Application of Digital Technology in the Operation and Safety of Rail Transit in China

Shanlin Huang *

Department of Transportation and Logistics, Southwest Jiaotong University, Chengdu, China

* Corresponding author: 206072109@mail.sit.edu.cn

Abstract. With the continuous improvement of living standards, people pay more and more attention to travel. Rail transit, as the main way for people to travel, has aroused widespread concern. In recent years, with the continuous progress and development of technology, more and more digital technologies have been applied to the field of rail transit, which has comprehensively improved the level of urban rail transit. This paper mainly discusses the application of digital technology in the field of rail transit safety and operation, and introduces the Device-to-Device Communication (D2D) technology, fully automatic operation technology. D2D technology can speed up information transmission efficiency, and fully automatic operation technology can reduce labor consumption and improve operation efficiency. Three-dimensional laser scanning technology and Building Information Modeling technology (BIM) are new technologies in traffic safety. Three-dimensional laser scanning technology can improve detection efficiency and avoid accidents. The traffic operation and maintenance management system based on BIM technology can quickly detect equipment failures and minimize losses after failures. It suggests paying more attention to automatic operation technology, interconnection technology and intelligent operation and maintenance management technology to improve the operation performance, and help urban rail transit further intelligent and information-based development.

Keywords: Digital technology, Urban rail transit, Application, development direction.

1. Introduction

In modern cities, rail transit in urban traffic system occupies an extremely important position. , As the economy continues to grow and urbanization speeds up,the traffic volume increases, which leads to traffic congestion becoming a serious problem. As a large-capacity public transportation mode, the urban rail transit system plays an important role in human activities, economic development and social progress. The rail transit system has established a fixed track line in the city, and rail transit runs on a fixed track, usually with predetermined stations and routes. This feature can reduce the risk of traffic jams and accidents and also enable rail transit to provide stable and efficient transportation services. Compared with other modes of transportation, rail transit can carry a large number of passengers, reduce urban traffic flow, alleviate the problem of road congestion and improve traffic efficiency.

Rail transit has the characteristics of centralized transportation. Compared with private cars, it can greatly reduce energy consumption and exhaust emissions, thereby reducing air pollution, improving urban environmental quality and promoting the sustainable development of cities, which is in line with the concept of green development. The network construction of rail transit can make people reach different areas of the city more conveniently and quickly, and improve the interconnection within the city. Arranging and planning traffic stations can encourage a more compact and mixed-use urban development model and reduce land consumption, which not only promotes the accessibility of the city but also improves the efficiency of land use. A good rail transit system can provide a convenient way for urban residents to travel. In the face of long commuting, residents can reach their destinations faster and reduce commuting time and travel costs.

China has formed a large-scale urban rail transit infrastructure system. By the end of 2022, 53 cities in mainland China had opened 290 urban rail transit lines, with a total length of 9,584 kilometers. It mainly includes subway, urban express rail, light rail, tram and maglev transportation, among which the subway is the most commonly used urban rail transit system, accounting for about 80%. Under the background of high-quality development, during the 14th Five-Year Plan period, urban rail transit will gradually enter the stage of considering both construction and operation, and the attention to the quality of transportation services will be further enhanced, and urban rail transit has become an important choice for residents to travel [1].

However, the current development of rail transit still faces many problems. For example, Zhengzhou, a city in China, was hit by torrential rain, and urban rail transit Line 5 was seriously flooded, causing 14 passengers to die and the whole network stopped [2]. Therefore, there is still room for improvement in safety and disaster prevention. To improve the safety and convenience of rail transit, many new technologies are gradually applied to rail transit, such as 5G communication technology and artificial intelligence technology. For example, artificial intelligence technology has been widely used in intelligent security, intelligent maintenance and intelligent operation, which has comprehensively improved the intelligent level of urban rail transit [3].

In this paper,the current state and issues of rail transportation are discussed, along with an examination of how new technologies can be implemented to improve operations and safety.

