Analysis of Timetable Rescheduling Policy for Large-scale Train Service Disruptions

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Abstract
When a train disruption happens, dispatchers should make a train rescheduling plan quickly and manage both trains and crews to reduce serious congestion at disrupted area. Timetable rescheduling is quite domain specific work that requires a lot of experience, knowledge and decisive skills for dispatchers to make an adequate operation plan by taking account of various constraints. Furthermore, in recent years, dispatchers are expected to consider less impact on passengers to improve transport service quality. Thus, workload of train dispatchers become larger year by year. Then we have developed a dispatcher's decision-making support tool for train rescheduling. Our proposed prototype enables to recommend when and where turn around operations should be performed based on analysis results using historical operated train timetable data.

Keywords
Timetable Rescheduling, Simulation, Big Data Analysis

1 Introduction

In the Tokyo metropolitan area, approximately 15 million people use railway service every day. Train disruption in Tokyo area affects a great number of passengers for a long time. During a train disruption, dispatchers must modify train timetable to restart train service operation as soon as possible. Modification work of train timetable is called train rescheduling. In the operation control centre of JR East company, hundreds of train dispatchers need to quickly make a rescheduling timetable plan by taking account of delays of trains, train resource, human resource (i.e. crews), congestion, weather condition and so on.

Timetable rescheduling work gives strong stress to dispatchers because it requires a lot of experience and knowledge. Especially, in recent years, dispatchers are expected to reduce impact for passengers in addition to quick recovery to a planned timetable by performing turn around operations to provide enough transport capacity during a train disruption. Though work of a dispatcher will become more harder and more stressful, dispatching operation is still manually performed and depends on individual skill and experience. Furthermore, workload reduction and efficiency are desired because train rescheduling know-how is not shared among dispatchers effectively.

Therefore, we propose a new decision-making support system for dispatchers to make a better train rescheduling plan. We introduce data-driven approach to recommend train rescheduling operations using historical train operation data derived from train management system. By utilizing many dispatcher's operation history, we believe that train rescheduling skills of an individual dispatcher improve efficiently.

Some technologies for supporting dispatchers work have been already proposed. To support dispatcher's decision-making, two process are essential. One is generating process of train rescheduling plan. Many research based on mathmatical optimization approach have been presented as shown in Shakibayifar et al.(2018) and Huang et al.(2018). The other is evaluation process for effectiveness of train timetable plans. A macroscopic indicator named SCORE for evaluating a train disruption impact quantitatively was proposed by Tsunoda et al. (2015). With SCORE, dispatchers can review their rescheduling work from the viewpoint of passengers after a train disruption convergence. As a succeeding research, a SCORE-based simulator for making a train rescheduling plan was developed by Yamashiro et al. (2017). Dispatchers can make an optimal plan by comparing predictive SCOREs calculated based on normal travel demand of passengers. In addition, by their works, the effects of turn around operations during a train disruption have been revealed from the viewpoint of passenger's extra travel time. Other simulation researches also have been proposed. Kunimatsu et al. (2015) have evaluated turn around operations from a passenger's perspective with their simulator. In addition, monitoring system for train delay and congestion for dispatchers have been developed by Sakairi et al. (2016). Integration framework of primary work process for disruption management have been proposed by Besinovic et al. (2015). However, there have not been established method to recommend a rough design policy such as whether turn around operation should be performed or not for a dispatcher. Our motivations of this research are as follows.

(1) Support a dispatcher to make an optimal train rescheduling plan at the initial stage
(2) Indicate possibility of utilizing historical operated data in railway operation field

This paper is structured as follows. In Section 2, we describe train rescheduling operation problem and propose our research methodology. In Section 3, train rescheduling operation extraction method are presented. In Section 4, evaluation results are shown. Finally, Section 6 concludes the paper.

2 Research Methodology

2.1 Train rescheduling operation

Train rescheduling is one of the most important tasks for train dispatchers to recover train operation during a train disruption happens. Train dispatching workflow is as follows.

(i) Emergency notification

Dispatchers receive emergency notification from a station staff or a train attendant. Once an occurrence of train disruption is confirmed, they immediately stop all related trains.

