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Research article

Real-time high-speed train rescheduling based on a Human-Computer Interaction framework

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ABSTRACT

During railway operations, trains normally run as scheduled, but the occurrence of unexpected events will disrupt traffic flow and cause train deviation from the original timetable. In order to assist dispatchers in rescheduling trains, this paper introduces an innovative Human-Computer Interaction framework. This framework enables train dispatchers to propose different timetable adjustment instructions to the original or adjusted timetable. These instructions will be processed, stored, analyzed, and digested by computer program, which finally lead to the modification and calculation of the embedded mathematical model, then a new adjusted timetable will be produced and provided to dispatchers for checking and modifying. This framework can iterate for unlimited times based on dispatchers' intentions, until the final results satisfy them. A demonstration system named RTARS (Real-time Timetable Automatic Rescheduling System) is developed based on this framework and it has been applied in Beijing Railway Administration, which shows its effectiveness in reality.

1. Introduction

By the end of 2022, Chinese high-speed railway has exceeded 40,000 kilometers, the quick expand of railway network also brings great challenge to the operation department. Due to unpredicted external and/or internal factors, trains might deviate from the scheduled arrival and departure times. In such cases, with the purpose of mitigating the impact of unexpected events and recovering from a disturbed or disrupted situation as soon as possible, the original timetable needs to be rescheduled. This procedure is referred as Train Rescheduling Problem (TRP).

In the past few decades, TRP has been well studied. As described in Ref. [1], the related literature could mainly be divided into two main categories, known as microscopic and macroscopic. Microscopic studies focus on small perturbations, namely disturbances, many researchers tend to use Alternative Graph (AG) model to get a new conflict- free schedule, the AG model is introduced in Ref. [2] and it is based on job shop scheduling problem, in which jobs represent running trains and machines correspond to block sections. For more information related to it, we recommend interested readers to read the research results of Refs. [3–6]. Some other theories are also adopted to solve the problem, Ref. [7] uses space-time network and proposes an innovative cumulative flow modeling method that could implicitly describe capacity constraints. Ref. [8] build integer programming formulations based on event-activity network, aiming to tackle the situation where partial or complete blockages appear. On the other hand, in macroscopic approaches, stations in railway network are described as nodes and details of both block sections and signal conditions are ignored. A mix integer programming model is presented in Ref. [9], where reordering and rerouting of trains are considered. In order to improve the algorithm efficiency, Ref. [10] designs a heuristic greedy approach for the same problem, trying to find a good solution quickly.

In practice, the railway dispatching command system is also constantly upgrading. In Netherlands, Ref. [11] develops AGLIBRARY (Alternative Graph LIBRARY software) and designs real-time railway traffic management system ROMA (Railway traffic Optimization by Means of Alternative Graphs) combined with blocking time theory, which aims to support dispatchers in order to resolve conflicts when dealing with delays and disturbances. The European ON-TIME project proposes a Real-Time Railway Traffic Management framework, Ref. [12], which consists of multiple modules connected in series: Conflict Detection and Resolution (CDR), Train Path Envelope Calculation (TPEC), Trajectory Calculation (TC), Advice Generation (AG), Driver Advisory System (DAS), etc. The CDR module monitors and dispatches

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trains according to the real-time status of the system, which mainly includes real-time information such as track circuit occupancy, train operation position and speed. According to Ref. [13], a Traffic Management System (TMS) is developed under two subsequent EU projects, named COMBINE and COMBINE 2. Borndörfer team has made a lot of research on TMS, reflected in three railway lines with different optimization approach, operative rules and automatic level [14]. Swiss Federal Railway Company (SBB) has developed Railway Control System (RCS) to optimize the application of railway infrastructure, transportation capacity improvement of the railway network and punctuality of train operation. It can realize real-time train operation control, conflict resolution, event analysis and other functions [15]. In the existing academic studies, TRP is usually regarded as a decision-making problem. According to Ref. [16], the different types of rescheduling decisions can be divided as follows:

(1) Re-timing of trains by allocating new arrival and departure time, including the modification of speed profiles.
(2) Re-ordering of trains by adjusting the meet-pass plans.
(3) Re-tracking of trains by allocating new tracks in stations.
(4) Re-routing of trains by allocating alternative paths in the railway network.
(5) Cancellations and/or turning trains earlier than expected.

The normal approach of determining these five types of decision variables is through proposing problem formulations, building corresponding mathematical models and designing effective algorithms. With the powerful computational capability of computers, these optimization-based models can provide optimal or suboptimal solutions when faced with some simple, small and medium-sized problems. Despite this fact, only few successful optimization- based decision-support application cases in railway traffic disturbance management could be noticed in recent years, we believe that two characteristics related to TRP can explain the reason:

(1) The enormous problem scale, specifically:
    a) There are five types of rescheduling decisions in total that needs to be determined in the timetable rescheduling process. Considering all of them will greatly increase the complexity of mathematical model. In the literature, according to Ref. [1], many studies tend to investigate only a subset of these rescheduling measures such as the re-timing and re-routing problem, few of them consider the integrated optimization of them all.
    b) As the expand of railway network and increase of disrupted trains, the number of decision variables rockets.
    c) In order to simplify the modeling process of TRP, in theoretical studies most of them make some idealized assumptions, while many of these assumptions do not hold true in reality. For example, Ref. [17] assumes that "Trains that have entered the disrupted segment when a disruption occurs can go on according to the original timetable". Ref. [18] makes the assumption that "We do not consider to utilize the back-up rolling stock to serve the disrupted passengers". Ref. [19] mentions that "Trains which passed their last stop before the blocked segment at the moment the disruption occurs need special attention. It is not clear whether these trains did or did not pass the critical point which caused the disruption. Therefore we assume in this research that these trains just continue as planned".

(2) The uncertainty and ambiguity of optimization objective. In traditional studies related to TRP, the objective function is usually set in many ways. Some models build single-objective functions and set the optimization goal as minimizing total train delay, passenger delay or passenger waiting time, e.g., Refs. [20–22]. Others take multiple aspects into consideration and build multi-objective functions with pre-determined weight. For example, Refs. [19,23] focus on minimizing the number of canceled trains and the total weighted delay. Ref. [17] takes both the passenger's convenience and the train operational cost into account, aiming at minimizing the total generalized travel cost for the passengers and the operation cost for the railway company. However, the real-time train operations are intrinsically a dynamic and full-of-randomness process, which means that if we want the model-calculated results can depict the reality well, the optimization objective of TRP model may need to be dynamically modified from time to time.

These two features of optimization-based method seriously restrict its application in reality, making the model-computed results sometimes deviate far from the actual state of railway traffic. Therefore, in many countries, e.g., in China, the timetable rescheduling task is still mainly conducted by human dispatchers, the main advantages of manual operation are as follows:

(1) The great flexibility. Under different circumstance, train dispatchers can adopt various flexible and subjective adjustment measures to guarantee the operation safety and train service quality at any time.
(2) The utilization of experience and intuition. In the long years of work of dispatchers, they have accumulated a lot of experience. Even when they encounter situations they have not dealt with, they can rely on intuition to quickly make coping strategies.

Therefore, we reach to the conclusion that during the real-time timetable rescheduling process, it is necessary to take both human and traditional optimization-based method into consideration and integrate them together. Obviously, these two approaches can complement each other and give full play to their respective advantages. With this motivation, this paper introduces an innovative Human-Computer Interaction (HCI) framework into the timetable rescheduling process, the process is shown in Fig. 1.