2. Application of Digital Technology in Rail Transit Operation

2.1. Communication Based Train Control (CBTC) system

The CBTC system is a railway signal system that utilizes train and track equipment telecommunications for traffic management and infrastructure control. It offers benefits such as high capacity, minimal delay, and low loss, thereby guaranteeing the effective and secure operation of trains. CBTC system needs to obtain real-time information such as position, speed and running state between trains to ensure the safe distance and running order between trains. Device-to-device communication (D2D) technology can transmit data through wireless communication, speed up information transmission and improve information transmission efficiency. At present, the CBTC system can only realize the Train-to-ground (T2G) technology by using D2D, so that the train can exchange data with the ground, which could lead to the situation that the train can't get the state of the preceding vehicle in time due to the failure of the wayside equipment and so on, thus causing a collision accident.

D2D is a direct communication technology between devices, which allows wireless devices to communicate directly without relays through base stations. Additionally, this technology is a product of the advancements in 5G, aiming to decrease mobile traffic congestion, lower energy usage, and optimize the utilization of the radio spectrum presently accessible [4]. D2D communication is a key part of 5G communication technology, which plays a significant role in improving communication quality of equipment, so it can optimize and improve the whole subway system [5]. The application of D2D communication technology can give full play to the role of user terminals, eliminate the dependence on traditional base stations, and integrate the functions of servers and clients [6].

D2D technology can obtain the train operation in real-time, which can not only ensure the coordination of trains but also prevent serious safety accidents. With the application of this technology, the time delay of the subway communication system is controlled, and the train running interval is gradually shortened, which helps improve operational efficiency and meet people's personalized travel needs [5]. In the future, T2T communication technology (Train-to-Train) based on D2D communication technology can be added to make T2G communication mode coexist with T2T communication mode, and then resources can be allocated to maximize the channel capacity of the whole system and solve the existing problems on the premise of ensuring the signal-to-noise ratio of communication links [7].

2.2. Fully Automatic Operation System (FAO)

FAO system is a new generation of urban rail transit system, which includes modern computer, communication, control and system integration technologies to realize the automation of the whole process of train operation. The main technologies of the FAO system include unmanned train technology, integrated automatic dispatching control technology and RAMS integrated support technology based on the whole life cycle. It is the highest level of train operation automation, which can reduce the safety risks caused by human behavior, thus providing safer and more efficient technical support for rail transit operations. FAO system is complex, it covers the whole line, each station and each train. It can be divided into GoA4 unattended automatic operation (UTO) and GoA3 attended automatic operation (DTO). GoA3 level does not need drivers, but needs attendants to manage the door opening and closing and deal with emergencies, while GoA4 level is unattended, which can fully automate all scenes [8].

2.2.1. System composition

FAO is composed of central monitoring system, station subsystem, on-board controller and vehicle-ground communication network, covering the whole line, every station and train [9].

Central monitoring system: The central monitoring system is the backbone of the automated subway operation system. Its primary task is to monitor and manage the entire subway network's operation in real-time. By collecting and analyzing the data transmitted by the onboard controller and the station subsystem, the central monitoring system can monitor the running status of subway lines, train position and passenger flow in real time. In the event of an emergency or abnormal situation, the central monitoring system can take corresponding measures for scheduling and emergency treatment to ensure the safe and smooth operation of the subway.

Station subsystem: The station subsystem is located in the subway station and provides passengers with access to the station and related services. It includes platform door control, passenger information display system, train arrival warning system and safety monitoring system. The station subsystem communicates with the onboard controller and the central monitoring system through the vehicle-ground communication network to ensure coordination and safety between the train and the platform.

Onboard controller: The onboard controller is used to monitor and control the running state of the train. It is an important piece of equipment installed on the subway train the speed, position and acceleration of the vehicle are obtained by sensors, and the acceleration, deceleration, braking and steering operations of the vehicle are automatically controlled according to the preset operation scheme and automatic driving algorithm to ensure the safe operation of the train according to the specified route, speed and interval.

Vehicle-ground communication network: Vehicle-ground communication network is a communication network connecting a vehicle-mounted controller, station subsystem and central monitoring system, which is used for data transmission and information exchange. Through the vehicle-ground communication network, the vehicle controller can interact with the central monitoring system and the station subsystem in real time, which helps realize the overall coordination and safe operation.

