A METHOD TO GENERATE AND CLASSIFY TENTATIVE TRAIN SCHEDULES FOR KEEPING TIME TO SEARCH AN OPTIMAL PLAN IN CONPUTER-AIDED TRAIN RESCHEDULING

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ABSTRACT

Train rescheduling is often needed when train operation disordered by train accidents, natural disaster, and so on. This task generically depends on the experiences and personal decision of the professional dispatchers. They do not have quantitative criteria for evaluating goodness of their operation and their task is therefore substantially difficult. Thus, operators have requested a computer-aid system.

The authors propose a computer-aided train rescheduling system. This system consists of two parts, one part is for creating plans and another is for evaluating the plans. This paper deals with a method generating possible train operation plans.

Train rescheduling needs many steps for reacting events timely after a disruption. If you have to start the rescheduling plan right after an accident, you have no time to investigate possible plans carefully.

Hence, authors insert a tentative train diagram between the time of the accident and start of the executing rescheduled plan.

The best choice of tentative diagrams depends on the interval length between the accident and the start of recovery actions. However , you must prepare ready-made patterned operational candidates in advance because the tentative plan must be immediately selected and applied just after an accident. In this paper, authors discuss appropriate methods related to train rescheduling on directional quadruple tracks.

Keywords: Train rescheduling, Computer-aid system, Passengers' flow

1 INTRODUCTION

Rescheduling train operation is indispensable when train operation is disordered by various causes such as accidents. The main tasks of train rescheduling are still done by train dispatchers rely on their experience. This work is very hard, because many factors must be considered for making train rescheduling plan such as location of trains and rolling stocks, tracks and train layout, location of crews, passengers' demand, and so on. In addition, quantitative evaluation for rescheduling train operation plan is not established. Dispatchers have requested a computer-based assistance system to create rescheduling train operation plans quickly and precisely.
The authors proposed a method to evaluate train operation plans quantitatively based on the passengers' point of view. To use this evaluation, we construct an assistance system that chooses an assistance system that chooses an appropriate method to modify a train schedule [1].
In this paper, the tentative operation plan between the time of accident and the time to start the rescheduling operation plan is introduce in order to consider the time for creating the plan. Since the tentative plan must be created quickly before decision the train rescheduling operation, we consider the simple pattern as the tentative plan. We introduce the method to decide the pattern for the tentative operation plan, and verify the method with a model line.

2 TRAIN RESCHEDULING SYSTEM

2.1 Composition of train rescheduling system

Our train rescheduling system creates a train rescheduling plan based on regular train schedule and information about delay. This system consists essentially of two parts, one is creating a train rescheduling plan and another is evaluating the plan. Figure 1 shows a composition of the computer-based train rescheduling system.

