Optimization of Computer-aided Decision-making System for Railroad Traffic Dispatching Command

Ziyuan Liu

China Academy of Railway Sciences Corporation Limited, Beijing,100081, China, liuziyuan310@outlook.com

Corresponding author: Ziyuan Liu, liuziyuan310@outlook.com

Abstract. This paper provides an in-depth analysis and optimization of the railroad traffic dispatching command and decision system through a computer-aided approach. Based on the analysis of the advantages and adaptability of the multi-intelligence system, the multi-intelligence-based cross-region comprehensive transportation emergency dispatching technology is proposed, in which two types of physical entities, namely the disaster site and the emergency material storage center widely distributed in all areas, are modeled as the demand point and the rescue point bits of intelligence respectively, and the "rescue-request" behavior among the bits of intelligence is realized by defining the interaction rules. This simplifies the complex multi-source and multi-sink task assignment problem. Based on the results of the system business process and feature analysis, the paper identifies the system functional requirements for emergency resource inventory, emergency dispatch plan decision, emergency auxiliary management, basic information management, etc., the system data requirements for efficient integration and flow, and the system performance requirements containing three aspects of information such as performance index, facilities and equipment, and operation environment. The comprehensive transportation emergency resource data warehouse integrates comprehensive transportation resource data and emergency material reserve information, while the cross-regional emergency material intermodal auxiliary decision-making platform provides decision support for the whole cycle of emergency dispatching tasks in three stages: before, during, and after.

Keywords: Railroad traffic; scheduling command decision; computer-aided; system optimization
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1 INTRODUCTION

With the rapid development of the social economy and the speeding up of the urban agglomeration process, rail transportation in urban agglomeration area also develops from a single system to multiple systems, and gradually forms a transportation network with the high-speed railroad, intercity railroad, general railroad, urban railroad, and urban rail transportation as the backbone. However, due to the traditional technology and management system, multiple systems are working separately, and information is not accessible, so they cannot realize mutual linkage, which makes the transportation capacity and service quality greatly reduced. The study of integrated and cooperative transportation organization of multi-format rail transit has become the key to improve the quality and upgrade of regional rail transit. The regional rail transit hub is the heart of the regional rail transit network, and the research on the cooperative transportation organization of the hub has become the core of the problem. The lack of linkage between multiple modes of transportation connected to the regional rail transit hub and the failure of the hub's yard facilities to match the interchange flow between modes are important factors that limit the efficient operation of the hub. The only way to build a service system that satisfies spatial, temporal, and functional cooperation and coordination is from the perspective of transportation organization, which is the key to improve the transportation capacity and service quality of the hub. Compared with the large-capacity subway system, the medium-capacity rail transit system has a lower investment in construction cost, and the subsequent operation and maintenance cost is also relatively low, which has a better economy and reduces the requirement for city's economic strength; the line direction of medium-capacity system is flexible, mostly using ground or elevated lines, which can well adapt to the line planning requirements, effectively reduce the amount of demolition and relocation, and reduce the project cost and construction difficulty; the construction cycle is relatively short, which can be quickly and efficiently coordinated [1]. The construction period is relatively short, which can be put into operation quickly and better solve the traffic demand. A medium-capacity system can not only be used as an auxiliary line of urban rail transit backbone line to connect passenger flow into the backbone network and collect passenger flow for the backbone line, but also as a backbone line of rail transit in some medium-sized cities.

In the traditional train operation adjustment method, the trains following the initially delayed trains generally only adopt the strategy of catching up points for operation adjustment, that is, try to adopt the minimum stopping time and the minimum interval running time for the operation to achieve the purpose of restoring the normal operation status of trains as soon as possible [2]. However, this strategy often does not consider the uneven arrival of passengers at each station along the line, and the train stopping time is closely related to the number of passengers getting on and off the train, especially when the train is delayed, passengers are very likely to be backlogged. The stopping time of the initially delayed train and its trailing train must be adapted and matched with the passenger flow at each station, and timely and reasonable adjustments must be made to cope with the fluctuation of passenger flow caused by the delay. When the delays are long, the adjustment efficiency cannot meet the operation requirements well because the traditional strategy of catching up points saves relatively limited train travel time in stations and intervals. From a practical point of view, Wang et al. [3] compared with the station-stop adjustment strategy, the skip-stop strategy can make the trains return to the planned operation status faster by running across stations, and can also fully consider the passenger flow status of each station. The stopping strategy can reduce the travel time of passengers at a global level by formulating a stopping plan that matches the passenger demand.