2.2.2. Advantages of FAO system

① Compablue to the traditional operating system, the FAO system has the capability to significantly mitigate the security risk resulting from human error. The traditional system relies too much on the personal response of the train driver, while the FAO system could respond immediately through computer program control without being disturbed by factors such as the driver's state.

② The FAO system has the capability to relieve drivers from performing repetitive tasks, assign crew members to the train, enhance passenger service quality, and simultaneously monitor the train's operation status [10].

③ FAO system takes driving as the core, and the signals are deeply integrated with vehicles, integrated monitoring and communication systems, so as to improve the system integration, solve the problem of unified maintenance and reduce the maintenance cost.

2.2.3. Cases

The demonstration project of the Yanfang Line of Beijing Metro adopts the fully automatic operation system, which is a complex giant system composed of 7 majors, 31 subsystems and hundreds of thousands of driving acquisition points. Combined with analysis, the system formed 41 fully automatic operation scenarios, including 18 normal operation scenarios and 23 abnormal operation scenarios, which improved the automation level of the system. Each component of the system cooperates, which realizes the efficient operation of trains and the comfortable travel experience of passengers, and also improves the operation efficiency and management level, providing important experience and reference for the future development of subways.

3. Application of Digital Technologies in Rail Transit Safety

3.1. Structural deformation monitoring of rail transit tunnel

The construction and maintenance of subway tunnels are based on the effective detection and monitoring of the convergence and deformation of tunnel (underground space) rings. Therefore, the efficiency and quality of rail transit tunnel monitoring are the key elements. Conventional monitoring mainly adopts the total station cross-section sampling method, which has some problems, such as fixed location of sampling point, dependence on manual operation and high cost. As an important part of the new surveying and mapping technology, 3D laser scanning technology can quickly collect the position information, detail information and attribute information of ground objects without any contact with the observed objects [11], thereby reducing the monitoring cost and improving the efficiency.

3.1.1. Principle of technology

Three-dimensional laser scanning technology uses a high-speed rotating laser transmitter to continuously emit laser pulses to the measurement target and continuously receive reflected signals, thus measuring the distance from the laser reflection point on the measurement target to the center of the laser transmitter. This method can accurately obtain the information of the surface of the measured object. In measurement practice, the point data captured by equipment is called point cloud, which can truly reflect the overall structure and shape of the target. By processing and analyzing a large number of point cloud data, three-dimensional models can be generated for measurement and inspection [12].

3.1.2. Advantages of technology

As an advanced technology, 3D laser technology plays an extremely important role in rail transit. Compared with traditional manual measurement methods, the advantages of 3D laser scanning technology are mainly reflected in the following aspects:

① 3D laser technology can quickly and accurately obtain the data of subway structure and shape, with high measurement efficiency and greatly saving time and labor costs.

② By generating detailed point cloud data, 3D laser scanning technology can better understand all parts of the subway and provide accurate reference for engineering design and maintenance.

③ 3D laser scanning technology can detect without touching the measurement target, and realize nondestructive detection, which will not have a negative impact on the target.

④ The erection site of 3D laser scanner can be freely selected, and the errors caused by environmental factors can be ignored.

3.1.3. Cases

Three-dimensional laser scanning technology is used in the subway project in Wuhan for monitoring technology. Zhao et al. took a subway tunnel with a length of 1456.54m in the Wuhan line as an example, and compared the detection efficiency of the two methods by using three-dimensional laser scanning technology and total station cross-section sampling method, respectively, through the analysis of shield ring diameter convergence. The author measured a station with a range of 30m, completed the interval scanning operation through two skylight operation points, obtained the convergence data of 1116 shield ring segments, and analyzed the staggered platform between adjacent ring segments [13]. The diameter convergence information of all shield ring pieces monitored by 3D laser scanning technology is shown in Figure 1. In addition, the author also uses the total station cross-section sampling method to check the convergence analysis results of shield ring diameter. The convergence errors of the two monitoring methods are within 5mm, with an average of -3mm and a standard deviation of 1mm, which is within the error range. The comparison results show that the 3D laser scanning technology has completed the monitoring task in a shorter time and with less manpower under the condition of satisfying the accuracy, and it has more advantages than the traditional monitoring methods.