(ii) Monitor the situation

Dispatchers receive follow-up reports of the incidents from stations and trains involved in the accident.

(iii) Rough design of train rescheduling plan

Table 1 shows a list of major train rescheduling operations. Required level of train rescheduling operations depends on a train disruption scale. When a large-scale disruption happens, dispatchers estimate operation restarting time and make a train rescheduling plan roughly. In a long time, service suspension case, dispatchers are often expected to provide extra trains and turn around operations to supply transport capacity for passengers as much as possible. On the other hand, in case of small-scale disruptions, combination of local rescheduling operations such as changing train departure orders are focused.

(iv) Confirm assets and human resource

After deciding an initial design for rescheduling plan, dispatchers make a detailed plan by considering train assets and human resource. Especially crew assignment is a complicated issue. For local train service operation in Tokyo metropolitan area, both train driver and attendant, i.e. at least two crews are essential to operate. Once asset and human resource are secured, dispatchers input rescheduling contents to train management system one by one.

(v) Catch up on planned timetable

When dispatchers restarts operation of disrupted trains, they concentrate recovering to original planned timetable. In other words, they gradually reduce train delays by combination train cancellation, changing train departure order and departure time. As mentioned in the above, train operation in the Tokyo area requires many human resources. Then it is desired that they operate according to the planned timetable from a perspective of train crews.

Table 1: Primal train rescheduling operation in Tokyo metropolitan area

No.	Rescheduling Operation
1	Extra train
2	Extend operational section
3	Change train type (local, rapid, express)
4	Change departure time of a train
5	Cancellation (fully and partially)
6	Turn around operation
7	Change train track
8	Change train id in train diagram
9	Change departure order at a station

During large-scale train disruptions, a dispatcher repeats monitoring process and re-planning process by taking account of various resource constraints. Figure 1 shows difference of two rescheduled timetables. We choose two disruption cases happened in the similar situation, i.e. both disruptions happened in same service line and almost same time. Main difference between case1 and case2 in Figure 1 is whether turn around operation was operated or not.

The left rescheduled timetable of Figure 1 has the following features.

- Most of trains have been stopped for nearly an hour.
- Significant impact on passengers because trains didn’t move entirely.
- Train operation were restarted at once.
- Rapidly recover to the planned timetable after a disrupted train restarted

On the contrary, the features of the right rescheduled timetable of Figure 1 is as follows.

- Some trains have been operated even immediately after a disruption happened.
- Less impact on passengers than the right case of Figure 1 because they could take a

train even in during a disruption.

- It is considered that workload of dispatchers was heavy because it has taken a long time to recover.

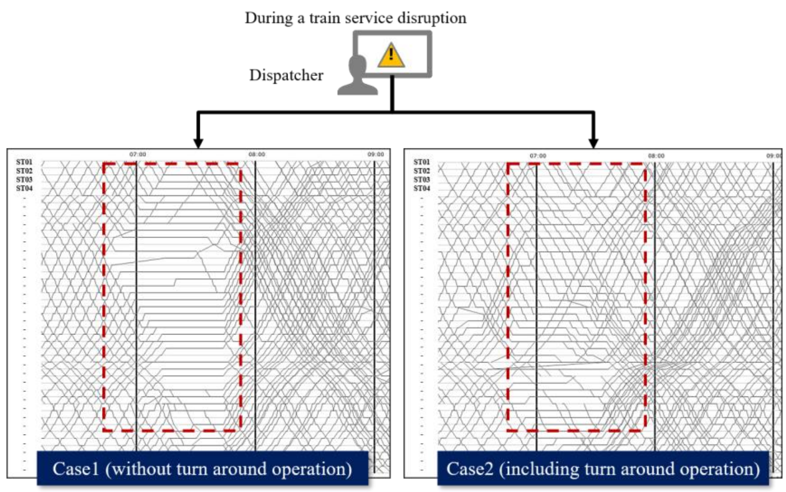

Figure 1: Comparison of two train rescheduling operations

Table 2 shows analysis results regarding the effects of turn around operations. It shows a ratio of transport capacity and an extra travel time per passenger for one actual disruption case. In this disruption case, accidental train service line can be divided in 9 operation sections and turn around operations were performed from section 7 to section 9. Alternative train service line exists around section 4, 5 and 6. From table 2, it is found that turn around operations increased transport capacity remarkably. Hereby, extra travel time per passenger decreased according to turn around operations.