Muniandi [4] considered the dynamic interaction between trains and passengers, calculate the stopping time of trains at each station based on the number of passengers boarding and alighting, and construct a model to minimize passenger dissatisfaction, and finally find a train delay management solution based on a heuristic algorithm that minimizes passenger dissatisfaction. Graham [5] designed a hybrid optimization algorithm combining decomposition algorithm and simulated annealing algorithm, and finally demonstrate the stability of the algorithm with examples. To ensure the line capacity under the severe delay conditions, Hassannayebi et al. [6] proposed a method to adjust the schedule of urban rail trains by combining a reserve train and a skip-stop strategy and established a model to minimize the sum of train arrival times. Wang et al. [7] developed a multi-point siting-routing model considering the failure scenario of the transportation network for the siting of facilities in the pre-disaster emergency preparedness phase and the distribution route arrangement in the post-disaster response phase.

In terms of interchange time, it fails to consider the difference in the timeliness of interchange waiting time for passengers of different systems, and fails to consider the capacity matching of local time; in terms of information cooperation, the existing research focuses on the framework construction of information system and lacks the implementation of information system for multi-system cooperation. The existing research focuses on the framework construction of information systems, and lacks the implementation of specific function guidance of information systems for multi-format coordination, and lacks the support of information systems for interchange time coordination and spatial flow line coordination. We study the basic theories related to cross-regional integrated traffic emergency dispatch, analyze its process, dimensions, and other elements, extract the key issues most closely related to cross-regional integrated traffic emergency dispatch, establish a cross-regional integrated traffic emergency resource dispatch model, and provide a theoretical basis for the design of the auxiliary decision-making system; study the design methods and specifications of the auxiliary decision-making system, analyze the business requirements, data requirements, and performance requirements of cross-regional integrated traffic emergency dispatch, and develop a cross-regional integrated traffic emergency dispatch system. The system prototype supporting data visualization management, automatic generation of emergency dispatching plan, and other decision-making functions are established, and the development and implementation of some functions are completed.

2 OPTIMIZATION ANALYSIS OF COMPUTER-AIDED DECISION-MAKING SYSTEM FOR RAILROAD TRAFFIC DISPATCHING COMMAND

2.1 Computer-aided Decision-making System Optimization Analysis

Cross-city rail transit contains multiple systems with large gaps in travel speed, and passengers riding different systems of rail transit have different requirements for interchange timeliness, so this paper introduces the concept of different system timeliness weights based on minimum waiting time to optimize the waiting time of interchange passengers in a targeted manner. For the whole cycle, the passenger volume tends to meet the matching requirements, but ignores the problem of mismatched volume in local periods, i.e., the short-time large passenger flow of inter-city rail transit interchange to commuter rail transit can cause congestion to the commuter rail transit system, so this paper also considers the balanced degree of the number of passengers picked up by commuter rail transit trains. According to the synergistic mechanism, the differences between subsystems exist, and the perfect realization of one subsystem's goal often conflicts with the goals of other subsystems. The degree of loss of each subsystem to their respective goals needs to be weighed to pursue relative cooperation in the absolute differences. The conflict of flow lines in the hub is inevitable, and the degree of conflict in different cases needs to be weighed to meet the overall minimum conflict. When optimizing the spatial flow lines, each flow line should be separated as much as possible, for example, inbound passenger flow, outbound passenger flow, and transfer passenger flow should not interfere with each other as much as possible, and vehicle flow, passenger flow, and cargo flow should not interfere with each other as much as possible. As the passenger transfer distance affects the efficiency of passengers in the hub, and increases the time of passengers in the hub, adding pressure to the hub operation, therefore, minimizing the passenger transfer distance will effectively improve the hub transfer efficiency, as shown in Figure 1.