The remainder of this paper is organized as follows: Section 2 provides an overall description for the HCI framework. Information about modules in the framework are elaborated in Section 3, containing respective technical details and/or underlying difficulties in achievement. We develop a demonstration system based on our framework in order to reveal its feasibility and effectiveness, and it is shown in Section 4. Section 5 gives some conclusions and provides some discussion about future research.

2. The Human-Computer Interaction closed-loop framework of real-time timetable rescheduling

For the purpose of avoiding ambiguity, in the remaining part we use the word "human" to represent those who directly or indirectly participate in the process of making timetable rescheduling decisions when unexpected events take place, such as dispatchers, assistant dispatchers and superiors of railway operation department. Also, the word "intention" may only refer to the human adjustment intention to the original or model-computed timetable. The full picture of HCI framework is illustrated schematically in Fig. 2.

As shown, there are four modules in total in HCI framework: Human Intention Generator (HIG), which contains a human-computer interface; Human Intention Recognizer (HIR), which contains a database and an intention recognition program; Human Intention Translator (HIT), which contains a mathematical model for solving TRP; Human Intention Presenter (HIP), which contains an interface for presenting the model-computed results. The framework runs based on the original timetable. Every iteration produces a new adjusted timetable, achieving the given intentions from human while preserving the older ones. Each module in HCI framework can only communicate with the next one in a pre- determined data format, and every module is composed of two sub-modules.

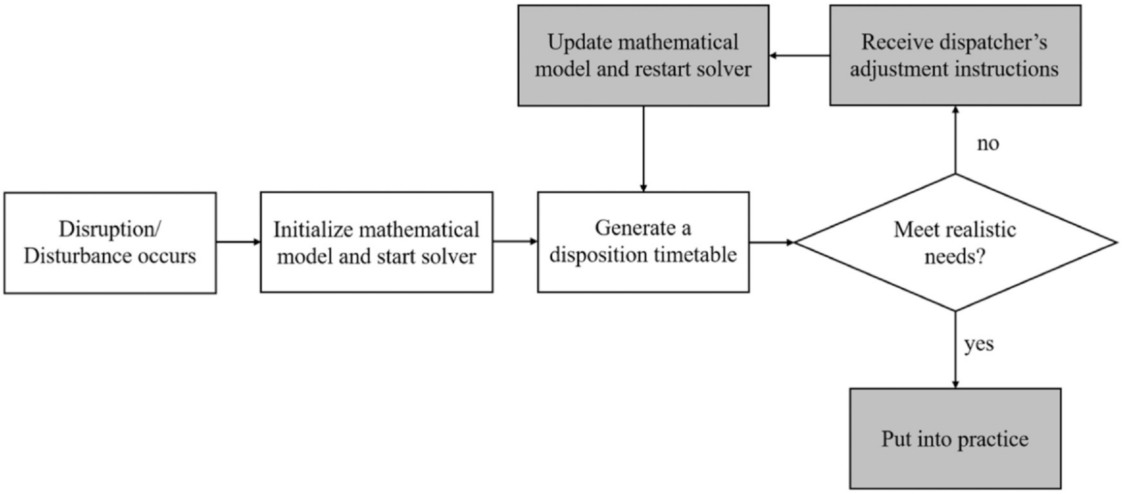


Fig. 1. The working loop of solving TRP with HCI framework.

The framework runs clockwise and first starts from HIG, which begins with an information collection process. When an unexpected event happens and disrupts the original railway traffic (e.g., partial segment blockage, complete segment blockage), dispatchers need to collect information related to the event, including the influenced infrastructure, trains, passengers and so on, and then input adjustment instructions into computer. Fig. 3 displays three types of information that human usually concerns. Generally speaking, this process is not one-time but multi-stage. Train dispatchers will first focus on collecting information related to the disruption itself such as the disrupted sections and expected duration, and expect to get an adjusted timetable in which safety is guaranteed. After that, they will pay more attention to the information in other aspects and make timetable rescheduling measures with the aim of improving the quality of train services or satisfying passenger demand better.

For example, when a complete blockage occurs, dispatchers need to reschedule the original timetable and make sure that no train enters the blocked sections until the blockage ends for the sake of train operation safety. With the help of HCI framework, they will first input the information related to the blockage into computer through the human-computer interface. After the framework iterates once, an adjusted timetable named T_1 will be generated and it satisfies the basic safety requirements. If dispatchers still feel unsatisfied about some details in T_1 such as the meet plan or the dwell time of several trains, they can keep modifying these details in the interface manually, until the result T_2 finally satisfy them. The process is shown in Fig. 4.

As we can see, we regard dispatchers' operation on the human-computer interface as the intention input process. In order to make computer perceive those given intentions, we get inspired by the system of automatic drive which is mentioned in Ref. [24]. In Fig. 5, the left part is a flow chart that demonstrates how a car reacts when it meets a pedestrian walking across the road. The in-car camera will first activate the installed sensors on the vehicle to collect the pedestrian's motion data such as his/her moving direction and moving speed. Based on these collected data, the automatic driving system is able to deduce the pedestrian's action intention and control the car to make corresponding reactions such as braking, steering or accelerating. Similarly, in the timetable rescheduling process, we regard dispatchers as the "suddenly appeared pedestrian". The right part of Fig. 5 shows how do we map this idea to HCI framework. In order to recognize dispatchers' adjustment instructions, it is necessary to set up a database to store the intention data and develop an intention recognition program. Therefore, we design two sub-modules in HIR to satisfy these two requirements.

The analysis results from HIR are sent to HIT, in which concrete intentions are structured and translated into model recognizable data and lead to the modification and/or calculation of the built-in mathematical model. The modified contents may include:

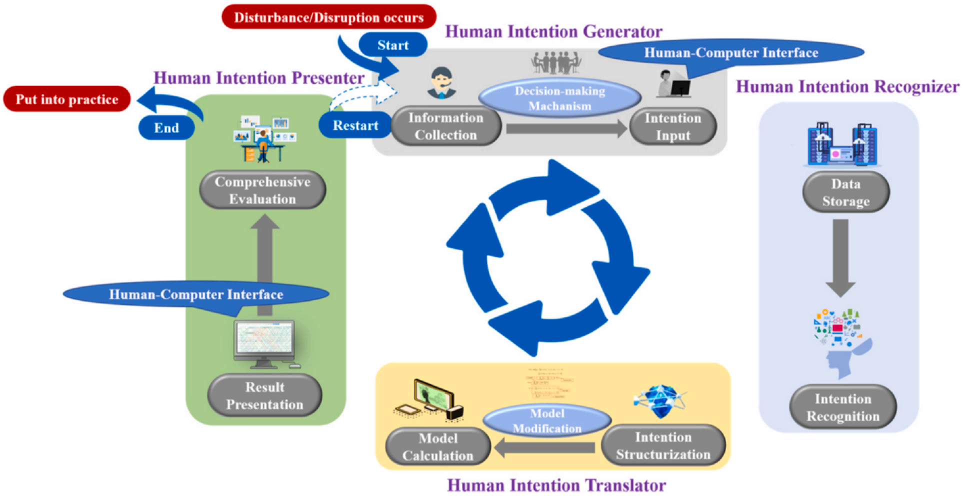


Fig. 2. Full picture of Human-Computer Interaction framework.