Table 2: Comparison of influence on passengers by operation section

Operation Section	Ratio of Transport Capacity (disrupted day / normal day)	Extra Travel Time per Passenger (min)
All section	66%	12.4
Section 1	7%	27.0
Section 2	14%	27.8
Section 3	27%	24.5
Section 4	60%	18.7
Section 5	72%	15.0
Section 6	77%	14.9
Section 7	119%	9.8
Section 8	119%	7.9
Section 9	120%	7.2

Recently, railway operators have been strongly encouraged to manage train timetable to minimize the effect on passengers. As one method to achieve that, turn around operations during a disruption are focused. However there haven't been enough analyzed that when and where turn around operations should be performed. Currently, train dispatchers decide it depending their experience and individual intuitive. Therefore, we propose a dispatchers' decision-making support system which can recommends turn around operation plan based on historical data analysis. Nevertheless, thinking process history of rescheduling planning weren't stored in any existing systems. Then we focus utilizing operated train timetable data history to reproduce train rescheduling arrangement process.

2.2 Train operated data

The key dataset in this research is historical train operated data obtained from the train management system. A train management system oversees the location of each train and it is possible to know how long the train is delayed comparing to the actual location with the original transportation plan.Table 3 shows primal information included train operated data. Table 3(a) is an example of normal operation. Table 3(b) shows am example of turn around operation. These train operated data are stored daily as a text-based data. It includes spatial and temporal information of all trains, i.e. stopping station, planned departure and arrival time, operated departure and arrival time as shown in Table 3. In the case of turn around operation, operated time records were disappeared partially. In addition to this, it includes previous and next train Ids. With these datasets, we can trace change of train Ids thorough one day.

Table 3: Example of operated train timetable data
(a) Normal operation

Direction	Train Id	Train Type	Order	Station	Arr. Time (planned)	Dep. Time (planned)	Arr. Time (operated)	Dep. Time (operated)
Inbound	1xxA	Local	1	ST01		8:52:30		8:52:30
Inbound	1xxA	Local	2	ST02	8:54:40	8:54:50	8:54:45	8:54:55
Inbound	1xxA	Local	3	ST03	8:56:20	8:56:40	8:56:30	8:56:45
Inbound	1xxA	Local	4	ST04	8:58:30	8:58:50	8:58:35	8:58:55
Inbound	1xxA	Local	5	ST05	8:59:45	9:00:15	8:59:50	9:00:15
Inbound	1xxA	Local	6	ST06	9:01:20	9:01:40	9:01:20	9:01:45
Inbound	1xxA	Local	7	ST07	9:03:40	9:04:00	9:03:50	9:04:30
Inbound	1xxA	Local	8	ST08	9:05:40	9:06:00	9:06:00	9:06:20
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(b) Turn around operation (operated from ST05 to ST08)

Direction	Train Id	Train Type	Order	Station	Arr. Time (planned)	Dep. Time (planned)	Arr. Time (operated)	Dep. Time (operated)
Inbound	1xxB	Local	1	ST01		8:52:30		
Inbound	1xxB	Local	2	ST02	8:54:40	8:54:50		
Inbound	1xxB	Local	3	ST03	8:56:20	8:56:40		
Inbound	1xxB	Local	4	ST04	8:58:30	8:58:50		
Inbound	1xxB	Local	5	ST05	8:59:45	9:00:15		9:00:15
Inbound	1xxB	Local	6	ST06	9:01:20	9:01:40	9:01:20	9:01:45
Inbound	1xxB	Local	7	ST07	9:03:40	9:04:00	9:03:50	9:04:30
Inbound	1xxB	Local	8	ST08	9:05:40	9:06:00	9:06:00	

If an operation of train is cancelled, operated time data of that train Id will be blank. In case of turn around operations, operated time data will be recorded from an intermediate station. Extension of operation section can be detected by finding only operated time data were recorded, i.e. planned time data are blank for extended section. In addition, extra trains and change of train type can be detected by comparing another day's operated train timetable. From the preliminary analysis, we considered that it can be automatically estimated that how train rescheduling operation were performed by comparing each train Id's normally planned information and operated history. Then we start to generate normal operated train data named "regular train data" to extract train rescheduling operation.