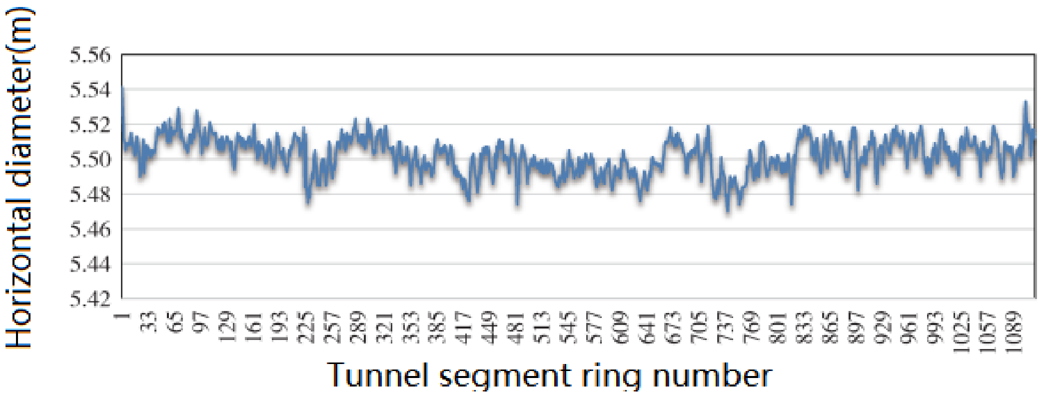

Figure 1. Loop-by-loop water convergence results [13]

3.2. Railway maintenance

3.2.1. Operation and maintenance management system based on BIM technology

Building Information Modeling technology (BIM) is a digital representation method that uses computers and software systems to create, manage and visualize building projects. Through this technology, engineers and other participants can operate on a unified platform.

In order to address issues such as inadequate coordination, single professional management, and limited integration in railway operation and maintenance management, China Academy of Railway Sciences Group Co., Ltd. has developed a railway infrastructure operation and maintenance management platform using BIM technology. This platform aims to enhance the maintenance level and efficiency of subway facilities and equipment by enabling visual operation and maintenance.

3.2.2. System composition

In the railway's internal service network, the system carries out data interaction with many other systems through the data service platform. These systems include a railway engineering management platform, railway natural disasters and foreign body intrusion monitoring system, Beidou infrastructure monitoring system, integrated video monitoring system, signal centralized monitoring system and power supply 6C data center. In addition, the system also interacts with the railway geographic information platform to realize the call of maps and functional services [14].

3.2.3. Main functions of the system

The integration of BIM technology in the operation and maintenance management system enables comprehensive information management. This includes detecting and monitoring, analyzing data, scheduling production, conducting field operations, and evaluating quality. Additionally, the implementation of the integrated maintenance management system with BIM technology enables the following functions [15].

① BIM+GIS visualization function. The system combines BIM+GIS with single point defect of equipment, section unit evaluation and Track Quality Index (TQI) data, intuitively displays the quality status of equipment, and knows the equipment problems at the first time.

② The function of data detection and monitoring is operational. The system is capable of data sharing, identifying mobile, repairing monitoring and static inspection data, and subsequently enhancing the capacity to differentiate equipment defects in order to conduct more effective remedies.

③ Production scheduling management function. The system can establish production planning according to information such as equipment overhaul date, equipment function and equipment status, and can conduct inspection and maintenance according to this information to improve the stability of equipment operation.

④ Spare parts management function. The system can know the detailed information of equipment, input and manage spare parts, ensure the effective use and inventory control of spare parts, so that spare parts can be provided and handled as quickly as possible when equipment fails, and greatly reduce the losses caused by equipment failure.

3.2.4. Cases

In 2020, a pilot of the operation and maintenance management system that utilizes BIM technology was conducted on the Beijing-Zhangjiakou high-speed railway. The system inputs railway infrastructure-related information, establishes a perfect data management system and digitally manages the three-dimensional space of the subway [14]. The system takes the efficient organization of the production process as the core and establishes a closed-loop production organization process of inspection, state analysis, production planning, online operation, safety control and quality evaluation. The system also visualizes the equipment, facilities and quality status, and gives the changing trend, which can be adjusted as quickly as possible.