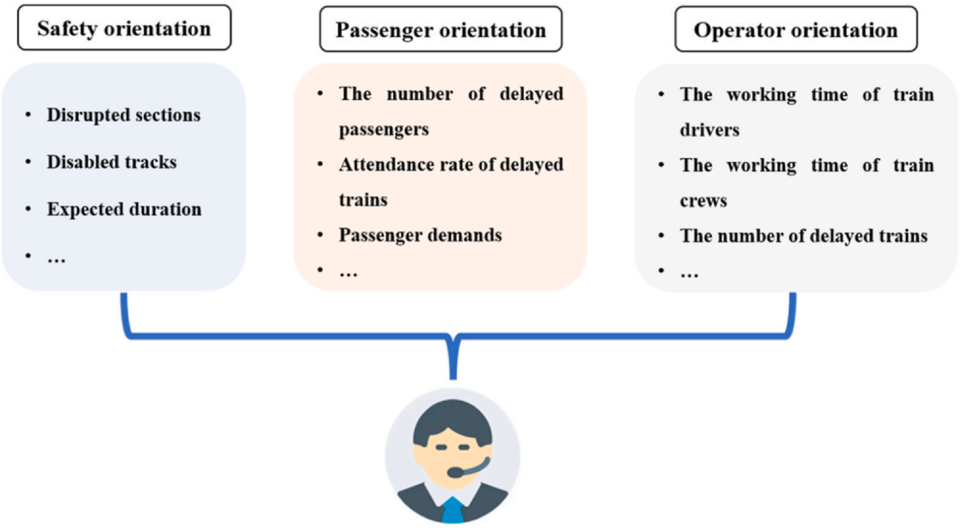


Fig. 3. The collected information by dispatchers in HIG.

(1) Modify the objective function, for example, from single-objective to multi-objective, or modify the respective weights of multi-objective members;
(2) Modify the constraints and/or dispatching strategies, for example, from First-Come-First-Served to First- Scheduled-First-Served;
(3) Modify the static parameters, for example, shorten the minimum station dwell time.

Once the model is revised, the solver will be restarted immediately and output a new timetable. A visualization sub-module is introduced in HIP which provides graphical representation of the new timetable, along with some relevant performance indicators (e.g., total number of delayed trains, total number of delayed passengers, capacity utilization rate). Dispatchers can conduct a comprehensive evaluation on the solution and judge if the results could be implemented into filed.

In the next section, we provide a concise description of all the modules composing the presented framework. For each module we describe its main function and/or explore the underlying difficulties in achievement.

3. Functional description of the modules

3.1. Human Intention Generator: a transformation from information to instruction

HIG is the only module in HCI framework that completely relies on human, and the significance of designing this module is that we hope to introduce human into timetable rescheduling process. As mentioned above, TRP is a large-scale decision-making problem. Under different types of disrupted scenarios, the optimization objective usually remains unclear, while the participation of human can help reduce the problem size and clear the optimization goal. For example, when a temporary segment blockage occurs, the arrival and departure order of influenced trains needs to be rearranged. We assume a scenario in which there are three trains named G1 (high level, low passenger attendance rate), G3 (medium level, medium passenger attendance rate) and G5 (low level, high passenger attendance rate) running from station M to station P, and they are all blocked at station M due to the temporary blockage. Fig. 6 demonstrates two adjusted timetables based on two different rescheduling strategies, passenger-oriented and train-class-oriented respectively, the solid line represents the original schedule and the dash line is the adjusted one. Without dispatchers' intervention, it is uncertain which strategy should be adopted, and this is the reason why HIG is indispensable.

Before dispatchers achieve the intention input process, a decision-making mechanism is indispensable. It is due to reason that some timetable rescheduling measures like canceling or arranging extra trains could have huge effects traffic flow or train service, especially in large railway networks or heavily congested areas. Hence those measures must be admitted by the superiors of railway operation department before being implemented.

The main difficulty in the achievement of HIG lies in designing appropriate human-computer interaction methods hat enable dispatchers to clearly express their various intentions. For example, if a dispatcher wants to change the departure sequence or arrival sequence

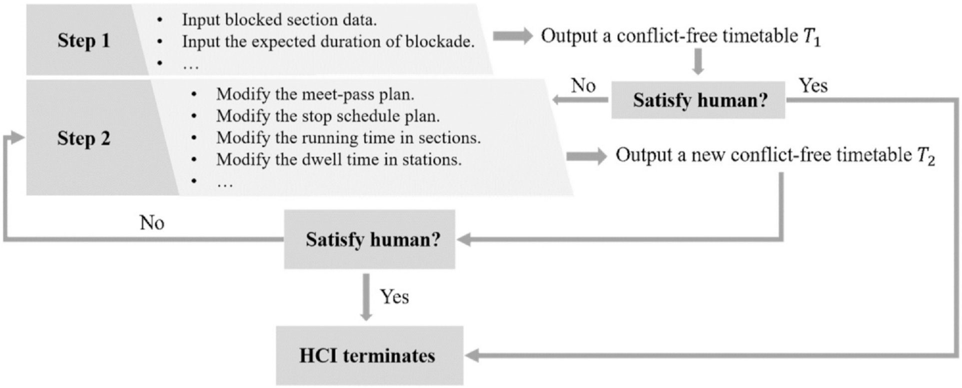


Fig. 4. The process of handling a complete blockage with HCI framework.

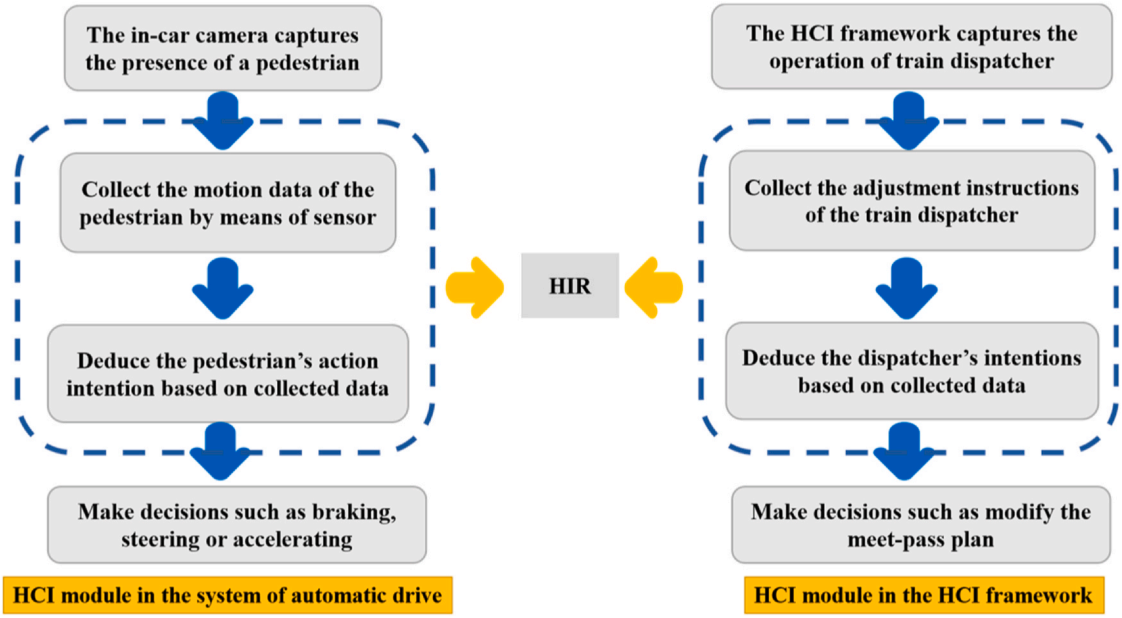


Fig. 5. Demonstration on how HIR module works.

of several trains, how should he/she operate on the human-computer interface? For the sake of convenience and ease of use, a practical and visual method is letting the dispatcher perform operations on the graphical train paths on the screen directly. We can of course adopt other methods according to realistic needs and computer technical level.