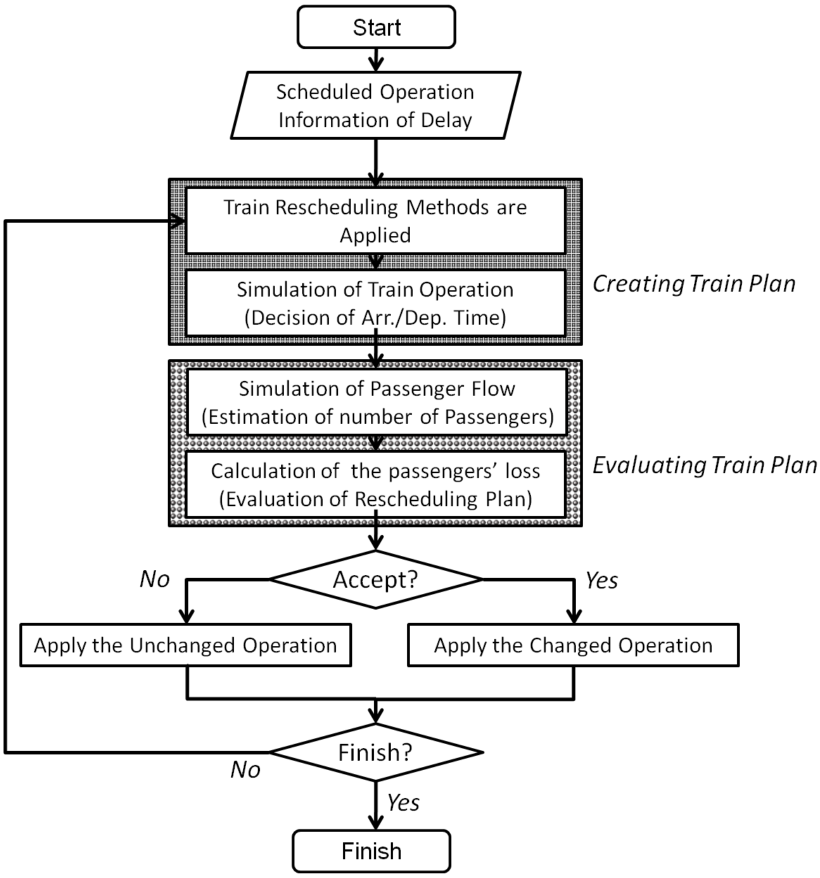


Figure 1 – Composition of train rescheduling system

2.2 Creation of train operation plan

In the creating part, the system applies a method of train rescheduling; simulate train operation to fix arrival and departure time of each train to satisfy many constraints of operation as shown in Table 1. The method to simulate train operation is introduced as follow.

Table I – Example of constraints of train operation

Regular arrival or departure time	The arrival or departure time of each train in each station is provided beforehand. This schedule is a regular schedule. A train must not run earlier than a regular schedule.
Regular running time	To run between stations, a train requires longer time than regularly defined by the type of rolling stock, number of cars, stop or pass of stations, and so on.
Regular stopping time	A train stops at the station longer than the defined time. If the train does not stop at the station, the weight of the link equals to 0.
Conflicting routes at a station	A certain interval is required between trains whose routes conflict at a station or a yard. The weight of the link is time interval between departures and arrivals.

Blockages between stations	Trains more than defined number cannot run at the same time between stations.

2.2 Simulation of train operation

We use graph theory to represent train operation. Nodes represent departure and arrival of trains at each station. Links represent running and stopping of trains and constraints. Figure 2 shows an example of the graph.

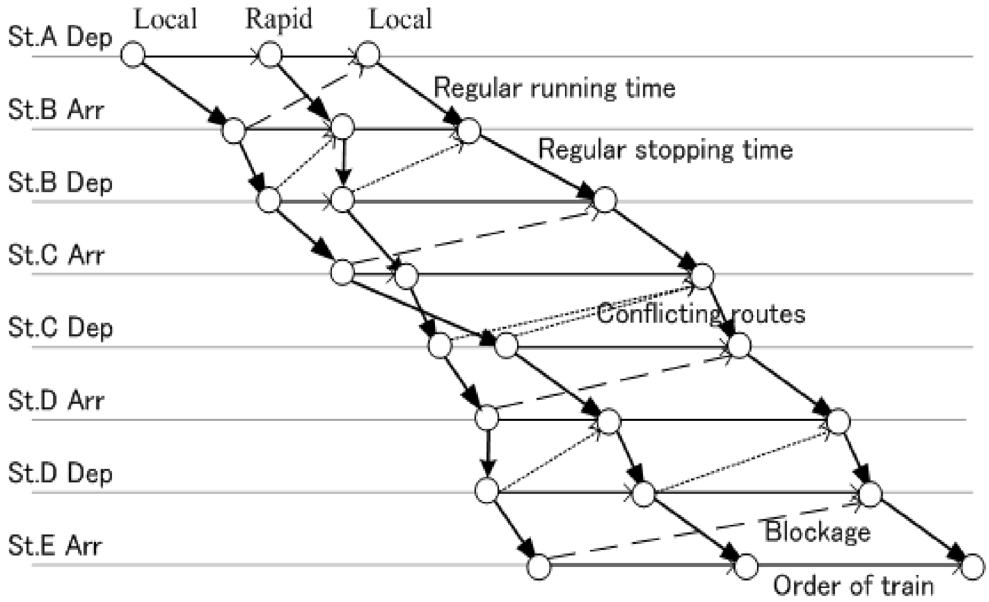


Figure 2 – An example of a graph representing train operation

By finding the longest path to each node from the node expressing time origin, itis possible to obtain departure or arrival time of each train at each station as the length of the path. We use PERT(Program Evaluation and Review Technique) to search the longest path. It is necessary to change the information on nodes or links appropriately to express the application of train rescheduling techniques.

