The Resilience Analysis of the Urban Rail Transit System

Siyu Chen*

International School of Luxembourg, Luxembourg, L-1430, The Grand Duchy of Luxembourg

*Corresponding author's e-mail: luchen@islux.lu

Abstract. The urban rail transit (URT) system, a crucial component of urban transportation infrastructure, plays an indispensable role in ensuring the seamless operation of cities. The resilience of the URT system, defined as its capacity to withstand, absorb, and recover from disruptions, encompasses attributes such as robustness and survivability. This concept has become a focal point of academic and practical research. A diverse array of methodologies, including topology analysis, virtual simulation, data - driven approaches, and model optimization techniques, have been developed to evaluate URT system resilience. These research efforts have laid a solid foundation for enhancing the resilience of URT systems. However, several challenges remain. There is significant room for improvement in integrating multi - source data and enhancing the accuracy of simulations in complex scenarios. Looking ahead, the integration of emerging technologies such as big data analytics and artificial intelligence holds great promise. Leveraging these cutting - edge tools can facilitate more in - depth interdisciplinary research, thereby strengthening our understanding and practical application of URT system resilience. By addressing real - world challenges through these advancements, we can promote the sustainable development of URT systems and enhance their pivotal role in urban development.

Keywords: urban rail transit, resilience, stable operation

1 Introduction

Over the past few years, the uncertainty and instability became the new status of the public transport, and it causes negative impacts of urban rail transit system. In order to improve the ability of preventing consequences of damages, The State Council of China enacted the Plan of the Comprehensive National Transport Network, it stated that the transport network resilience and the ability of address the risk will be improved significantly by 2035. Although the experts have stated different definition on the "resilience", the core implication of the "resilience" is the resistance, ability of absorption when the system faced disruptions and the capability of recovery after disruptions.

Urban rail transit system (URT system) will be affected by the facility malfunction, signal malfunction, electrical malfunction, the trouble caused by passengers, explosion, terrorist attack and climate and other perturbations during operation. If the service of the URT system have been interrupted, it would cause the delay of traveling of massive

© The Author(s) 2026

D. Magni et al. (eds.), *Proceedings of the 2026 3rd International Conference on Applied Economics, Management Science and Social Development (AEMSS 2026)*, Advances in Economics, Business and Management Research 389,
https://doi.org/10.2991/978-94-6239-672-2_71

number of passengers, it would even cause the congestion, and the stampede, increasing the risk of the public security. Therefore, the safeguard of the security of the URT system and the capability of addressing the abrupt public security incidence is vital. Base on this, people started to use the indicative "resilience" to measure the performance of the URT system.

The traditional study utilized the network topology indicator, the vulnerability of the network been disrupted and the robustness and the reliability of the network remaining operating normally to measure the network resilience. Nevertheless, the indicator based on the URT network resilience conforms to the definition of the resilience more, indicating the resilience of an URT system by investigating the change of the system performance by the time.

This passage will consider the effect of different disruption on the passenger flow of the URT system and construct a model, in order to better evaluate the capability of the response when an URT system facing different disruptions.

The structure of the passage is as follows: First, the study background and the importance of studying the resilience of a URT system will be discussed; Next, the current status of the study on the URT system resilience will be reviewed; Then the quantitative method of the URT system resilience analysis will be introduced; Finally, the content will be concluded and the approaches of future study will be stated.

2 Literature Review

Urban rail transit (URT) systems are integral to modern urban infrastructure, carrying a vast number of passengers daily and ensuring the smooth functioning of cities. However, these systems are susceptible to various disturbances, such as natural disasters, operational accidents, and terrorist attacks. As a result, the resilience of URT has emerged as a crucial area of research in recent years.

In the research conducted by Jiateng Yin and al., the authors suggested a combination of approach based on knowledge and data for quantitative investigation of resilience in for modelling the causal relationships to compute the relevance of different disruptions to the general resilience standards. The authors build a group of key units associated to the risk assessment and system resilience by utilizing historical data of Beijing Metro. Next, the authors established a training program by utilizing the structure of Bayesian Network and historical data. Finally, the authors insert this hybrid research into software that is practiced to Beijing Metro network. The results reveal that the system resilience is associated with different categories of disruption. [1]