The demand point intelligence sends distress messages to the surrounding rescue points from near and far, and continuously receives rescue applications from each rescue point intelligence. The rescue point bits of intelligence are distributed both in the area where the disaster site is located and outside the area. After an emergency occurs, the disaster site needs a variety of emergency material resources. According to the type of emergency supplies, the demand for emergency supplies is divided into several "segments" (tasks), and the information for rescue is released separately. Before planning the rescue route, the intelligent body at the rescue point needs to choose a reasonable transportation mode and judge whether the transportation object meets the restrictive transportation conditions [8]. The conditions that restrict the choice of transportation of emergency materials are mainly divided into two categories: timeliness and the nature of the goods themselves, for example, emergency materials represented by medical and life-saving items have very high requirements for timeliness, so only air transportation is considered, while emergency materials represented by coal are only considered for road/rail transportation due to the physical/chemical nature of the goods themselves, and no change of clothes along the way. For the emergency materials which are not so constrained by timeliness and nature of goods, we can consider the time and cost factors and make full use of three modes of transportation, such as railroad, road, and air.

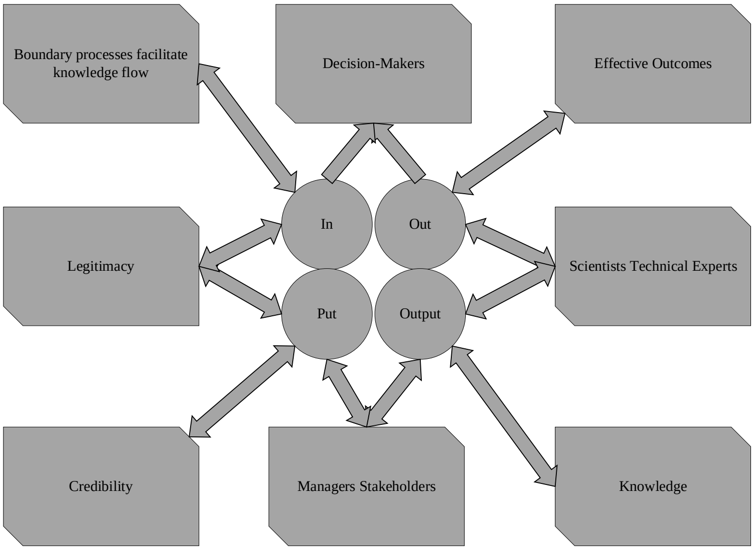

Figure 1: Optimization framework of the computer-aided decision-making system.

The fully automatic operation system of urban rail transit includes the fully automatic operation of trains and the fully automatic operation control of station equipment. A fully automatic operation system should include unattended fully automatic train operation system and unattended fully automatic control of station equipment, to realize the automation of traffic, intelligent maintenance, and self-service of passengers. The fully automatic train operation is to have the work performed by the train driver completed by the train operation system, with the functions of automatic train wake-up and sleep, automatic train inspection, automatic entering and leaving the yard, automatic cleaning, automatic driving, station stopping and starting, automatic door opening and closing, automatic turning back, etc.; and has multiple operation modes such as regular operation, degraded operation, and disaster conditions, with higher safety, reliability, availability, and maintainability. The fully automatic operation of urban rail transit trains can be classified according to whether there is a driver or not and can be divided into manned fully automatic operation (DTO) and unmanned fully automatic operation (UTO); according to the capacity, it can be divided into a small capacity fully automatic operation system, medium-capacity fully automatic operation system and large capacity fully automatic operation system; according to the coverage area, it can be divided into mainline fully automatic operation system and full area operation system with the yard.

The control center of the fully automatic operation system realizes comprehensive monitoring of fully automatic train operation, including remote service for passengers, remote control of train operation and troubleshooting, detailed monitoring of each equipment system, maintenance and scheduling of each equipment, and related linkage control of each system [9]. The operation mode of the fully automatic operation system is determined according to the line conditions, system function realization, the comprehensive performance of equipment and system, personnel quality and skill proficiency, completeness and applicability of rules and regulations, etc. The system of rules and regulations should be adapted to the operation scenarios under different operation modes, and the responsibilities and handling procedures of each position under FAM and degradation should be clarified. The operating unit should focus on the frequency of FAM degradation events of the fully automatic operation system. The organization rules of the fully automatic operation system are divided into rules of traffic organization, rules of dispatching command, rules of train operation, rules of station traffic organization, rules of passenger organization and service, and rules of vehicle base organization, as shown in Figure 2.