3.2. Human Intention Recognizer: a transformation from instruction to intention

In order to perceive dispatchers' intentions, HIR is introduced after HIG. The raw inputted intention data from HIG will first be cleaned and then processed into a specifically designed scheme and stored in the back-end database, after which the intention recognition program will be started. However, due to the reason that ambiguous situations may arise, it is a challenging task to build a complete set of intention recognition approaches that could avoid ambiguity to the greatest extent. We default that dispatchers adjust timetable by moving the train paths in the human-computer interface to express his/her intention and use the example illustrated in Section 3.1 to demonstrate a scenario.

In this scenario, we assume that the train-level-oriented timetable rescheduling approach is first adopted. However, due to some reasons a dispatcher suddenly wants to change the departure sequence of trains in station M and make Train G3 leave first after the blockage. We simulate his/her operation in the human-computer interface, drag the train path of G1 horizontally to the gap between Train G3 and Train G5 to show the intention. the red arrow represents the moving process. Fig. 7 displays a situation where the dispatcher accidently makes the train path of G1 and the train path of G3 encounter at a same point, which means that Train G1 and Train G3 depart from Station O at the same time.

Under this circumstance, the dispatcher's real intention cannot be explored, since the performed operation may contain at least four underlying adjustment instructions:

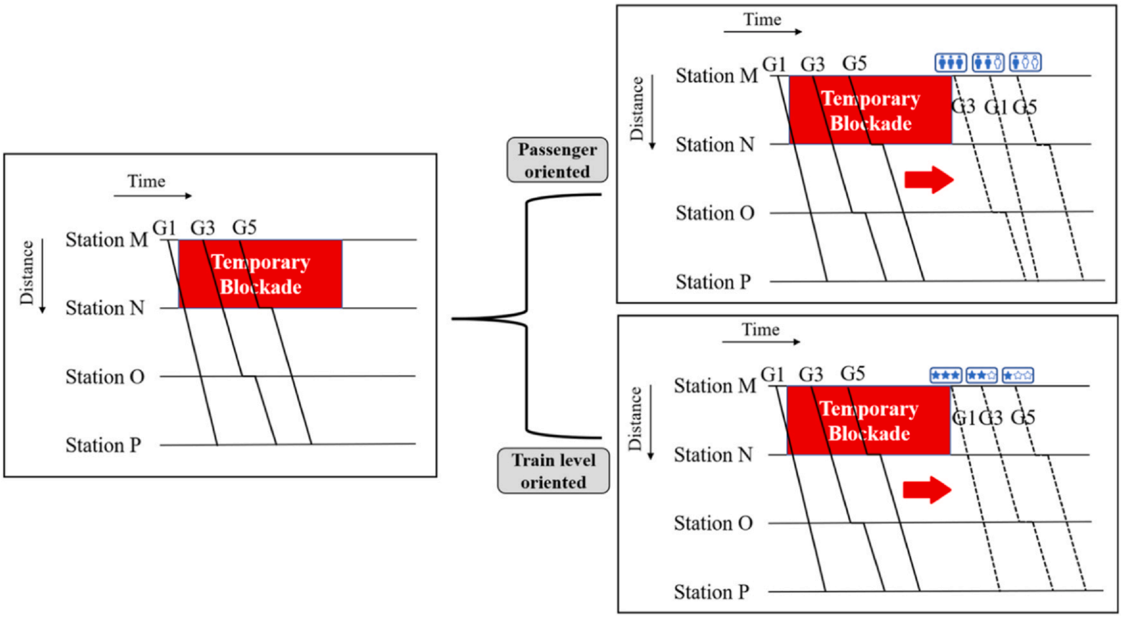


Fig. 6. Illustration of rescheduled timetable based on two different strategies.

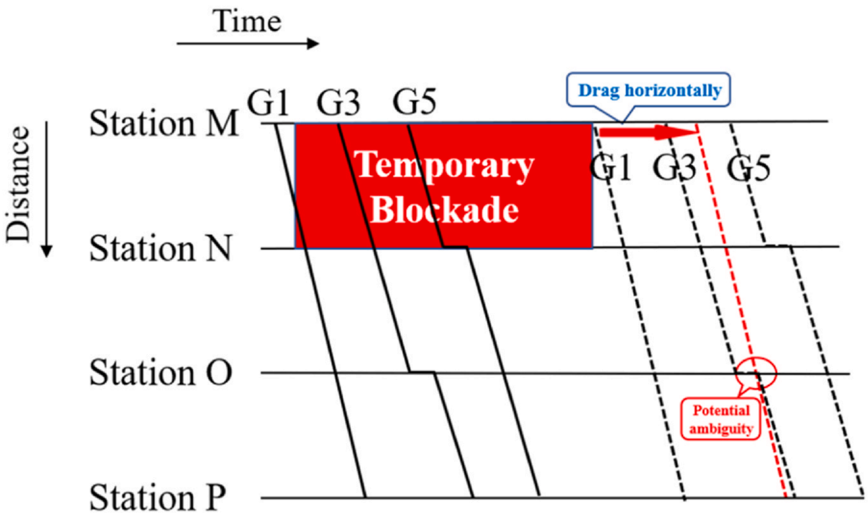


Fig. 7. Exhibition of an ambiguous scenario.

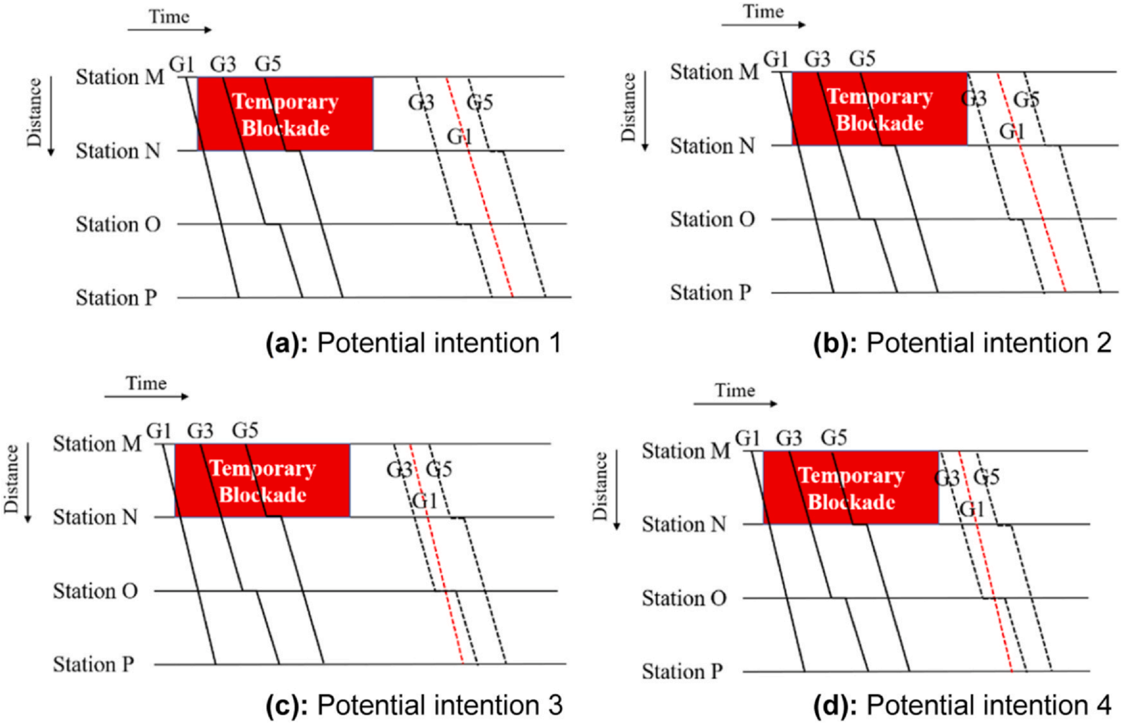
1. The dispatcher wants to change the departure order of Train G1 and G3, making G3 leaves Station M after a certain time gap, as shown in Fig. 8(a).
2. The dispatcher wants to change the departure order of Train G1 and G3, making G3 leaves Station M immediately when the temporary blockage ends, as shown in Fig. 8(b).
3. On the basis of (1), the dispatcher also wants Train G1 to overtake Train G3 at Station O, as shown in Fig. 8(c).
4. On the basis of (2), the dispatcher also wants Train G1 to overtake Train G3 at Station O, as shown in Fig. 8(d).