2.3 Our goal

To develop a decision-making support tool that is enabled to recommend train rescheduling operation plan for train dispatchers, we propose two-step analysis method.

Step1: Generate a regular train timetable based on historical train operation data.

Step2: Extract differences between a disrupted day's timetable and a regular timetable.

Our objectives of this paper are as follows:

(1) To extract train rescheduling operations automatically from historical data
(2) To evaluate accuracy of the proposed method by comparing with dispatcher's manual report
(3) To demonstrate a prototype of decision-making support tool

3 Train Rescheduling Operation Extraction Method

In the subsection 3.1, we describe a data process for generating a regular train timetable. Then, in the subsection 3.2, we explain how train rescheduling operation can be extracted automatically.

3.1 Regular train timetable

First, we defined regular train timetable data schema shown in Table 4. As essential factors of a regular train timetable, it is considered that each train's property, a sequence of stopping stations, planned arrival time and planned departure time are necessary. Train property includes line name, direction, train Id, previous train Id and next train Id. In addition, based on the preliminary analysis result, operated day factor was included because it is found that some trains are operated in limited season, day of week and so on.

Table 4: Data schema of regular train timetable data

Direction	Train Id	Operated day	Station #1	Dep. Time #1	Station #2	Arr. Time #2	Dep. Time #2	---
Inbound	1xxA	weekday	ST01	8:52:30	ST02	8:54:00	8:54:30	---
Inbound	1xxA	holiday	ST01	8:50:00	ST02	8:51:30	8:51:50	---
Inbound	1xxC	weekday, only Monday	ST05	9:00:20	ST06	9:02:00	9:02:30	---
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Data process for generating a regular train timetable is as follows.

(1) Count operated numbers for each train Id by yearly and by day of the week.
(2) Extract train Ids that meet the following conditions.
 -Number of operated days is over than 2.
 -Year-based operated ratio is over than 80%
(3) Set "Operated day" flag for train Ids that seems be operated in only limited day of the week.

It is necessary to generate regular train timetables at least by yearly for train operations in Tokyo metropolitan area because a large-scale train timetable revision is held in every March. We have analysed 7-years train operation data with the proposed method. Table 5 shows the result of regular timetable generation for Line A that is operated in Tokyo central area.

Approximately 800 trains were extracted as regularly operated trains for weekday. Holiday regular train numbers is less than weekday. In FY2011, the reason why number of trains operated with limited-time were large is found that impact of Great East Japan earthquake (March 11th, 2011).

Table 5: Number of regular trains on Line A

Fiscal Year	Weekday			Holiday	
	Total	Only Friday	Limited time	Total	Limited time
2011	835	2	83	649	2
2012	778	3	13	644	1
2013	777	4	3	649	0
2014	784	3	9	651	0
2015	779	1	16	659	0
2016	776	0	3	661	0

Though generating a regular train timetable requires only calendar information, i.e. it is necessary to calculate operated ratio by year, other data processing flow can be implemented automatically. Then it is expanded for new dataset easily.

3.2 Extract differences

Train rescheduling operations can be detected by comparing a disrupted day's train operation data with a regular train timetable. The rules or data processing flows to detect each train rescheduling operation are shown in Table 6. Comparison between planned time data and operated time data brings long-time train stop detection besides. Extra operated time of a train can be easily calculated by subtract planned travel time from actual travel time. Each travel time between adjacent stations is calculated by using departure time at one station and arrival time at a next station.