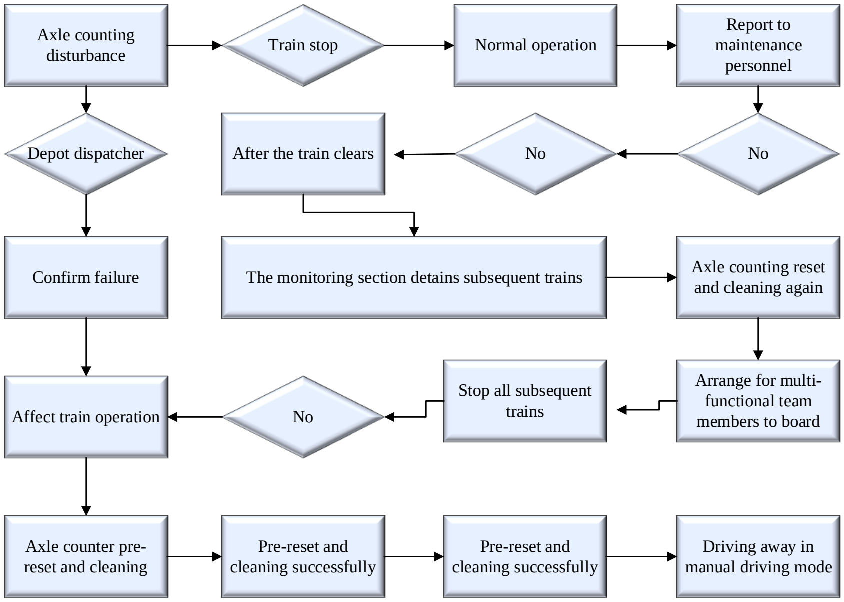

Figure 2: Scene of disturbed fault in counting axis.

In the automatic blocking section, two or more trains running in the same direction run in a station interval with a blocking partition as the interval, that is, tracking operation. The tracking train interval time is the minimum interval between two trains that will not interfere with each other during operation, which depends on the tracking interval distance of trains in the same direction, the interval running speed, and the type of signaling, interlocking, and blocking equipment. At the same time, to ensure the safety of trains, not only the minimum tracking interval time requirement but also the minimum departure interval time requirement needs to be met between neighboring trains.

For the construction plan of the information system, we need to understand the needs of users in the information age first and analyze them according to their needs to make the construction of the information system more practical. Due to the different demand sides, the purpose and implementation means of information collaboration are different, and the functions realized by the system are also different. According to the analysis of user needs, the collaborative information system is set up for passengers and operation units respectively, and the two systems share all the basic databases and have the same key dictionary settings, which can be called and modified by each other [10]. The main connection between the two systems is that, through information collection and analysis, they can provide the best choice for passengers and influence their behavioral choices, thus improving the operational efficiency of passengers and operators; at the same time, through the feedback of passengers' choice behavioral data, they can react to the regulation plan of operators and adjust the regulatory measures and methods of operators to achieve the optimal state under the current time. The two systems interact with each other to form a virtuous cycle, thus achieving the purpose of unified operation within the hub.

2.2 Experimental Analysis of Railroad Traffic Dispatching Command Decision

Since the regional rail hub is inside the city, it faces the demand of transferring many passengers in and out of the city during large events or holidays, so the security prevention and control of information systems are especially important when this situation occurs. Based on real-time monitoring of passenger flow inside the hub and the roads connected to the hub, the carrying capacity inside the hub is analyzed, and evacuation plans under unexpected passenger flow are given by establishing evacuation models, including measures such as reducing the frequency of traffic modes driving to the hub and increasing the frequency and traffic modes of traffic leaving the hub, to improve increasing the evacuation capacity of the hub, reducing the number of people inside the hub, and improving the operational efficiency of the hub The purpose of this project is to increase the evacuation capacity of the hub, reduce the number of people in the hub, and improve the efficiency of the hub. The basic data of each traffic operation department's data is collected and connected to the information exchange platform, and the processed data is applied to three functional modules, through which the models are applied to provide services for the passenger side and the operator side, respectively. The general architecture of this cooperative information system is shown in Figure 3.