4. Discussion

At present, the rail transit system mainly focuses on three aspects: fully automatic operation technology, communication technology and intelligent operation and maintenance management technology.

4.1. Fully automatic operation technologies

At present, there are still some problems in the development of fully automatic operation technology, and the following aspects need to be studied in the future:

① With the increase in the service life of facilities and equipment, their reliability could gradually decrease. It is difficult to evaluate which is the greater risk in the absence of reasonable management and maintenance or the risk caused by human error. Further research is needed to determine how to balance the maintenance of equipment reliability and the reduction of risk and cost loss.

② In the FAO system of rail transit based on this technology, the highest level is that the rail transit system can automatically monitor and deal with the dangers that occur in operation, such as fire and equipment failure, etc. At present, the ability of this system to deal with such sudden problems still needs to be improved.

③ When fully automatic operation technology is used in rail transit, it is necessary to meet many goals such as safety, punctuality, comfort, accurate parking and energy saving. Different operation scenarios have different requirements for each target, so it is necessary to automatically identify the current system operation status, clarify the weights of multiple optimization targets, and how to optimize and control after the weights of each optimization target are determined. At present, the research on this aspect of technology is still lacking and cannot meet the requirements.

4.2. Communication technologies

The main application of communication technology is to realize the interconnection of urban rail transit. However, at present, the realization of interconnection is restricted by the following aspects:

① The interconnection of lines is suitable for overall planning during the construction period, and it is best to build multiple lines at the same time, and formulate unified standards for them in order to achieve the maximum scale effect.

② The established standards must be forward-looking, because once the first line is built, the unified standards will be adopted for the subsequent lines, and the feasibility of adopting more economical and applicable technologies could be reduced.

③ The interconnection and transformation of the operated lines should be considered as a whole when they enter the overhaul period, so it could take a long time for cities with large urban rail transit networks.

④ There may be differences in infrastructure and technology such as train models and station layout in the same system, which could affect interconnection. It is necessary to establish a unified standard system for the urban rail transit industry and formulate a complete set of unified standards for vehicles, signals, power supply and platform doors for compatibility treatment.

4.3. Intelligent operation and maintenance management technology

At present, the realization of intelligent operation and maintenance of urban rail transit faces the following challenges:

① The data to be integrated and shared in urban rail transit involves many devices and systems, and the data formats are also inconsistent, so it is difficult to integrate and the cost is high. Moreover, the data collection and storage system using big data, cloud computing and other technologies is equally expensive, and the contradiction between extensive data collection and limited use is prominent.

② The data required by intelligent operation and maintenance management technology needs high quality and accuracy. However, the operating environment of urban rail transit is complex, and the data may be interfered with by external factors, resulting in errors and data loss. It is also a challenge to ensure the high quality and reliability of data.

③ The challenges to realizing intelligent operation and maintenance of urban rail transit in different cities are diversified, and the investment value is different in different cities, which will be different due to the city size and population density, whether the urban economic level can withstand the operational pressure and the level of existing transportation facilities. Therefore, for each specific city, it is necessary to make a detailed analysis, take into account various factors, evaluate the return and risk of investing in intelligent operation and maintenance systems, and determine its investment value.

5. Conclusion

The focus of this paper is on exploring the potential of future rail transit development through the utilization of new technologies and applications that enhance safety and operational efficiency. These technologies can not only improve the operation efficiency and safety of the rail transit system but also improve the passenger travel experience and promote the sustainable development of the city.

In the aspect of rail transit operation, the application of D2D communication technology in the CBTC system can speed up communication efficiency, improve the rate of information transmission, obtain the train operation in real time, ensure the coordination of trains, prevent serious safety accidents, and thus improve the operation efficiency. The fully automatic operation system based on various fully automatic technologies can improve the operation efficiency of traffic, the safety of train operation and the service level under the condition of reducing manpower consumption.