Table 6: Rules for detecting train rescheduling operation

No.	Rescheduling Operation	Detection Rule or Process
1	Extra train	Not included in a regular train timetable
2	Extend operational section	Compare operational section (a pair of origin station and destination station of each train)
3	Change train type (local, rapid, express)	Compare train type
4	Change departure time of a train	Compare planned departure time
5	Cancellation (fully and partially)	Operated time are not recorded
6	Turn around operation	Until an intermediate station, operated time are blank. From the intermediate station, operated time are recorded.
7	Change train track	Operated time are not recorded from an intermediate station to another intermediate station
8	Change train id in train diagram	Compare previous train Id/next train Id
9	Change departure order at a station	Make a list of train Ids based on a departure time by a station for both a regular train timetable and a disrupted day's data. Then compare departure order.

Data extraction results of train rescheduling operations are stored with data schema as shown in Table 7. In addition to No.1~No.9 listed in Table 7, detection results of long-time train stop can be stored in the same data table. As we described in the above, the proposed method enables to automatically extract all of train rescheduling operations in Table 7. In other words, amount of extracted data increases permanently day by day.

Table 7: An example of train rescheduling operation extraction result

Date	Train Id	Property	Rescheduling No.	Rescheduling Time	Detail	---
1st Feb 2015	1xxA	---	6 (turn around)	13:22:38	Operated from ST05 to ST08	---
1st Feb 2015	1xxB	---	5 (cancellation)	13:26:10		---
1st Feb 2015	1xxC	---	1 (extra train)	13:50:23	Operated from ST03 to ST10	---
1st Feb 2015	9xA	---		13:10:50	Long-time stop at ST06 for 15mins	---
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4 Evaluation

4.1 Extraction results

With 7 years dataset from July 2011 to April 2016, we analysed all of train rescheduling operations for Line A. Approximately 400 disruptions happens in Line A thorough 7 years. Figure 2 and Figure 3 analysis results of the two disruptions used in Figure 1.

Trains that stopped for a long-time are highlighted in Figure 2. Threshold for detecting "long-time" stopping trains used in this paper is 10 mins. Comparing two images in Figure 2, it is found that turn around operation case took longer time to recovery. With these extraction results of long-time stopping trains, we can estimate disrupted sections and timeslot easily. There is possibility of accumulating disruption information automatically instead of dispatcher's manual input.

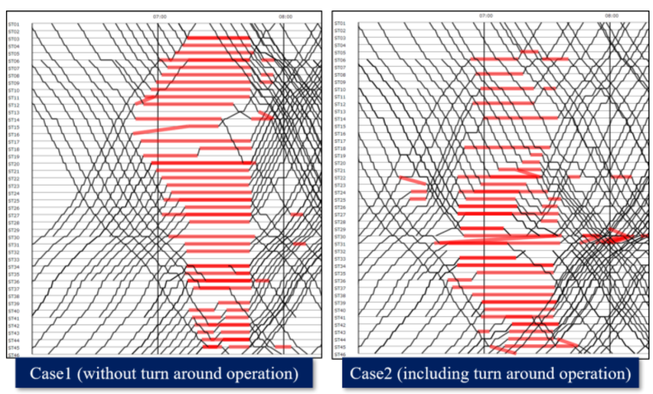

Figure 2: Detection results of long-time stop trains (same cases are used in Fig. 1)

Figure 3 shows turn around trains with blue lines. As described in Section 2, turn around operations had been performed only in Case2. Our proposed method extracted three turn operated trains as shown in Figure 3. It was confirmed that those extracted result was correct by referring daily operating report written by dispatchers.

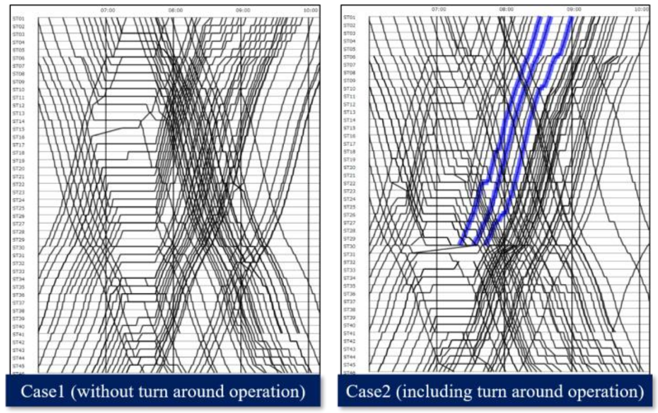

Figure 3: Detection results of turn around operated trains (same cases are used in Fig. 1)