The information exchange platform of the hub is the core of the multi-modal cooperative information system of the hub and is the link to connect various information. The information exchange platform mainly collects and updates the operation information of various transportation modes through the connection with the information collection equipment of each transportation operation system, and concentrates on the same platform to ensure the cooperation and unification of the information in multiple systems. By effectively classifying and identifying the collected information and standardizing it, it provides data support for hub management centers and management centers of various transportation modes. Each transportation mode integrates the information of passenger trips to the information exchange platform, which performs data fusion and processing based on passenger swipe card data, real-time monitoring passenger flow data, and passenger pre-trip data, and each application module can obtain real-time information on passenger flow, passenger density, and future passenger flow forecast in the local area.

The passenger flow analysis module obtains passenger travel information and facility and equipment information through the information exchange center, and through the analysis of passenger density in space, it can show the specific location and gathering degree of passenger distribution in real-time. For the passenger side, by obtaining real-time passenger flow and predicting passenger flow and utilization rate of facilities and equipment, it can substitute into the flow optimization model to get the optimal transfer flow and transfer plan under the current time or expected time; for the operator side, by calculating the matching degree of passenger flow with the capacity and operation speed of facilities and equipment, it can analyze the utilization rate of facilities and equipment, bottleneck points and provide a practical basis for the renovation and design of facilities and equipment. The module can realize real-time dynamic visualization and quickly identify congestion points at any time so that corresponding evacuation measures can be taken.

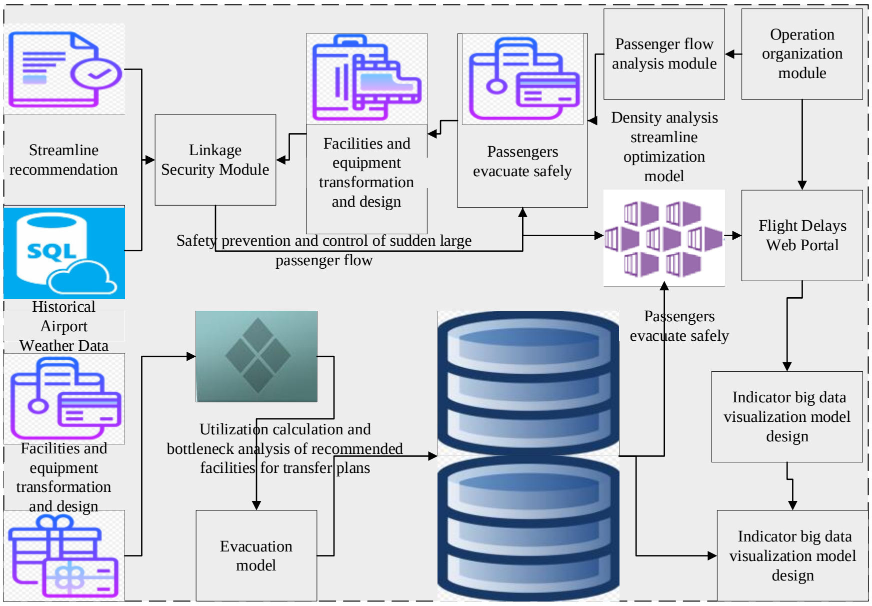

Figure 3: schematic diagram of the hub multi-modal collaborative information system architecture.

The operation organization module calculates the passenger detention time and other evaluation indexes under the current operation scenarios by obtaining the operation information of multiple transportation modes, passenger travel information, and simulation information output from the simulation system, and gives the current operation coordination level among the modes; calculates the optimal departure time through the interchange time co-optimization model to minimize the passenger detention time in the hub; through simulation. Through simulation, the parameters in the model are adjusted to give synergistic solutions under various scenarios, and the accuracy of the model parameters is corrected through comparison of actual data; the model is applied to real-time optimization, and the synergistic optimization model is applied to give staggering adjustment solutions for the differences in passenger flow of different traffic modes at different times. The linked security module is a solution for passengers and operators in case of mass passenger gathering in the hub or emergency. By applying the passenger evacuation model, the optimal evacuation routes for passengers at different locations are given in combination with the capacity of each facility and equipment, entrances, and exits of the hub, so that passengers in each mode of transportation can be evacuated in an orderly manner in space; in case of large passenger flows into the interior of the hub, the real-time evacuation plan is given by applying the passenger evacuation model and adjusting the departure frequency and interval of each mode of transportation in the hub so that the stranded people in the hub. By applying the passenger flow evacuation model, the frequency and interval of each traffic mode in the hub can be adjusted to give a real-time evacuation plan so that the stranded people in the hub can be reduced quickly, and the coordination of multiple traffic modes under sudden large passenger flow can be realized, as shown in Figure 4.

