TRAIN RESCHEDULING GENERATION CONSIDERING ROLLING STOCK TYPES AND CLOSED-OFF AREAS

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ABSTRACT

During railway operations, trains cannot operate on a scheduled timetable when a traffic accident happens. In such a case, exact re-operation time must be predicted and a rescheduling timetable after re-operation has to be generated quickly. Rescheduling timetables have been generated by manual operators. However, recently high-performance computers have also generated rescheduling timetables automatically. When a traffic accident happens, there are two main rescheduling plans considering traffic features on the tracks and infrastructure (for example, possible locations for a turning operation). In one plan, all tracks are closed and all trains re-started at the same time. In the second plan, the closed-off area is limited to only one part, and in other areas trains can run turning back operations. This rescheduling applies to where many trains run turning operations, and this type of rescheduling has the merit of continued traffic. Against this background, we are studying the automatic generation of rescheduling timetables. In Japanese urban areas, JR and some private company trains (rolling stocks) run through each other for passenger convenience, but the rolling stocks have limited running areas. For example, an area is operated by directory current rolling stock, but another area is powered by alternative current or diesel rolling stock operation. In this paper, we propose an improved rescheduling generation method that includes the closed-off area while also considering the rolling stock types. The generated rescheduling timetable includes turning operations in certain areas. With this method, a pausing time is set for each rolling stock, and other trains' paths may not cross the accident location. Of course, if the same pausing time is set for all trains, a rescheduling plan will be generated. Generated rescheduling plans are evaluated for passenger convenience; average headway time at each station for other directions and standard deviation time are evaluated. Shorter average headway time leads to larger transportation numbers, and smaller standard deviation means a more even passenger distribution for all trains. This method is applied to two scheduled timetables on a modelled double track line. Some rescheduling results are compared with different parameters. Generated rescheduled timetables include turning back operation.

Keywords: train operation, rescheduling plan, closed-off area, turning back operation, rolling stock types, average headway time.

1 INTRODUCTION

During railway operations, a traffic accident might happen, making it impossible to operate on schedule. In that case, operators need both an exact prediction concerning the operation time re-opening and a quick generation of the train rescheduling timetable after the re-opening time. Rescheduling timetables have been generated by manual operators. However, computer performance is advancing, and rescheduling timetables can be generated automatically. But automatic generation is realized under limited conditions because there are many circumstances to be considered, for example, the location of turning facilities on the tracks, trains location, and so on.

When a traffic accident happens, there are two types of rescheduling patterns. One is closing the whole track and all trains have the same re-opening operation time. The other one is closing a part of the track and trains are running a turning back operation around the closed-off area. In the first case, it is easy to return to the scheduled timetables after re-opening time, while the second one enables traffic to be continued.

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In this study, rescheduled timetables are generated automatically. In previous studies, we have considered mainly the first rescheduling type for a mixed operation with different rolling stock types [1]. However, a turning back operation while the accident area is closed-off has big merits, and therefore this rescheduling algorithm also takes this type into account. For example, reference [2] succeeded in quick turning back operations based on registered operation patterns due to time zone and accident location. Reference [3] used mixed integer linear planning to solve turning back operations. Computer processor performance improved and processors are able to solve realistic size problems [4]. And a train rescheduling algorithm considering rolling stock that uses a mixed integer linear program [5], and changing track at the station for delay [6] is also being researched.

In this paper, we present a method that includes turning back operations while also considering any different rolling stock types [7]. Possible routes per rolling stock type were registered, and the rescheduling timetable is a combination of route combinations including information on rolling stock types that can be used. Each pausing time for rolling stocks is initialized due to a traffic accident, and train routes do not cross the accident location. The rescheduling timetable is composed of these routes combinations by round robin, all possible to operate timetables are candidate solutions, a final solution depends on evaluation function determination. Generated rescheduling timetables are evaluated for average headway time at each station and standard deviation. For passenger convenience, shorter average headway time leads to larger transportation numbers, and smaller standard deviation means a more even passenger distribution for all trains.

By applying this method to several scheduled timetables on modelled tracks, we show that the method can generate rescheduling timetables that include turning back operations under different conditions.

2 TURNING BACK OPERATION AROUND A CLOSED-OFF AREA

2.1 Train rescheduling

In this study, train rescheduling means including changing destinations or changing starting order at the terminal stations. It does not include delay shortening.