4.2 Accuracy evaluation for turn around operation detection

To evaluate accuracy of detecting method for turn around operation, we compared extraction results with historical operating report manually input by dispatchers. Operating report includes disruption information and some of train rescheduling operations such as where turn around operations were performed as shown in Table 8. We selected 40 disruption case of Line A in which turn around operations were performed and compared operating reports with extraction results regarding turn around operation. Total number of turn around operations is 252 as for 40 disruption case. Then our proposed methods extracted 249 turn around operations. It was confirmed that operated sections, i.e. where turn around train run, were completely correct. Consequently, it is found that accuracy of the proposed method is quite high concerning turn around operations.

Table 8: Dataset of manual report for train rescheduling operation

Date	Line Name	Disruption Information	Number of turn around trains	Detail	---
1st Feb 2015	Line A	Station: ST06 Occurring Time: 10:15 Restart Time: 10:57	10	4 (at ST03, Inbound) 6 (at ST15, Outbound)	---
5th Feb 2015	Line A	Station: ST015 Occurring Time: 15:42 Restart Time: 16:38	8	2(at ST03, Inbound) 2(at ST05, Inbound) 4 (at ST20, Outbound)	
5th Feb 2015	Line B	Station: ST24 Occurring Time: 08:09 Restart Time: 09:30	5	2 (at ST20, Inbound) 3 (at ST28, Outbound)	
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5 Application and Case Study

We have developed a dispatcher's decision-making support tool for train rescheduling using historical train operation data. Our prototype enables to recommend when and where turn around operations should be performed based on the analysis results described in the above. The processing flow of the prototype is as shown in Figure 4.

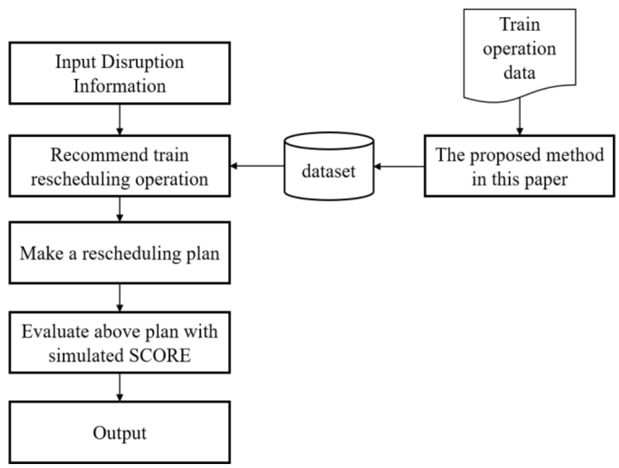

Figure 4: Framework of the proposed system

(1) Input the disruption information
An operator manually input three data, i.e. disrupted line, time of occurrence and predicted time to restart.
(2) Search a similar disruption case based on input information and recommend turn around operation performed in the past.
(3) Make a rescheduling plan (train timetable) with GUI by referring recommendation results.
(4) Evaluate a planned rescheduling timetable with SCORE simulation algorithm.
(5) An operator can confirm an evaluation result for a planned train timetable. Then he/she can continue to make a better rescheduling plan by back to step (3), if necessary.

According the framework in the above, we have implemented the prototype as shown in Figure 5. Basic functionality for making a new train timetable and evaluating it with a simulated SCORE have been already developed (Yamashiro, et al. 2017). We have improved the simulator to recommend a rough design policy for a dispatcher when he/she starts a train rescheduling work. Firstly, the prototype receives a disruption information from a dispatcher. Then the prototype searches a similar disruption among analysed results of historical train operation data and recommends number of turn around operations and at which station to be performed. As parameters of similarity, we used a timeslot of disruption occurrence (i.e. morning, daytime, evening), a service suspended time and a disrupted section. A train timetable making process itself needs some manual modification currently because the prototype doesn’t take account of all constraints such as facility and human resources.