2.3 Evaluation of the goodness of train operation plans

In evaluating part, estimation of passengers' behaviors and calculation passengers' discomfort are carried out. The part of evaluating train operation plan in the system receive the arrival/departure time of each train at each station from the part of creating train operation plan, and simulate passengers' act to decide the numbers of passengers between neighboring stations. We use also graph theory to estimate passengers' behavior as shown Figure 3. Nodes represent departure and arrival of trains on each station. Links represent behavior of passengers (e.g. transfer, boarding). And the paths that weight of links is shorter is calculated, we assume that passengers selects the paths based on disaggregate behavioral model[2].

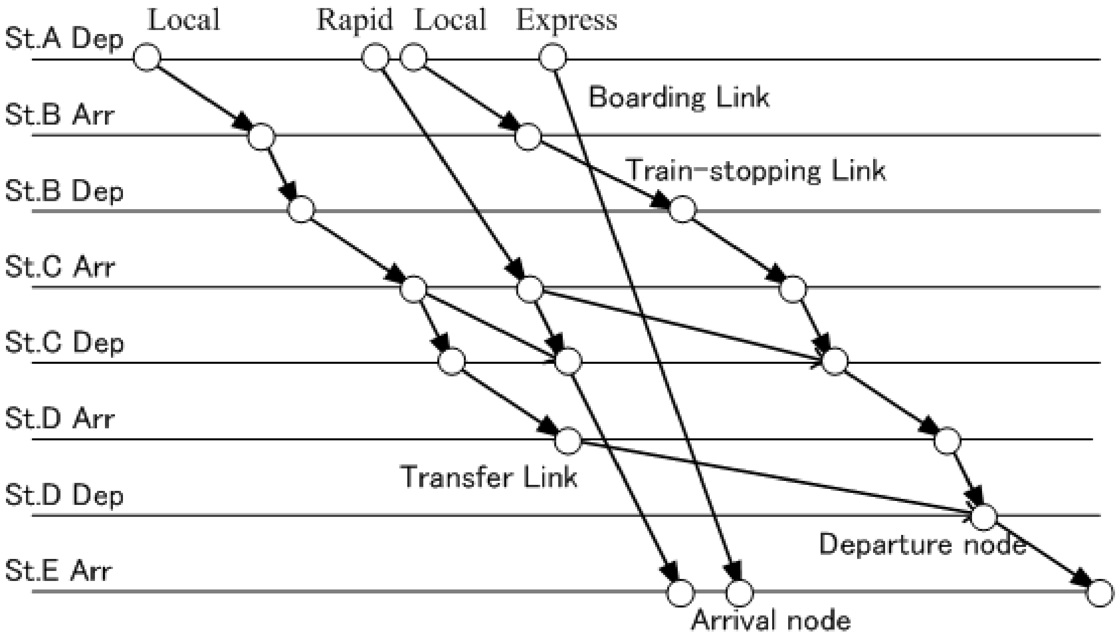


Figure 3 - An example of a graph representing passenger flow

After passenger flow analysis, the rescheduling plan is evaluated. There are many methods to evaluate train schedule, although the authors use the evaluated value based on passengers' point of view. The evaluated value is defined criterion for passengers' loss considering the following three evaluation indices; traveling time, burden of transfer, and congestion. These values are calculated with the result of passenger flow analysis.

2.3.1 Travelling time

Traveling time is the amount of time required from departure station to destination. Traveling time is defined as follows:

$$L_1 = \sum_{i=1}^{N} t_i \tag{1}$$

where *N* is the number of passengers, *ti* is the traveling time of passenger *i*.

2.3.2 Transfer

Burden of transfer varies according to construction of each station. For example, the transfer with stairs has a high cost. These burdens are calculated as passengers' loss in addition to the real time for transfer.

$$L_2 = \sum_{i=1}^{N} \sum_{j=1}^{M_i} r_{ij} \tag{2}$$

where r_{ij} is time equivalent to the burden of passenger i's j-th transfer and Mi is the number of transfers passenger i needs.

2.3.3 Congestion

Congestion is also considered as passengers' loss because passengers in congested train feel discomfort. This evaluation uses nonlinear function to convert passengers' discomfort, as shown in Figure 4[2]. Congestion loss is defined as follows:

$$L_3 = \sum_{k=1}^{n-1} \sum_{s=1}^{S_k} f_c\left(\frac{q_{ks}}{c_{ks}}\right) q_{ks} t_{ks} \tag{3}$$

where n is the number of stations, S_k is the number of trains which arrive at station k. q_{ks}, t_{ks}, and c_{ks} are the number of passenger in the train, the time required, and the capacity of the train between k-th and (k+1)-th stations respectively. f_c is the nonlinear function[3].