Therefore, if no intention recognition rule is built, it is impossible for computer program to come to a precise conclusion of the real adjustment instructions. This kind of ambiguous situation will happen frequently when the operation from human beings involves more train paths on the human-computer interface. Therefore, it is necessary to set up different rules according to different intentions.

3.3. *Human Intention Translator: a transformation from intention to revision*

Human Intention Translator is the place where abstract intentions are translated into structured model recognizable data and leads to the modification and/or calculation of the built-in timetable rescheduling mathematical model. Due to the reason that we do not expect extra variables, parameters or constraints to be introduced in the process of revision which could result in the increase of the complexity of model and longer computation time, we should pay much attention on choosing an appropriate and flexible model in this module. The chosen model should be capable of, on the one hand, solving TRP well and quickly, on the other hand, digesting programmed intention data and achieving automatic modification of corresponding constraints and/or objective functions.

For example, if we consider the railway system at a macroscopic level and ignore the details about block sections and signals, Event-Activity Network (EAN) is a good modeling tool that satisfies the



(a): Potential intention 1

(b): Potential intention 2

(c): Potential intention 3

(d): Potential intention 4

Fig. 8. Four potential intentions after manual operation.

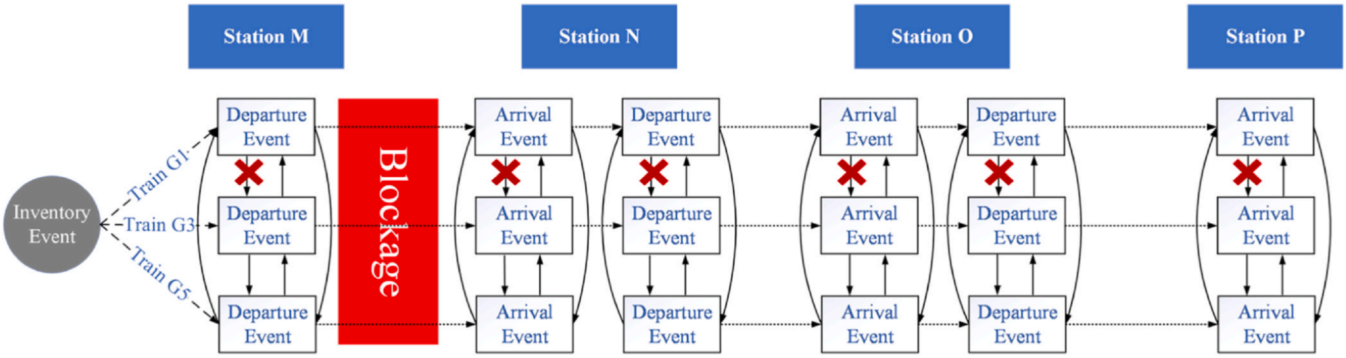


Fig. 9. The modified event-activity network for the example in Section 3.1.

characteristics mentioned above. The reason for this is that in EAN we use activity arcs between different events to represent the relations of trains, thus in cases where the running sequence of trains needs to be changed, we could achieve our goal through deleting the related arcs instead of adding new constraints in the process of establishing EAN. Fig. 9 is the modified EAN for the example in Section 3.2. It can be seen that a part of activity arcs between Train G1 and Train G3 are cut in order to make sure that Train G3 runs ahead of Train G1.

3.4. Human Intention Presenter: a transformation from revision to presentation

The result of revised model is presented graphically in the interface of HIP and shown to dispatcher for acceptance. The functions of the interface are shown in Fig. 10. In order to help them conduct a comprehensive evaluation on the adjusted timetable, we should provide some important performance indicators related to the new timetable such as total number of delayed trains, total train delay time and capacity utilization rate. Furthermore, some interactive functions should also be developed, for example, dispatchers can view downstream and upstream trains separately, or search for certain trains through giving the train names in the interface. In cases where they accept the new result, HCI framework terminates, otherwise a new iteration begins.

4. Application

In this section, a Real-time Timetable Automatic Rescheduling System (RTARS) based on the HCI framework is developed. This system has already been applied in the Dispatching Center of Beijing Railway Administration. It is composed of two parts: a web-oriented human-computer interface and an optimization engine. The functions of the interface are as follows:

(1) Enabling dispatchers to input information related to the happened disturbance or disruption, which corresponds to the intention input submodule in HIG;

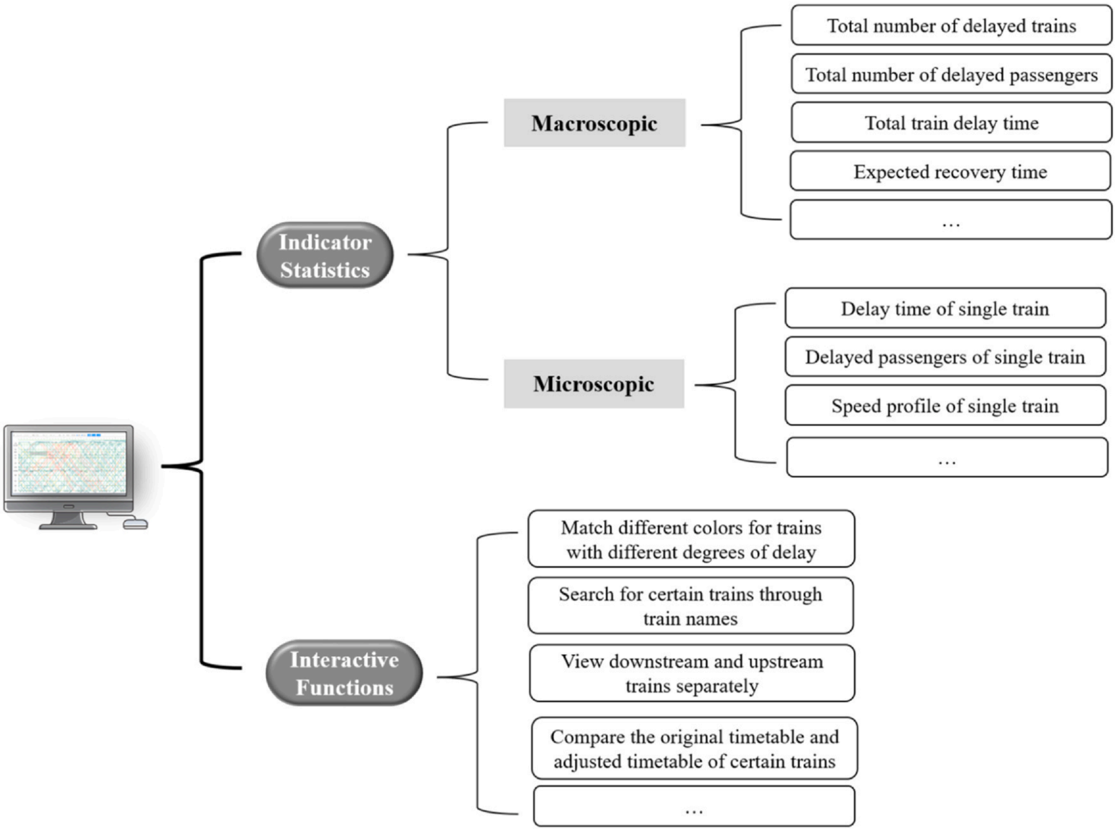


Fig. 10. Functions of the interface in HIP.