We are especially studying the automatic generation of rescheduling timetable taking rolling stock types into consideration because some private companies and JR trains operate by running through on each other’s tracks in Japanese urban areas.

Train rescheduling timetables are generated based on the following assumptions and modelling:

- Train operation unit time is 15 seconds. This means train locations are renewed every 15 seconds. The computed positions may differ from the real ones, but a shorter unit time can correspond to the actual location, operation and signalling systems.
- Minimum headway time between trains is 2 minutes.
- Minimum dwell time is 5 minutes at turning operation, and 30 seconds at the other middle stations.
- Running time between stations is the same on the scheduled timetable as on the rescheduling one. The train stops at stations only, does not stop between stations and does not operate at slow speed.
- All rolling stocks have the same driving performance. On Japanese urban lines, most trains use the same rolling stock type.
- Trains are never partitioned or combined.

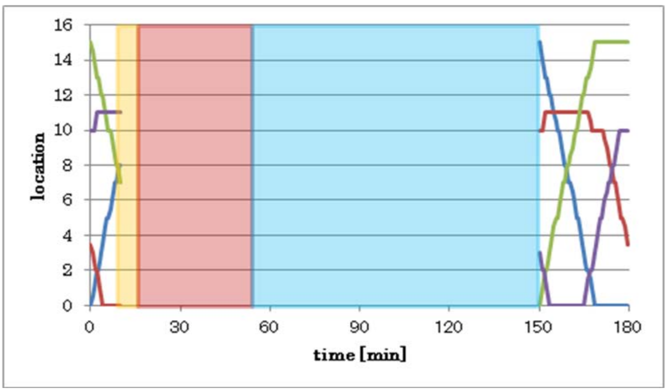
2.2 Turning back operation

When a traffic accident happens, there are two rescheduling methods.

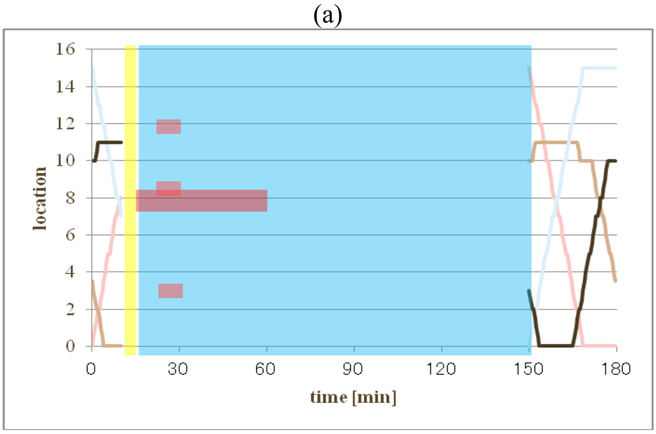
One is closing the whole tracks and re-opening operation time happens at the same moment for the whole tracks. The other one is closing a part of the tracks only, and trains are turning back around the closed-off area. The first method is mainly applied for trains that operate to the terminal station or on a circle track. This method has as merit to return easily to the scheduled timetable. The second one is applied to trains that have many turning back operations. This method can keep constant traffic on part of the tracks.

We have mainly considered the first method. In this paper, we improve the method proposed in reference [1] which considered rolling stock types.

We generate a rescheduling timetable including turning back operation around a part of the closed-off tracks. Each pausing time for rolling stocks is initialized due to a traffic accident, and train routes do not cross the accident location. Of course, if the same pausing time is set for all rolling stocks, the generated rescheduling timetable is the same as the one in which the whole tracks are closed.



(a)



(b)

Figure 1: Samples of train diagrams (yellow zone: communication time; red zone: pausing time; blue zone: rescheduling time). (a) Closing the whole area; (b) Closing part of the area.

3 GENERATION OF TRAIN RESCHEDULING TIMETABLE INCLUDING TURNING BACK OPERATION

3.1 Data

A train diagram means a traced graph which indicates the train location versus time. For the diagram expression, three data types are used:

- Track layout and location data which is divided in blocks
- Relation of the location versus time data
- Possible route data for each rolling stock

3.2 Pre-processing

There are three parameters for train rescheduling:

- Time and location of the traffic accident
- Communication time of accident information for all trains
- Complete recovery time to scheduled timetable

The train rescheduling timetable is generated between re-opening operation time and complete recovery time. For the generation of a rescheduling timetable which includes the closed-off area, also pausing time data for each train is needed. This data is an indication for the times each times each train should be stopped after the time the accident happened plus the communication time with other trains.