In terms of rail transit safety, three-dimensional scanning technology is used to monitor the structural deformation of rail transit tunnels, which improves the monitoring efficiency, obtains more detailed data and avoids accidents such as tunnel collapse. The operation and maintenance management system based on BIM technology can detect the monitoring equipment, quickly know the equipment problems and manage the production schedule, which can minimize the loss after the equipment failure and improve overall safety.

Through analysis, the fully automatic operation technology still has room for improvement in equipment reliability, ability to deal with unexpected problems and weight distribution of optimization objectives; At present, the interconnection is still restricted by the need for unified standards, and the long realization period of the large-scale rail transit network and the difficulty of interconnection caused by technical differences; Intelligent operation and maintenance management technology is still difficult in data collection and preservation, and its investment value is different in different cities. Future technological development and scientific research can be further studied in these aspects to improve the ability and usability of technology in all aspects.

In the future, more digital technologies could be applied to the rail transit system, which accelerates the transformation and upgrading of the subway, plays a role in its safety, operation and other aspects, realizes the intelligentization of rail transit, enhances the service experience of passengers, and meets the requirements of modern development.

References

[1] Ma Kunlong. Short term distributed load forecasting method based on big data. Changsha: Hunan University, 2014.

[2] Xinhua News Agency. The Investigation Report on the “July 20” Rainstorm Disaster in Zhengzhou, Henan Province Was Released. Fangfang. Research on power load forecasting based on Improved BP neural network. Harbin Institute of Technology, 2011.

[3] Ling, Cheng Zhao, Jing Liang, et al. Application and Exploration of Artificial Intelligence Technology in Urban Rail Transit [J]. Information and Computer (Theoretical Edition). 2022, 34 (13), 181 - 184.

[4] Garrocho, C.T.B., da Silva, M.J. & Oliveira, R.A.R. D2D pervasive communication system with out-of-band control autonomous to 5G networks. Wireless Netw. 2020, 26, 373 – 386.

[5] Li, Jian. Characteristics and Application of Metro 5G Communication Technology. Engineering Technology and Management. 2021, 5. 11.

[6] Dang Lili. Discussion on the application of 5G communication technology under the situation of Internet of Things [J]. Electronic production, 2020 (22): 75 - 76+89.

[7] Chen Yao. Research on resource allocation algorithm based on vehicle-vehicle communication in urban rail transit [D]. East China Jiaotong University, 2022.

[8] Lei Chengjian, Juck Zhang, Lv Haojiong, et al. Research and prospect of intelligent train operation technology under smart city rail [J]. Modern urban rail transit, 2020 (08), 38 - 44.

[9] Yan, F., Liu, B., Zhou, Y., Gao, C., Tang, T. Fully Automatic Operation System in Urban Rail Transit Is Applying in China. In: Jia, L., Qin, Y., Suo, J., Feng, J., Diao, L., An, M. (eds) Proceedings of the 3rd International Conference on Electrical and Information Technologies for Rail Transportation (EITRT) 2017. EITRT 2017. Lecture Notes in Electrical Engineering, vol 482. Springer, Singapore.

[10] Cappaert-Blondelle S. Media backgrounder metro automation facts, figures and trends—a global bid for automation. Director Communications & Publications, UITP, 2012.

[11] Wang Huanhuan. Summary of application of extracting agricultural information based on three-dimensional laser scanning technology [J]. Agriculture and Technology, 2020, 20 (40): 57 - 59.

[12] Peng, Wen. Application of 3D laser scanning technology and BIM technology in engineering survey. Geology and mineral mapping, 2019.

[13] Zhao Ningning, Wei Wu, Wang Yong. Research on application of deformation monitoring of subway tunnel structure based on 3D laser scanning technology [J]. China Mining, 2020, 29 (06): 176 - 180.

[14] Li Junbo, Shen Yi, Wang Dongyan, et al. Design and implementation of integrated maintenance production management information system based on BIM [J]. Railway Computer Application, 2021, 30 (12): 24 - 28.

[15] Yang Lingling. Application and prospect analysis of BIM technology in intelligent operation and maintenance of railway infrastructure [J]. Modern urban rail transit, 2021 (06): 96 - 102.