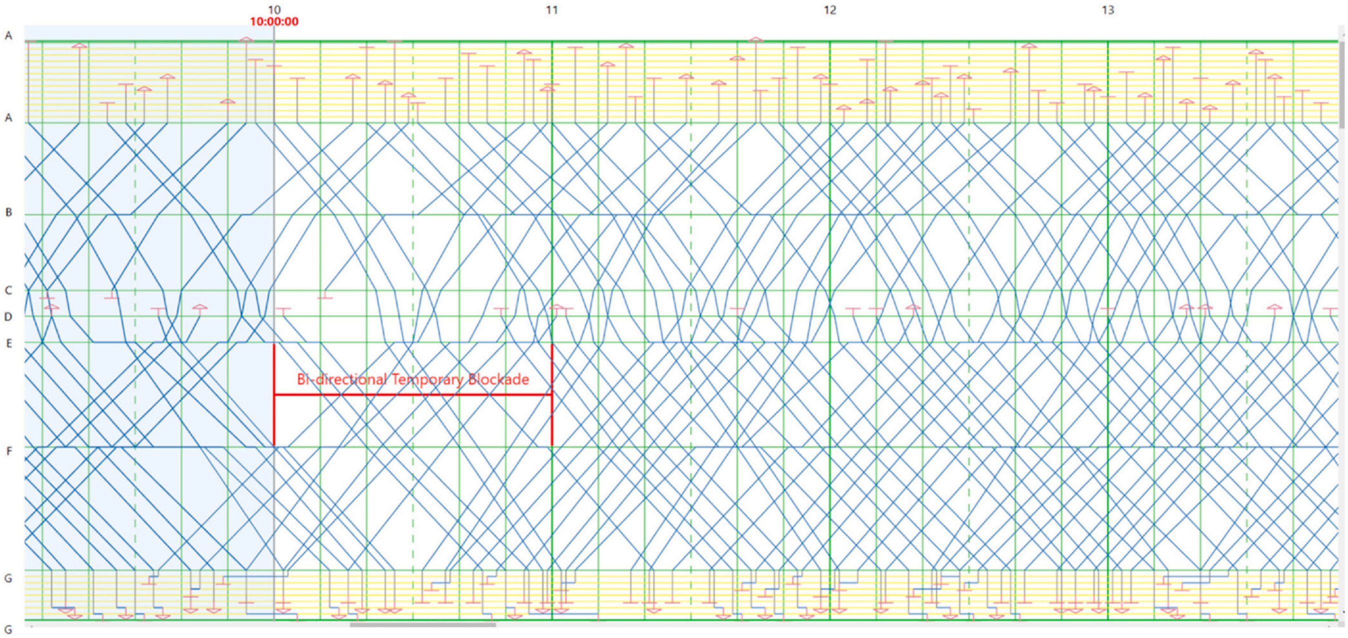


Fig. 11. Original timetable shown in the RTARS interface.

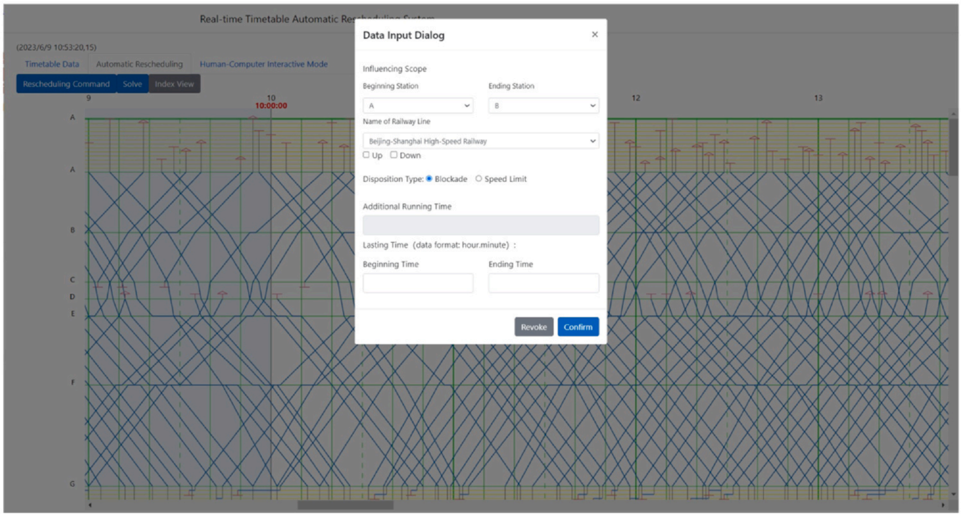
(2) Enabling dispatchers to perform operations on the graphical element of train paths to express his/her intentions, corresponding to the intention input submodule in HIG;
(3) Storing dispatchers' intentions in each iteration of HCI framework, which corresponds to the data storage submodule in HIR;
(4) Analyzing dispatchers' intentions based on the embed intention recognition algorithm, which corresponds to the intention recognition submodule in HIR;
(5) Providing graphical representation of adjusted timetable and important performance indicators, which corresponds to the result presentation submodule in HIP.

The engine achieves HIT and it contains a mathematical model for solving TRP. The description about the engine is elaborated in Ref. [25]. In order to show the effectiveness of our framework, we consider a scenario in which a technical failure happens and results in a bi-directional complete segment blockage. Under this circumstance, a dispatcher makes use of HCI framework and finally gets a satisfactory result. We assume that the framework iterates twice until the adjusted timetable finally satisfies the dispatcher. The iteration process is given as follows:

(1) In the first iteration, the dispatcher imports the information about the blockage, an initial adjusted timetable named T_1 is produced, aiming at minimizing the delay time of all trains. However, the dispatcher is unsatisfied with the schedule T_1.
(2) In the second iteration, the objective function stays the same, the dispatcher modifies the order of several trains in T_1 based on his/her experience and intuition. As a result, a new adjusted timetable named T_2 is produced, which satisfies the dispatcher.

A part of Beijing-Shanghai high-speed railway line is selected as the test bed, which includes 7 stations in total. The timetable used in our experiment is a real one in 2022, as shown in Fig. 11. The vertical grey line represents the current time, which is 10.00 a.m. when the screenshot was made.

The information related to the blockage could be imported into RTARS through a dialog box, which contains several drop-down boxes,



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Data Input Dialog

Influencing Scope

Beginning Station: A

Ending Station: B

Name of Railway Line: Beijing-Shanghai High-Speed Railway

☐ Up ☐ Down

Disposition Type: ● Blockade ○ Speed Limit

Additional Running Time

Lasting Time (data format: hour.minute) :

Beginning Time

Ending Time

Fig. 12. Blockage data input dialog in RTARS.