The trains which did not cause the traffic accident are re-operated soon, but the accident train continues to stop t minutes.

It is important to determine the destination for each train at re-operation time. More than one train cannot be located on the same track at same time, and generally, trains change to a nearer destination, but do not change to a farther destination because the rolling stocks have limitations concerning running-through operation.

In this present generation method, each train destination station remains the same as the original one. Even if several trains turn at the terminal station on the same track, most trains arrive at the destination at different times. When several trains arrive at the station at the same time, route conflict is avoided by using other tracks. When the accident train stops on a block section during rescheduling, other trains cannot run through that section and they change to a nearer destination.

On the other hand, because all train locations are determined at complete recovery time, the origin stations are also determined retrospectively. All train routes are researched between destination station after re-operation time and origin station before recovery time, and a rescheduling timetable is generated accordingly.

3.3 Generation rescheduling timetable

A train rescheduling timetable is generated as a route combination for each train in rescheduling time (between destination station arrival time after re-opening time and origin station starting time before complete recovery time). This route is a tree data structure based on different destinations for turning operation. This route is eliminated as solution if it includes the accident location with the accident train still stopped.

All routes which have a shorter total time than the rescheduling time are candidate solutions. Whatever time remains is distributed to the initial waiting time. Because this method cannot distribute soft buffer waiting time in the rescheduling time, the reschedule plan might be tight or without solution cases.

Fig. 2 shows examples of route combinations. For one train, several route combinations exist. Possible routes are searched for all trains, and all the combinations are searched by round robin. Only the combination that can be used in reality becomes the rescheduling timetable solution.

When different rolling stock types are in use, the trains can connect their operation with trains of the same type. These connection combinations are also searched by round robin.

When different rolling stock types are operated, the train diagram does not need to connect to the original operation. The condition for connection is that the same rolling stock types are used between re-opening time and complete recovery time. This allocation combination is calculated by round robin too. Fig. 3 shows a connection example for an operation using the same rolling stock type.

3.4 Evaluation for generated rescheduling timetables

Generated rescheduling timetables are evaluated for average headway time at each station and standard deviation. For passenger convenience, shorter average headway time leads to larger transportation numbers, and smaller standard deviation means a more even passenger distribution for all trains.

The evaluation value is the total amount average headway time ave_i by standard deviation s_i at station i for different directions.

$$E = \Sigma(ave_i * s_i)\ [\mathrm{min}^2]. \tag{1}$$

Under the same parameters, several rescheduling timetables can be generated, but the solution which has the smallest evaluation value is adopted as final solution.

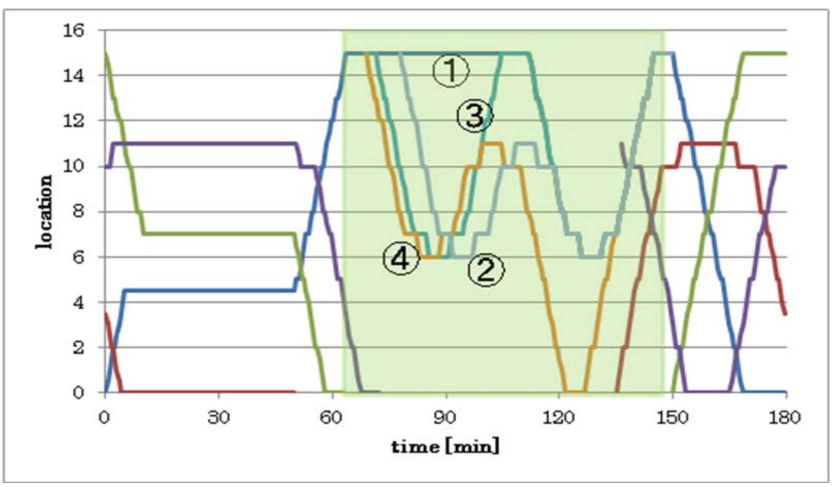
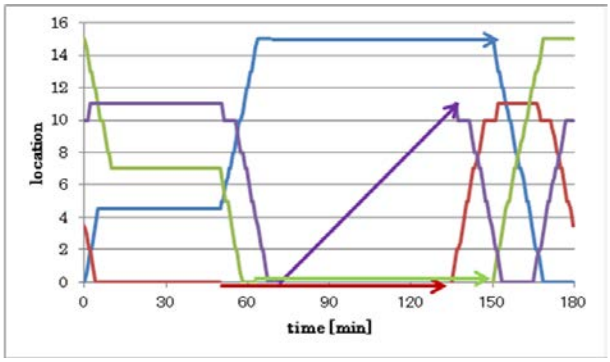
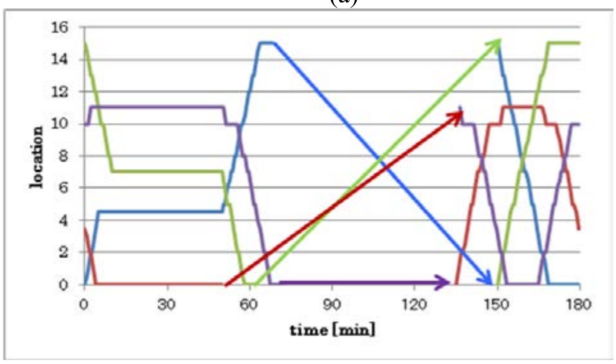