The urban rail transit system should include the information processing function of the digital intelligent facilities and equipment on the train, including the change and maintenance of the carriage display and arrival information, in addition to the functional requirements for the change of the basic schedule information table. Therefore, each administrative region and each operation management department should establish the concept of collaborative planning and development of the whole region, and through integrated transportation development, the transportation resources in the region should be planned and allocated according to the structure and requirements of the integrated transportation system, so that the road network as a link can drive the economic development of the whole region. The concept of regional transportation integration is mainly proposed, promoted, and implemented from the government level; therefore, government departments should fully understand the importance of regional transportation integration, think from the perspective of the whole region, and maximize the use of intra-regional transportation resources.

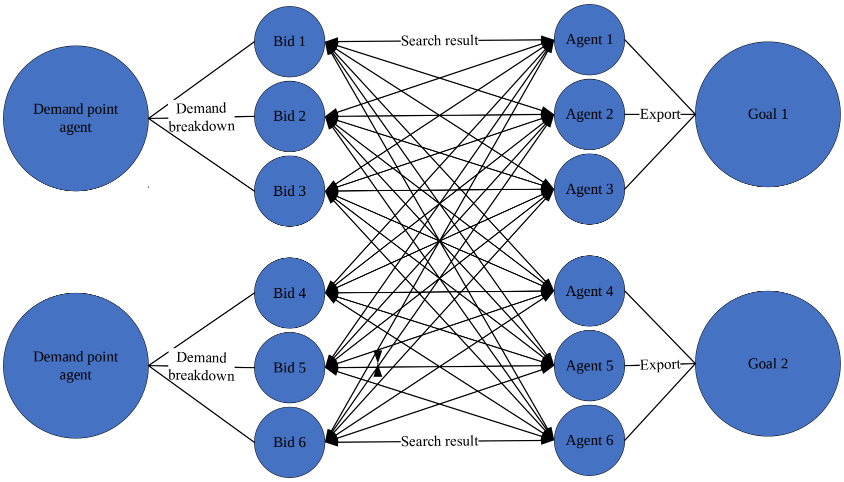

Figure 4: Main behaviors of demand point bits of intelligence.

3 ANALYSIS OF RESULTS

3.1 Analysis of Optimization Results

After a series of parameters are set and the train adjustment range is determined, the train operation adjustment scheme during the peak hours under this delay condition is optimally solved, and the optimized train operation diagram is shown in Figure 5. The conventional adjustment scheme in the figure refers to the conventional stop-and-go strategy for the initially delayed train and the trains following it, while the stopping time is generally not adjusted but only the inter-district running time is reduced because the passenger flow distribution is not considered in the case of non-short delays, i.e., shortening the stopping time may lead to a backlog of passengers unable to board and alight in time. The integrated adjustment scheme refers to the globally coordinated adjustment strategy adopted in this paper, and both the initially delayed train and its trains can be restored to the planned operation earlier under the integrated adjustment scheme.

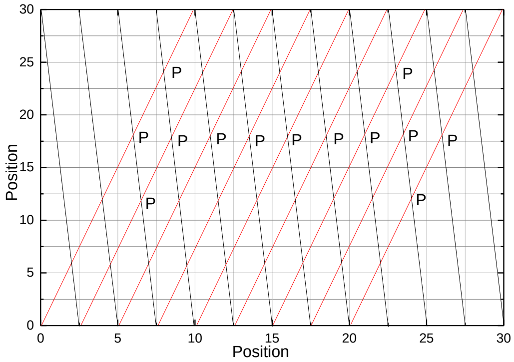

Figure 5: The train operating chart under the two adjustment schemes.