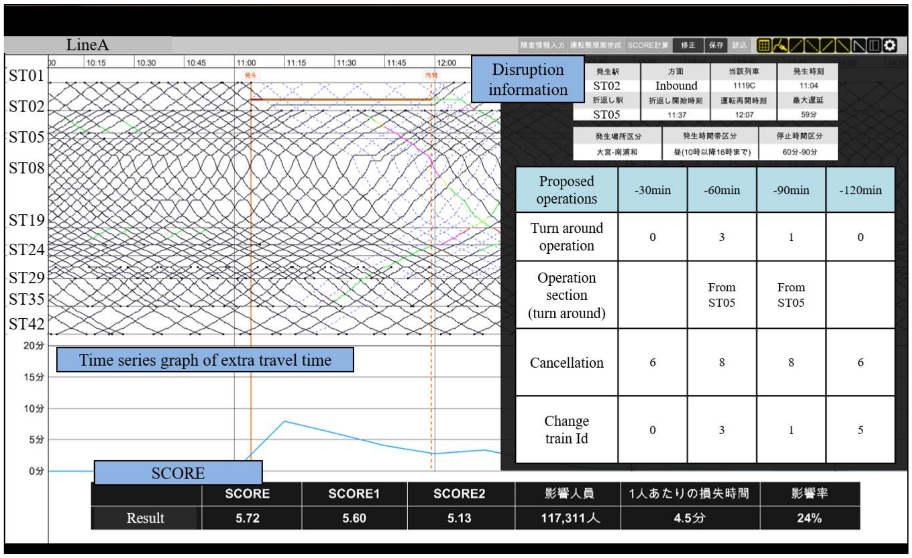

Figure 5: Overview of the prototype tool

To verify the prototype tool, we have compared the proposed timetable with operated timetable regarding the one disruption case in which turn around operations were performed. Case description is as follows.

- Disruption happened at ST05, outbound direction, at 11:05am
- Operation restarted at 11:59am
- Four turn around trains were operated at ST06 until restarting

We have input disruption information (place of a disruption happens, direction, time of occurrence, time of restart) to the prototype tool and confirmed the proposed timetable as shown in the left image in Figure 6. The prototype recommends three turn around operations at ST06. It is found that the operated station of turn around trains were correct though the number of turn around trains was slightly different. Although with a limited example, we have confirmed effectiveness and remaining issues of the prototype. Train headway and movement of each train should be considered to improve validity of the prototype.

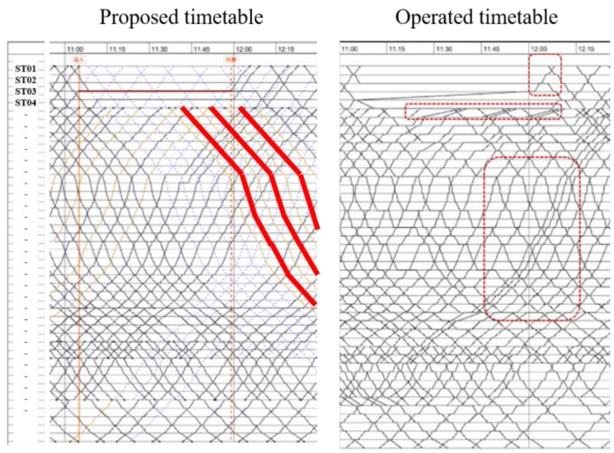

Figure 6: Comparison of proposed and operated timetables

6 Conclusions

We have proposed a new data-driven approach to support train rescheduling operation by analysing historical train operation data derived from train management system. It was confirmed that extraction accuracy as for turn around operations was sufficiently high. Furthermore, we have developed the prototype tool that recommends train rescheduling plan for dispatchers.

Future studies will focus on functional improvements of recommendation system. Prototype system should be improved to help dispatchers make more practical rescheduling plan. In addition, it is necessary to extent our extraction method for more complicated train service line including changes of train departure order.

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