Figure 2: Route combinations for a train.



(a)



(b)

Figure 3: Possible connection based on vehicle type. (a) No vehicle change; (b) Vehicle change.

4 RESULTS AND DISCUSSION

4.1 Modelled track

In this section, based on the above method, we show some rescheduling examples for a theoretical track modelled on an existing track.

Fig. 4 shows a modelled track layout and divided block sections, and Table 1 shows the conditions of the line under consideration.

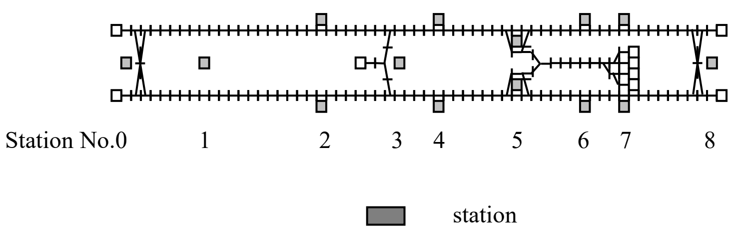


Figure 4: Theoretical track modelled on an existing track.

Table 1: Conditions of the line under consideration.

Number of stations	9 stations
Running time (non-stop)	15 [min]
Unit block time	15 [sec]
Total number of blocks	140
Number of routes	66
Number of rolling stocks	4
Train type	Local only

For this modelled track, there is a mixed operation of two rolling stock types, namely one type (blue and green trains) can run on the whole line, but the other type (red and purple trains) can run between station No. 0 and No. 5 only. This means, station No. 0 to No. 5 are for example powered by directory current, and stations No. 5 to No. 8 are powered by alternative current or diesel operation.

Fig. 5 shows a scheduled train diagram for the modelled track. Blue and green trains are operated by a rolling stock type which is able to operate on the whole line, but the red and purple trains are limited in operation between station No. 0 and No. 5. Only a local train is used as train type, and the timetable is cyclic per half hour, alternatively to the terminal and to station No. 5.

The scheduling timetable is rescheduled with the parameters shown in Table 2. A traffic accident happens to each train at different times, and the solutions are compared with each other.

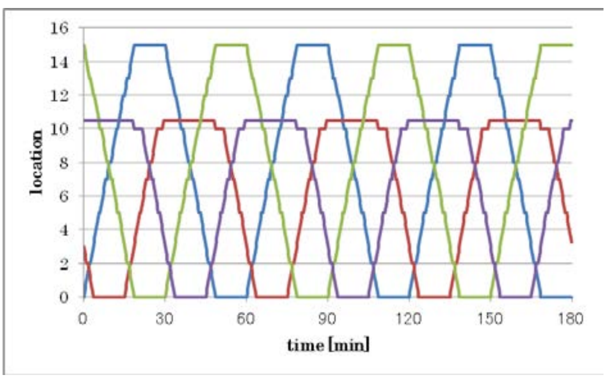


Figure 5: Scheduled diagram for the modelled track.

