Evaluation Methods for Transportation System Resilience

Year of publication	author	theme	Method Theory	Key Factors
2021	Wang Xinglong, Shi Zongbei, Chen Ziyan**Error! Reference source not found.**	Air traffic network motif identification and subgraph structure resilience assessment	Subgraph structural resilience	Transport network connectivity
2020	Lü Biao, Gao Ziqiang, Guan Xinyi, etc.	Urban road network resilience assessment based on daily traffic distribution	Urban road network resilience assessment model, interpolation solution, recursive formula	Travelers' cognitive updates, behavioral inertia, and network accessibility
2020	Lu Biao, Gao Ziqiang, Liu Yiliu**Error! Reference source not found.**	Assessment of road traffic system resilience and road section importance	Heuristic algorithm and nonlinear iteration method for road section importance	Network efficiency, resilience gain, and resilience loss
2022	Chen Changkun, He Fan, Zhao Dongyue, etc.**Error!**	Resilience evaluation method of urban road public transportation	Urban road public transportation system resilience assessment model based on system	City bus service rate and taxi online rate

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	Reference source not found.	system based on system performance curve	function curve, solved by Aitken algorithm	
2022	Tang Shaohu, Zhu Wei, Cheng Guang et al. [20]	Assessment of Safety and Resilience of Urban Road Traffic System under Rainstorm and Waterlogging	Hierarchical Analysis Method for Road Traffic Network Resilience	Safety and resilience factors of road traffic system, division of drainage network, road network, traffic network, and emergency network
2022	Pan Li [21]	Comprehensive Evaluation Study on Urban Traffic Network Resilience - Taking 40 Chinese Cities as Examples	Comprehensive Evaluation Model for Road Network Resilience	Congestion index and proportion of largest connected subgraph
2021	Zhu Yingqi [22]	Research on Safety and Resilience Assessment of Urban Rail Transit under Rainstorm and Waterlogging	SPRC model (interpolation method), ordered binary quantification method, entropy weight method and cloud model, system disaster theory, resilience theory, sustainable development theory	Resistance capacity, recovery capacity, adaptability
2020	Zhang Jiehua, Ren Gang, Ma Jingfeng [23]	Repair Scheduling Decision Method for Metro Network Based on Resilience Assessment	Space L method for building metro network topology, Dijkstra algorithm	Network average efficiency
2022	Hu Yuhua, Yan Shuiqin, Jiang Wenxin et al. [24]	Port Safety and Resilience Evaluation Model and its Quantitative Research under Major Emergency Events	Triangular Model of Port Safety and Resilience	Disaster system, bearing system, safety and resilience management
2021	Lv Cong, Guan Xin, Gao Ziwei [25]	Assessment of Metro Network Service Resilience and Optimal Recovery Strategy	Optimization model aiming at maximizing road network service resilience, and obtaining optimal recovery strategy based on genetic algorithm	Road network service efficiency, road network service resilience, node importance indicators
2019	Ji Xiaofeng, Xie Jun, Wu Jingqiong**Error! Reference source not found.**	Highway resilience assessment method considering different intrusion scenarios	Resilience Theory	Absorption capacity, adaptability, and recovery capacity

The application of numerical analysis in the research of resilience assessment of transportation systems is mainly model construction and solution. In model construction, the three-angle method, three-bending-moment method, etc. are used to construct interpolation functions to build an assessment model. In model solution, if the constructed model is a relatively simple linear equation, the linear equation solution method in value analysis can be directly applied to the model

solution, such as triangular decomposition method, Doolittle, Grout and other methods. However, when the model is relatively complex, the numerical analysis solution is mainly reflected in the model solution algorithm, such as the iterative theory used in genetic algorithms.

V. CONCLUSION

This paper reviews the factors involved in the research on "resilient" transportation at home and abroad, theoretical models, and how to build a "resilient" transportation system, focusing on the application of computational methods such as interpolation, iteration, and decomposition in numerical analysis in the study of transportation "resilience". With the development of cutting-edge technologies such as the Internet and cloud computing, the tools, theories, and models that can be used in the study of transportation "resilience" are very rich. At present, improving the "resilience" of transportation is mainly based on theories such as resilience, spatial technology, etc., and constructing models such as resilient networks and resilient coupling around the construction of transportation networks, the use of "resilient" materials, and big data monitoring. The assessment of transportation "resilience" is mainly based on the construction of network assessment, triangle assessment, hierarchical analysis and other evaluation models. Numerical analysis theory in the study of transportation "resilience" mainly involves data processing and initial model construction and solution

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