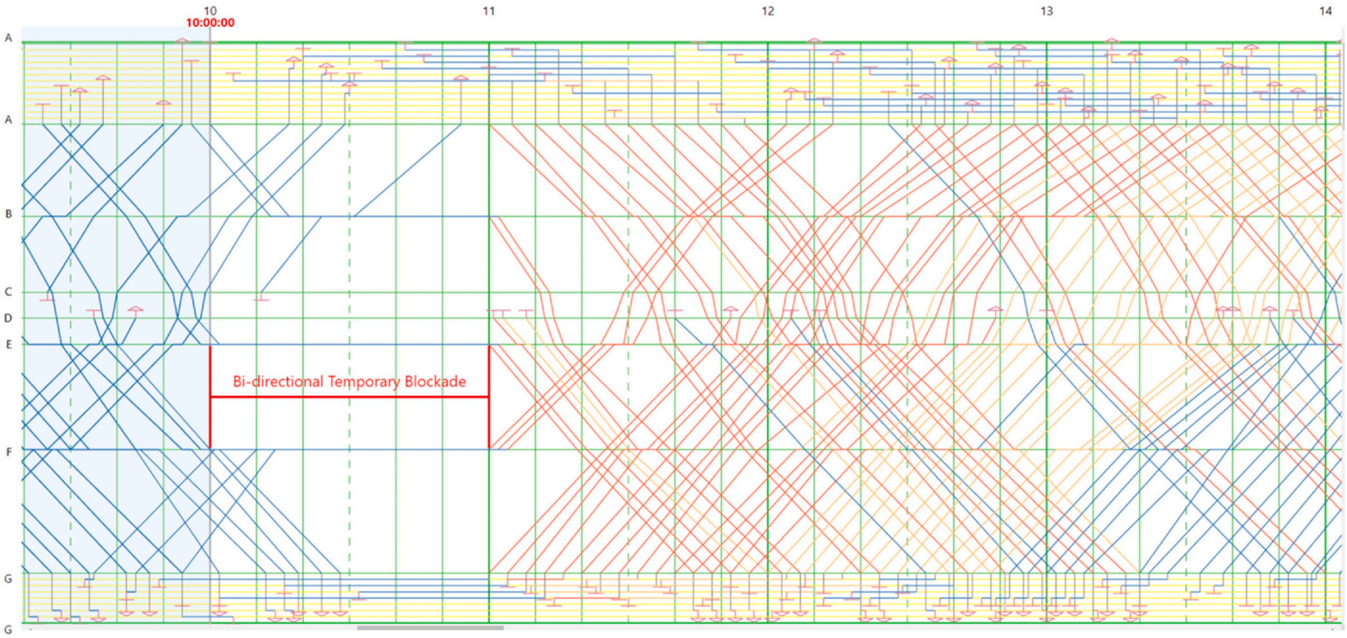

Fig. 13. Initial solution T_1 given by the optimization engine.

checkboxes and text input boxes, as shown in Fig. 12. Fig. 13 presents the initial solution T_1 given by the optimization engine.

As we can see, the initial model-computed results rearrange the order of trains based on a certain rule. The red lines in Fig. 13 means that the corresponding train is delayed for at least 30 minutes; the orange lines imply delays of 5 to 30 minutes; the blue lines mean that the train delay time is less than 5 minutes. We call the trains running from Station A to Station G as the downstream trains and trains running in the opposite direction as the upstream trains. There are four trains marked with labels in Fig. 14. As we can see, for downstream trains, G123 is the first train that departs from Station A and G1064 leaves Station F after the blockage ends. We now assume a situation in which a dispatcher is not satisfied with the train sequence in T_1 for some reason and wants G123 to leave after Train G181, and G1064 after G1568 similarly.

In RTARS, the intention expression method mentioned in Section 3.1 is adopted, the dispatcher is allowed to perform operations on the graphical element of train paths such as selecting, clicking and dragging. In order to input the intention about modifying the train orders, we design a straightforward way in which the dispatcher only needs to move the train path of Train G123 to the back of Train G181 and then repeats the same operation on Train G1064. Fig. 15 shows the manually adjusted timetable.

Apparently, the timetable in Fig. 15 is an unfeasible one since after manual operation many train path crosses could be noticed, which means trains have conflicts in sections. The HIR module in RTARS can

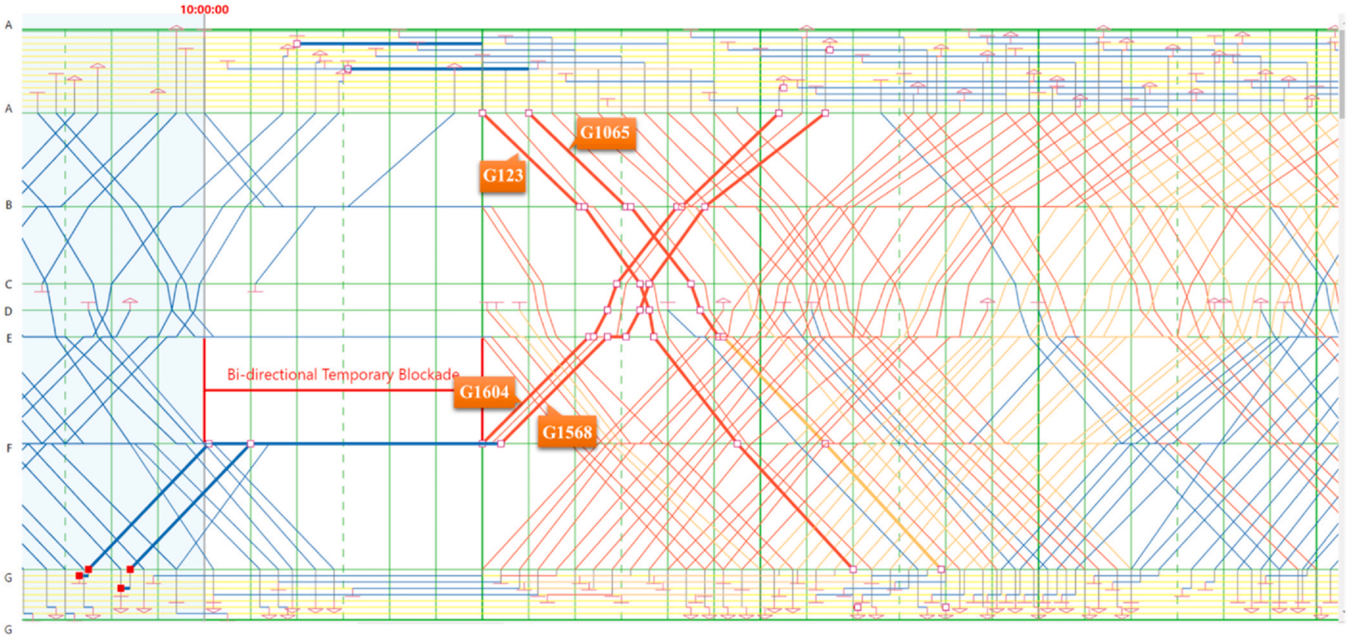

Fig. 14. Initial solution T_1 with four marked trains.