The total number of forwarding trains that eventually undergo coordinated adjustment is 3, and the details are shown in Figure 6. The closer the train is to the initially delayed train, the longer the total withholding time is, which allows more stranded passengers to board in time and reduces the waiting time of passengers. The increase in stopping time for Train 11 from Station 5 to Station 9 is 0, because the train is close to full capacity at these stations, and if the stopping time is extended at Station 4, there is no extra capacity for more passengers to board the train, which will increase the waiting time of passengers in the train.

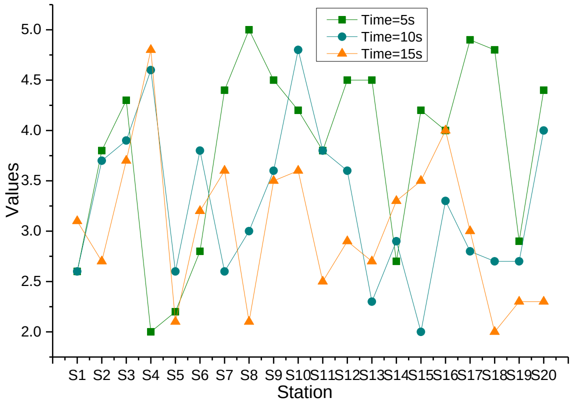

Figure 6: Increase in stopping time of forwarding trains at each station.

With the adoption of the dynamic stopping time strategy, the stopping time at most stations has been significantly reduced, which can effectively speed up the recovery of train delays. The increase in the stopping time at some stations with many boarding and alighting passengers allows passengers to have sufficient time to finish boarding and alighting in time, thus avoiding disorderly boarding, and alighting due to insufficient stopping time. In addition, it can be noted that the stopping time variation value of each train at stations 1 and 2 is 0 except for the skip-stop, which is due to the minimum tracking interval constraint of the train. At the same time, since the trains will return to the planned operation after several stations and interval adjustments and stop at the standard stopping time, and the trains will also stop at the standard stopping time under the regular adjustment scheme, there is no change in the stopping time of trains 15 to 21 at some later stations.

The proposed combination of withholding strategy for trains ahead of the initially delayed train, "skip-stop + catch" strategy for trains ahead of the initially delayed train, and dynamic stopping time adjustment method can reduce the total passenger travel time in all four scenarios, especially the optimization of platform passenger waiting time is most obvious. It can effectively alleviate the long waiting time of passengers due to delays or stranded passengers on the platform. By comparing the combined adjustment scheme for the four scenarios, when the train is delayed for a long period, a skip-stop strategy for the initially delayed train and its following trains can help reduce the total passenger travel time, while when the train is only experiencing normal delays, skip-stop measures are not necessary. When the train is delayed for a longer period or when the passenger flow is more intense, both the withholding strategy and the strategy of implementing dynamic stopping times in conjunction with each other can effectively reduce the total passenger travel time and the platform passenger waiting time. When the passenger flow is not too strong and the delay time is not too long, there is no need to consider the detaining and stopping strategy. From another point of view, that is, when the intensity of passenger flow or train delay time is so long that passengers will be stranded in some stations, the detaining and skipping strategy will be effective and necessary, and the more serious the passenger stranding situation is, the more trains will be detained and skipping strategy and the more stations will implement the corresponding strategy.

3.2 Analysis of Experimental Results

The cross-regional comprehensive traffic emergency dispatching is mainly for large-scale emergency emergencies, and the emergency resources need to flow across the region nationwide. Taking one of the lines with the largest road network span scale as an example, the number of tests is set to 10, and the Dijkstra algorithm and ACO algorithm are used to operate, and the results are shown in Figure 7. With the expansion of the number of points and edges in the road network structure diagram, the results of Dijkstra's algorithm and ACO's algorithm start to show inconsistency. However, the Dijkstra algorithm outperforms the ACO algorithm in terms of solution quality and speed. This shows that the classical algorithm still has some advantages for solving such non-NP type of path planning problems. The key problem of the system is the assignment of cross-regional dispatching tasks and the path planning of emergency material transportation. The multi-intelligent body technology is introduced, and the adaptability of multi-intelligent body technology to solve this problem is analyzed, and two types of physical entities, emergency material reserve point, and emergency material demand point, are modeled as the outgoing and demand point bits of intelligence respectively, and the autonomy of each type of bits of intelligence is given by defining business rules so that they form The interaction relationship of "request for help - rescue" is formed. The study focuses on the emergency intermodal path planning model and algorithm of the outgoing intelligent body.