In the study by Jinqu Chen and al., researchers built a resilient assessment model based on train schedule for assessing the URT network resilience in case of natural disasters, discussing the crucial gap in actual research. By looking at numerical data of Chengdu Metro, the researchers explore that the travel time based performance indicator can assess the performance of the network successfully, it shows that the train schedule could affect the resilience of a network largely. The researchers also state that Shuangliu and Wuhou are defined as districts in Chengdu that are vulnerable to rain-

storms and strong wind, respectively. Additionally, this research discovers that the network resilience could be influence by parameter and proposes some policy suggestions according to the results the researcher got. [2]

In the research conducted by Jie Liu and al., models are developed to enhance the URT system structure and resilience of URT system. The researchers developed a bi-level programming model in order to improve URT network's global accessibility and its efficiency to the largest extent. In order to improve the resilience of a disrupted URT network by enhancing the restoration arrangement of stations that are disrupted, the researchers suggested a simulation repair strategy. To enhance the Chengdu Metro network resilience, the researchers used these models. Results reveal that the bi-level programming model build a useful experience for the planning of new lines to upgrade the structure of Chengdu Subway network. The network's operators need to focus on operations of major important stations to prevent pertubation from causing negative impact on the network's normal operations. The simulation repair strategy works better than traditional strategies because of its efficiency on the Chengdu Subway network resilience is higher. [3]

In the research conducted by Xin Wen and al., researchers introduced a quantitative measuring method by first exploring the definition of the resilience in URT system and clarify related concepts, then categorized the commonly used resilience metrics as network topology metrics, supply-demand-based metrics, and comprehensive metrics, next the passage summarized the common URT system resilience measurement approaches in URT system, including the topological, data-driven, optimization and simulation approaches. Finally, the researchers gave some strategies and recommendations for improving the resilience of the URT systems and suggests the topics for future researches. [4]

In the research conducted by Yun Wei and al., the researchers describe the URT resilience's definition, which is the ability of the system to absorb, resist the effect of disruption and recover from it, and its properties is also stated, which contains robustness, vulnerability, rapidity and redundancy. The passage also states the metrics and approaches based on topology, characteristic, and performance to evaluate the resilience of URT. Then the passage compares each metrics and approaches and discovered that current researches combines conventional methods, such as network analysis and operations optimization theory and new methods, such as big data as well as intelligent computing technology. Finally, the passage identifies potential trends for future researches: analyzing resilience using multisource data, optimizing train diagram in multiple scenarios, accurate response to passenger demand through new technologies, and other method to analyze resilience. [5]

In the study by Zhiao Ma and al., researchers planned a life-cycle resilience assessment model of URT faced to passenger service. Researchers used this method to analyze the Beijing Rail Transit network resilience. Researchers discover that the importance of stations counts on the topology and the passenger flow and alternatives redundancy. The results show that the loop line has better resilience and has the capability to efficiently evacuation passengers in case of disturbance, whereas the hub transfers stations that connects to the suburb does not perform well. [6]

In the study by Wen Hua and Ghim Ping Ong, researchers present an approach to measure the ability to survive and recover of an urban rail-bus network when it is experiencing a disruption. To work out the number of passengers affected during a disruption in a rail transit network, the researchers created a maximum survivability-minimum recovery time approach, the passenger number who needs to change transport mode and the duration of recovery. The researchers also do a case study of Singapore MRT to proof the applicability of these proposals. These proposals could provide insights on the state of the rail network resilience when experiencing different disruption scenarios and evaluate the recovery time after disruption. [7]

In the research conducted by Nikola Besinovic, the researcher targets to set up a definition of resilience in railway transport and provide an inclusive, advanced discussion of railway resilience papers which is mainly about quantitative approaches. The review analyzes past papers from the recent decades. The results show that numerous papers published in recent years have been increased. The review categorizes metrics and approaches for measuring resilience. The results show that it has been recognized that system-based metrics have a better ability to seize the impacts on railway transport services its demand. Moreover, mathematical optimization reveals a great potential to evaluate and reinforce resilience of railway systems. Alternatively, data-driven approaches have a potential use for detailed ex-post investigation of past disruptions. Finally, the researcher identifies numerous emerging future topics for study, ranging from learning from historical data, to put interdependent critical systems and community resilience into consideration. [8]

In the research conducted by Junhong Hu and al., the researchers examine the existing research on resilience assessment and recovery strategies for urban rail transit networks. Firstly, the researchers analyze the characteristics of urban rail transit network and the method of model construction. Secondly, the researchers define the urban rail transit network resilience based on the combination of system resilience, while classifying and summarizing the conventional resilience metrics and assessment indexes. Finally, the researchers investigate and discuss the failure situations and recovery methods of urban rail transportation network. The research results show that scholars has been widely concerning about the URT network resilience. Moreover, in three aspects of resilience connotation, resilience assessment and recovery strategy, various results have been achieved. Nevertheless, these aspects need further researches. The researchers suggests future research directions including exploring modeling methods aligned with actual network topologies, building unified indexes for resilience assessment and focusing on resilience assessment and recovery strategies under uncertain disturbance events. [9]