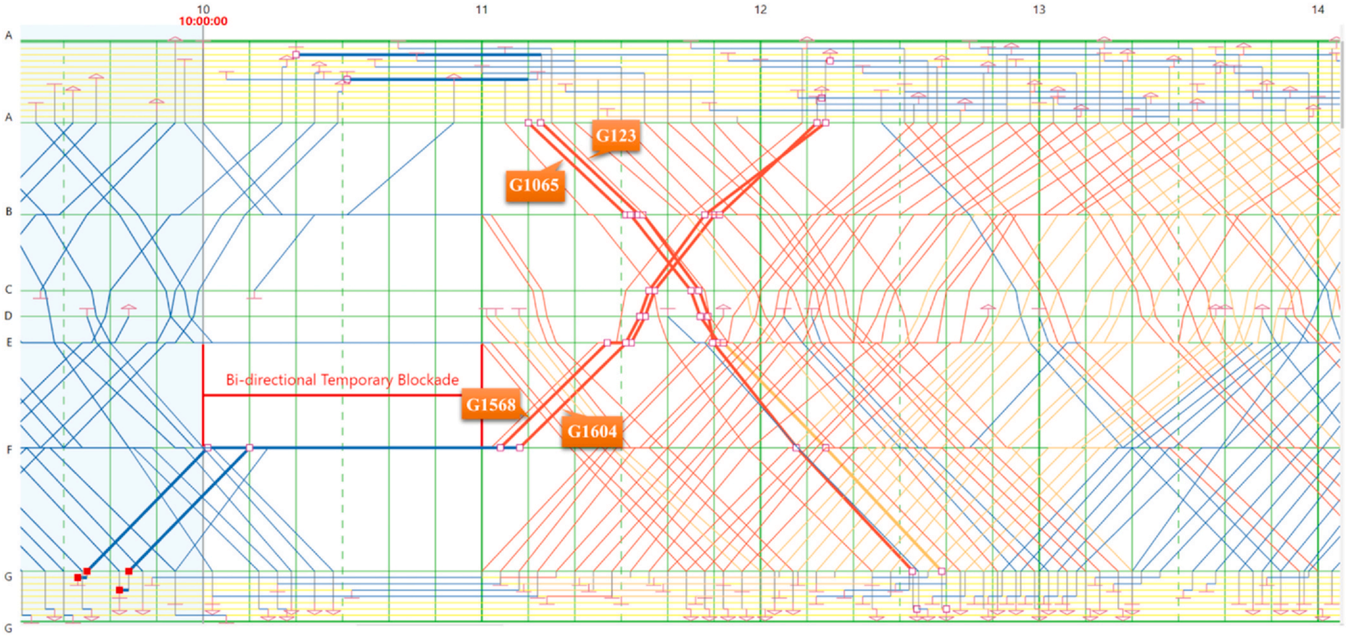

Fig. 15. The manually adjusted timetable on the basis of initial solution.

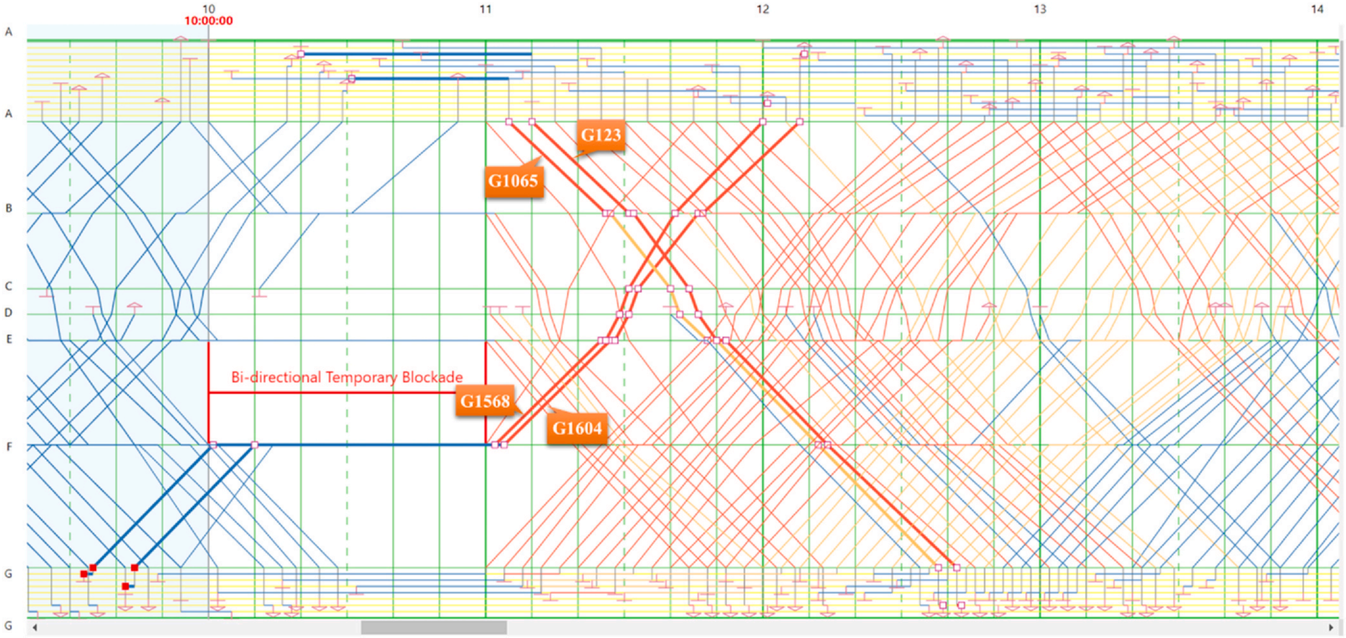

Fig. 16. The timetable T_2 after perceiving adjustment instructions.

effectively perceive dispatcher's intention about exchanging the departure orders of these four trains. The intention analysis results from HIR are programmed as JSON format and then sent to the engine, after which the engine will be restarted and a new conflict-free timetable T_2 is produced, as displayed in Fig. 16. We can find out that in T_2 Train G123 leaves Station A after Train G181 and Train G1064 follows Train G1568 at Station F, which is consistent with the dispatcher's adjusting intention.

5. Conclusions and further research

In this paper we introduce an innovative Human-Computer Interaction closed-loop framework for the real-time timetable rescheduling. Four main modules compose the framework. Human Intention Generator module is the place where dispatchers collect real-time information and express their adjustment intentions. These intention data will be filtered, stored and analyzed in Human Intention Recogizer module, which leads to the modification and/or calculation of mathematical model in the Human Intention Translator module. After the model calculation, the results will be provided to dispatchers for acceptance by means of a human-computer interface. The iterative process ends until human dispatchers are satisfied with the final solution and believe it can be implemented into field.

Our future research will address the following main extensions.

(1) In HIG, one direction is to achieve joint decision-making from information collection to various departments. In other words, each

department of railway system can share its information with other departments and propose its dispatching requirements. In addition, we could also digitalize the decision-making mechanism by using computer and standardize the intention input process, which is a great test for computer technology.

(2) In HIR, we could design more intelligent intention recognition algorithm. It can not only identify the adjustment intention in various scenarios, but also intelligently infer the adjustment habits and preferences of dispatchers by means of big data analysis.

(3) In HIT, we could design a universal model set. This set contains multiple mathematical models which integrate the functions of timetable rescheduling, rolling stock rescheduling and crew rescheduling together, achieving the integrated optimization on all types of duties, tasks and plans when unexpected events happen.

(4) In HIP, we could design various ways to present the model-computed timetable. It is due to the reason that for different departments of railway system, they often have different interests thus pay attention to different performance indicators. For example, the train dispatching department usually wants the disrupted traffic to recover as soon as possible, thus they focus more on the degree of delay propagation. For those departments which are responsible for train crews and rolling stocks, they care more about the crew duty and rolling stock duty and pay little attention on other indicators such as the total number of the delayed trains. Through presenting the adjusted timetable in different forms, the results evaluation task can be completed by various departments, rather than train dispatchers themselves.

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