The fault diagnosis method incorporating the Diikstra algorithm processes and inputs the real-time data of current and power during the conversion and operation of the above rutters into the model to obtain the operating conditions of ACO reads the fault data in the knowledge base and fits and compares the real-time data with the fault model in the knowledge base to output the diagnosis and prediction results. At the same time, when new fault data and fault types of rutters are generated, they are put into the model for training to form a new model, and the new diagnostic model is called to judge the fault conditions to improve the learning and application capability of the data.

Firstly, the health status of turnouts is divided into three categories: healthy, sub healthy, and faulty. And the overall situation of all turnouts at line or line network level is displayed on the interface, including the number and proportion of normal turnouts, faulty turnouts, and sub healthy turnouts. Secondly, according to the evaluation of health degree, the faulty turnouts and sub healthy turnouts are listed according to the severity, so that the users can carry out the hidden troubleshooting of rutters according to the listed sub healthy and faulty conditions, and feedback to the fully automatic operation scenarios to trigger the corresponding scenario disposal and operation organization processes. Once again, the data is analyzed by a deep learning algorithm for trend and health prediction, and the key equipment health management interface provides the fault trend of turnouts, which can remind the operation and maintenance personnel to execute the maintenance and repair strategy according to the trend of turnout faults.

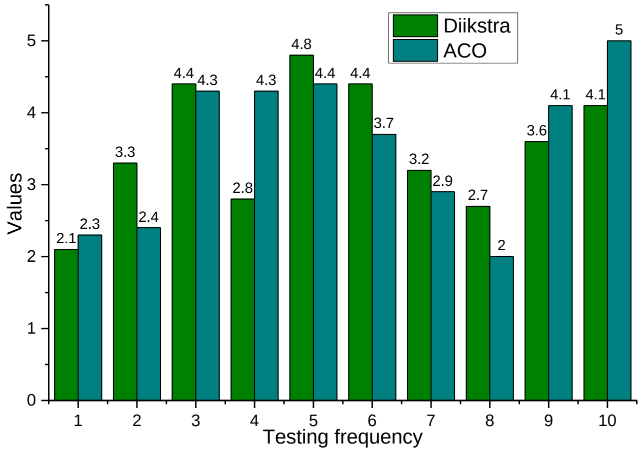

Figure 7: Performance Comparison.

4 CONCLUSION

Based on the study of the basic theory of cross-regional integrated traffic emergency dispatching, the business process and characteristics of cross-regional integrated traffic emergency dispatching auxiliary decision-making system are analyzed, the demand analysis is carried out from three aspects of function, data, and performance respectively, the overall system architecture is proposed, and the detailed design of each component such as the system integrated traffic emergency resource data warehouse and cross-regional emergency material intermodal auxiliary decision-making platform is carried out. It is considered that the task of cross-regional integrated traffic emergency dispatching involves many departments and is highly independent, so it is not easy to control centrally, so based on the idea of a multi-intelligent body system, the cross-regional integrated traffic emergency dispatching technology based on multi-intelligent bodies is proposed. The core problem of automatic generation of emergency dispatching plans is solved by giving autonomy and coordination to the behavior of "rescue" among intelligent bodies. In terms of spatial flow coordination, it is difficult to quantitatively optimize the complex interchange flow in the regional rail transit hub. This paper constructs a flow optimization model considering three aspects: flow level, flow obstruction coefficient, and flow distance respectively, and taking the minimum interchange cost of passengers as the objective function. The optimized flowline solution has been shown to reduce the number of conflict points and bottlenecks with a small increase in interchange distance and a 6.9% reduction in interchange cost.

Ziyuan Liu, https://orcid.org/0000-0001-5085-2605

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