Table 2: Parameters for rescheduling generation.

Accident happening time	5 [min]
Communication time	2 [min]
Pausing time	40 [min] (accident train) 5 [min] (other trains)
Complete recovery time	140 [min]

4.2 Generated rescheduled timetable and discussion

4.2.1 A traffic accident happens to train No. 0

Fig. 6 shows the rescheduled diagram after a traffic accident happened to train #0 (blue train). Train No. 0 stops before station No. 2, and the red train waits (does not start) at terminal station No. 0. The green train turns at station No. 3 towards terminal station No. 8. A solution which considers both rolling stock types and the closed-off area is generated. The purple train is waiting on the turning track at station No. 5.

4.2.2 A traffic accident happens to train No. 1

Fig. 7 shows the rescheduled diagram after a traffic accident happened to train No. 1 (red train. Train No. 1 waits at terminal station No. 0 to turn. Station No.0 has two tracks, so the green train uses another free track to turn. The blue and purple trains are continuing their operation.

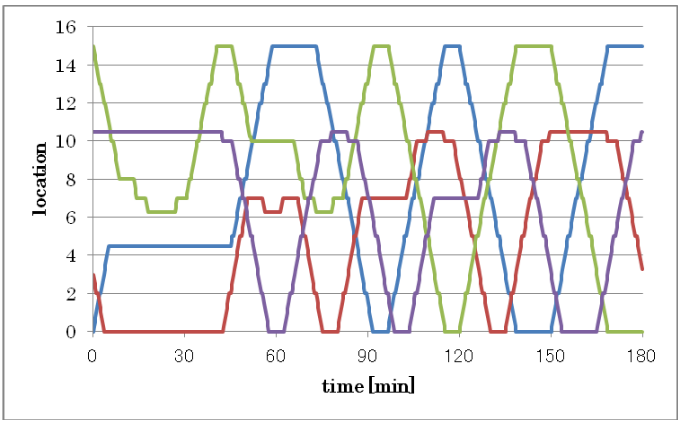


Figure 6: A rescheduled result (blue train accident).

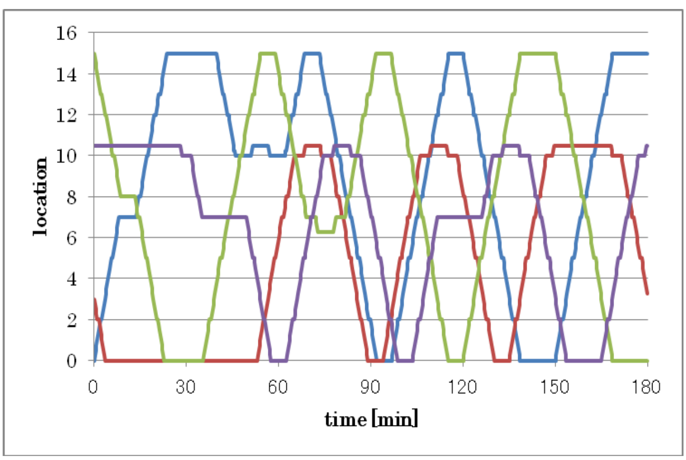


Figure 7: A rescheduled result (red train accident).

4.2.3 A traffic accident happens to train No. 2

Fig. 8 shows the rescheduled diagram after a traffic accident happened to train No. 2 (green train). Train No. 2 is stopped between station No. 5 and No. 6, and the purple train is continuing its operation. The blue train runs on a track parallel to the accident track. However, depending on the cause of the accident additional conditions that do not allow this kind of solution might be necessary. Also, in this solution, the blue and green rolling stocks which are of the same type have swapped operation.

4.2.4 A traffic accident happens to train No. 3

Fig. 9 shows the rescheduled diagram after a traffic accident happened to train No. 3 (purple train). Train No. 3 is waiting on the turning track at station No. 5. The train is not located on the main track. Therefore, the blue and green trains are continuing their operation while the purple train is waiting. The red train is turning back at station No. 3 because the train cannot turn at station No. 5 as was expected on the scheduled diagram.

4.2.5 Comparison turning back when all operation is stopped

Fig. 10 shows a sample rescheduled diagram in which all trains are stopped under the same conditions as given in Table 1.