In the study conducted by Wei Bi and al., the researchers assessed the flood resilience of an urban rail transit system, focusing on dynamic operational performance of service delivery under realistic flood disruption scenarios. A model is tailored to incorporate a broader range of real-world factors into complex network modelling than adopted previously, including physical URTS network features, plausible flood disruption scenarios, and resourcing for recovery. The researcher estimated the results for loss of satisfied travel demand numbers in the different year span and its revenue loss. This

research emphasizes that the popular normalized resilience index can detect system performance loss. However, it has a low ability to evaluate recovery time, which is important when there is a long time for recover. This research provides a essential quantitative approach for assessing the current level of system resilience and paves the way for testing the ability of potential precautions for reduction of disaster risk in operation and management. [10]

To sum up, the study of the URT system resilience has been increased, numerous researchers had been researching it, and formed significant results. By reviewing the relevant papers, the definition of the URT system resilience is clarified as the ability of a system to defend, absorb and recovery from the disruption, involving the robustness, survivability, and recoverability, and it formed a conceptual foundation for further study. It also includes topology analysis, virtual simulation, data-driven, model optimization as its multiple methodology. The topology analysis method analyzes the static criteria such as the system efficiency, despite the simplicity, it lacks the description of the dynamic operation status of the system; virtual simulation method can imitate the disruption of the system to reveal the dynamic change of a system, but it lacks a general framework; the model optimization method constructed a mathematical model based on the actual operation of the network, while it faces the difficulties on the accuracy in complex situation; The data-driven method, as a new approach, it provides a new perspective by using multiple data. All in all, these explorations construct a systematic research framework and it stimulate the development on this field. However, the current study still has some drawbacks.

3 The Methodology

The method of the calculation of the resilience of a URT system involves three methods, including the “resilience triangle”, “performance integral ratio” and “decrease ratio” method. The "resilience triangle" method conceptualizes URT resilience as a function of three interrelated dimensions: robustness, redundancy, and rapidity, as shown in Fig.1 . The "performance integral ratio" method takes a more data - driven approach. It calculates the ratio of the integral of the system's performance over a specific time period during a disruption to the integral of the performance during normal operation. The "decrease ratio" method, in contrast, focuses on the magnitude of performance decline during a disruption. It calculates the ratio of the difference between the system's pre-disruption and post-disruption performance to the pre-disruption performance.

All three methods have its similarities, especially the starting steps are exactly the same. The starting steps are:

a. to construct a grid including time(t) as x-axis and the efficiency of the rail transit operation a y-axis;

b. to decide the efficiency of the rail transit system when operating normally and drawing the normal-operation curve (100% curve);

c. to determine the time when the disturbance events happens (t1) and when the disturbance events ends (t2);

d. to use the passenger flow data through the time to sketch the curve of the overall efficiency change with the time (noted Q(t)).

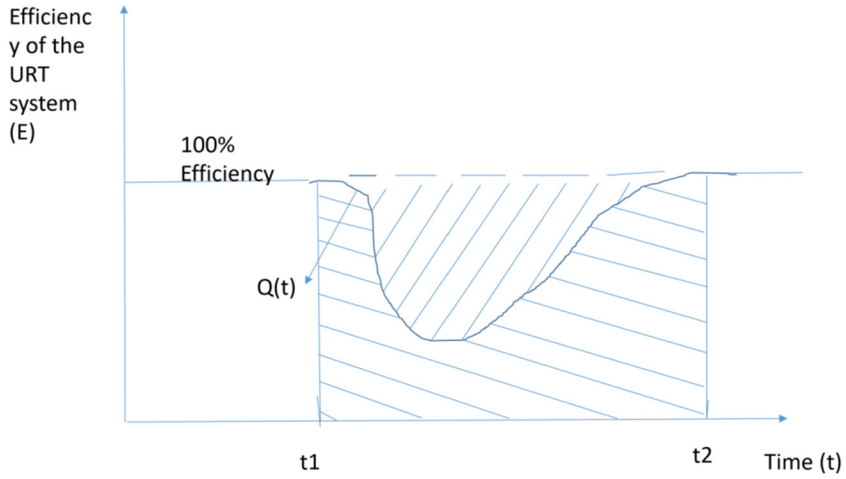

Fig. 1. The relationship between time and the efficiency

Nevertheless, for the precise calculation, three methods have its own feature.

For The Resilience Triangle method, the value will be using the integral of the normal-operation curve minus the integral of the disturbance curve (Q(t)) in the range of the perturbation time. So this method is valid for calculating the efficiency loss of the URT system.

For the Performance Integral Ratio method, the value will be using the integral of the disturbance curve (Q(t)) divided by the normal-operation curve. This method is valid for calculating the overall efficiency performance during the perturbation of URT system.

For the Decrease Ratio method, the method will be more complex. First, the model creating of this kind of perturbation is needed, then using the model to create the worst situation of the perturbation, then use the lowest efficiency to make the calculation. This method has the disadvantage: it does not include the resume time as a consideration, which didn't conform with the definition of the resilience.

Furthermore, a combination of these methods, known as hybrid approaches, provides a more comprehensive understanding of urban rail transit resilience, accounting for the dynamic and complex nature of these critical transportation systems.

4 Conclusion

The urban rail transit system, as an important constituent of the urban transportation, its resilience is vital for the stable operation of the city. The current study defined clearly the URT system resilience as the ability of a system to defend, absorb and recovery from the disruption, and it involves robustness, survivability and other features.

The topology analysis, virtual simulation, data-driven and model optimization and other method are developed to assess the resilience. These progress made a foundation for the improvement of the URT system resilience. However, it also has a space to improve on the integration of the multiple data, the accuracy of the simulation in the complex scenarios. In the future, the big data, the Artificial Intelligence and other new techniques is proposed to be utilized to deepen the inter-disciplinary study, strengthening the understanding and application of the URT system resilience in order to face the actual challenge, booth the sustainable development of URT system and playing an important role on the urban development.

References

1. Jiateng Yin, Xianliang Ren, Ronghui Liu, Tao Tang, Shuai Su, Quantitative analysis for resilience-based urban rail systems: A hybrid knowledge-based and data-driven approach, Reliability Engineering & System Safety, Volume 219, 2022, 108183, ISSN 0951-8320, https://doi.org/10.1016/j.ress.2021.108183.
2. Jinqu Chen, Xiaowei Liu, Xinyue Hu, Bo Du, Yong Yin, Resilience assessment of an urban rail transit network under natural disasters, Transportation Research Part D: Transport and Environment, Volume 139, 2025, 104587, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2024.104587.
3. Chen, J., Liu, J., Peng, Q., & Yin, Y. (2021). Strategies to Enhance the Resilience of an Urban Rail Transit Network. Transportation Research Record, 2676(1), 342-354. https://doi.org/10.1177/03611981211037888
4. Wen, X., Si, B., Wei, Y. et al. Resilience assessment of urban rail transit systems: a literature review. Public Transp (2025). https://doi.org/10.1007/s12469-024-00385-4
5. Yun Wei, Xin Yang, Xiao Xiao, Zhiao Ma, Tianlei Zhu, Fei Dou, Jianjun Wu, Anthony Chen, Ziyou Gao, Understanding the Resilience of Urban Rail Transit: Concepts, Reviews, and Trends, Engineering, Volume 41, 2024, Pages 7-18, ISSN 2095-8099, https://doi.org/10.1016/j.eng.2024.01.022.
6. Zhiao Ma, Xin Yang, Wenlong Shang, Jianjun Wu, Huijun Sun, Resilience analysis of an urban rail transit for the passenger travel service, Transportation Research Part D: Transport and Environment, Volume 128, 2024, 104085, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2024.104085.
7. Hua, W. and Ong, G.P. (2017), Network survivability and recoverability in urban rail transit systems under disruption. IET Intell. Transp. Syst., 11: 641-648. https://doi.org/10.1049/iet-its.2017.0102
8. Bešinović, N. (2020). Resilience in railway transport systems: a literature review and research agenda. Transport Reviews, 40(4), 457–478. https://doi.org/10.1080/01441647.2020.1728419
9. Hu J, Yang M, Zhen Y. A Review of Resilience Assessment and Recovery Strategies of Urban Rail Transit Networks. Sustainability. 2024; 16(15):6390. https://doi.org/10.3390/su16156390
10. Wei Bi, Jennifer Schooling, Kristen MacAskill, Assessing flood resilience of urban rail transit systems: Complex network modelling and stress testing in a case study of London, Transportation Research Part D: Transport and Environment, Volume 134, 2024, 104263, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2024.104263.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.