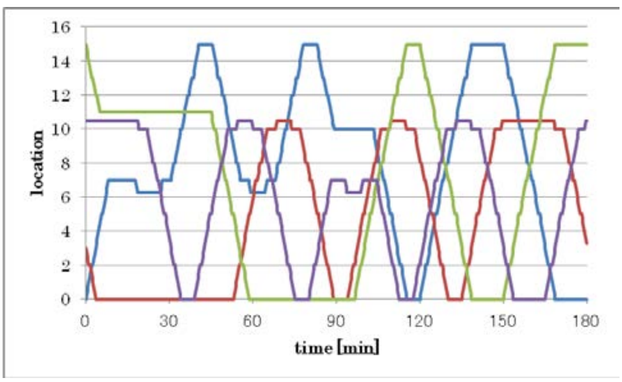


Figure 8: A rescheduled result (green train accident).

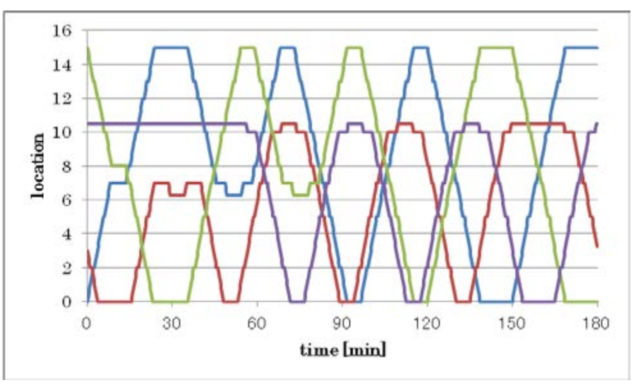


Figure 9: A rescheduled result (purple train accident).

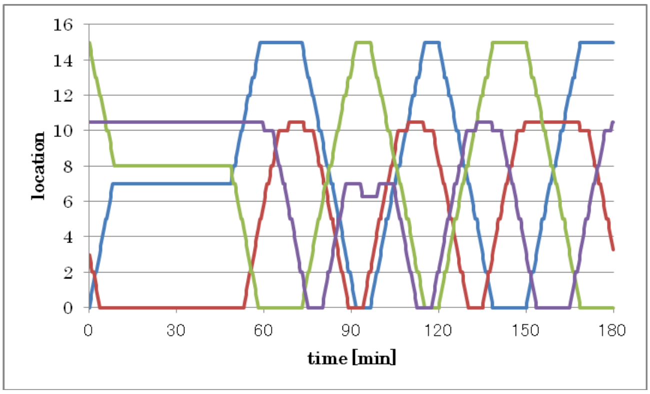


Figure 10: A rescheduling result when all trains stopped due to blue train accident.

Table 3: Evaluation values when considering rolling stock type and closed-off area, and when all trains are stopped (min^2).

Accident train no.	0	1	2	3
Considering rolling stock type and closed-off area	2411.8	2377.6	3088.0	1948.1
All trains are stopped	3972.8	4033.0	4120.3	4033.0

Table 3 shows evaluation values including both a part of the closed-off area and when all trains are stopped. Evaluation values are average headway time and its standard deviation. Accordingly, convenience is high when the operation number is high and the headway time is homogeneous. Therefore, a generated rescheduling timetable in which an operation turns back around the closed-off area has better evaluation values.

5 CONCLUSION

In order to maintain partial traffic, we presented a train rescheduling generation method in which a part of the track closes when a traffic accident happens.

As for rescheduling generation considering any deferent rolling stock types, stopping time for each train was set, and the rescheduling timetable is a combination of route combinations including information on rolling stock types that can be used. Running trains could not cross the tracks where the accident train was located, and a train rescheduling timetable which includes turning back operation was generated. The rescheduling timetable is composed of these routes combinations by round robin, all possible to operate timetables are candidate solutions. The evaluation values are average headway time at each station for other directions and standard deviation time for passenger. This method was applied to a modelled track, and a rescheduled timetable in which trains operate turning back around the closed-off area was generated under specified conditions.

While we are also considering rolling stock types operation, we have to select between turning back operation around a part of the closed-off area to maintain traffic or closing whole tracks to return to normal operation in short time, due to line characteristics.

In future research, we will deal with a higher number of trains, in order to generate rescheduling timetables for real-life scheduled timetables.

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