The total passengers' loss is the sum of above three types of loss.

$$L = L_1 + L_2 + L_3 \tag{4}$$

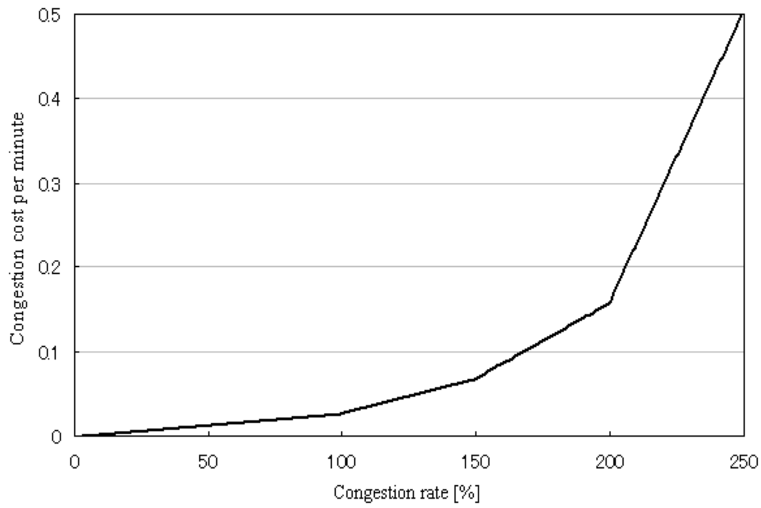


Figure 4 - Relationship between congestion rate and equivalent congestion cost per minute

3 TENTATIVE OPERATION PLAN

3.1 Insert of tentative operation plan

Train rescheduling have many actions on timeline. Upper part of Figure 5 shows main action of train rescheduling. We must consider every action, but in this paper these actions are divided into three parts, before accident, between accident and start of rescheduling plan and after rescheduling. The part that is between accident and start of rescheduling plan is defined as “tentative plan” and we describe the method to make the tentative plan as follow.

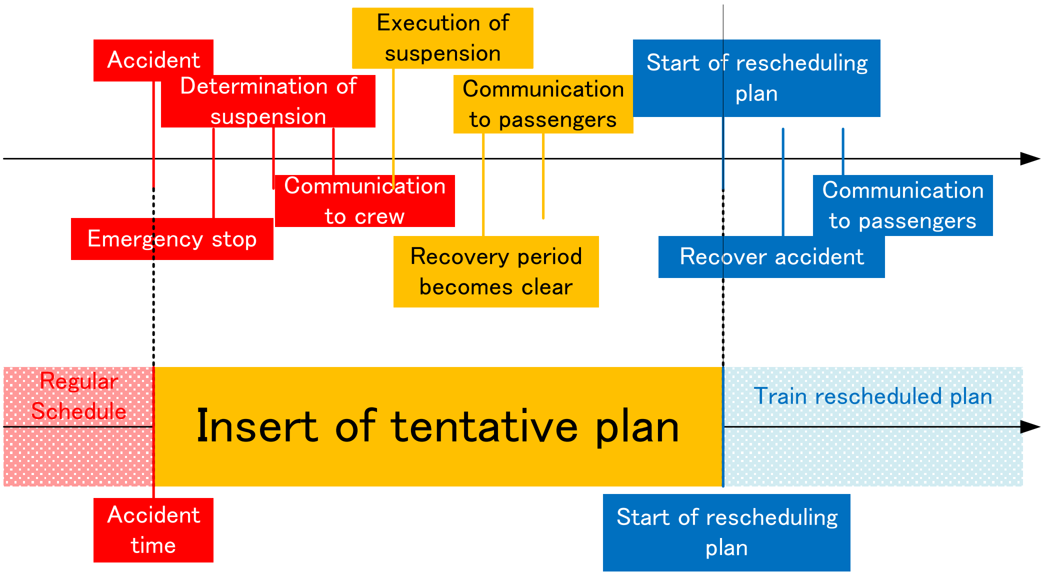


Figure 5 - Various events after an accident and insert of a tentative plan

3.2

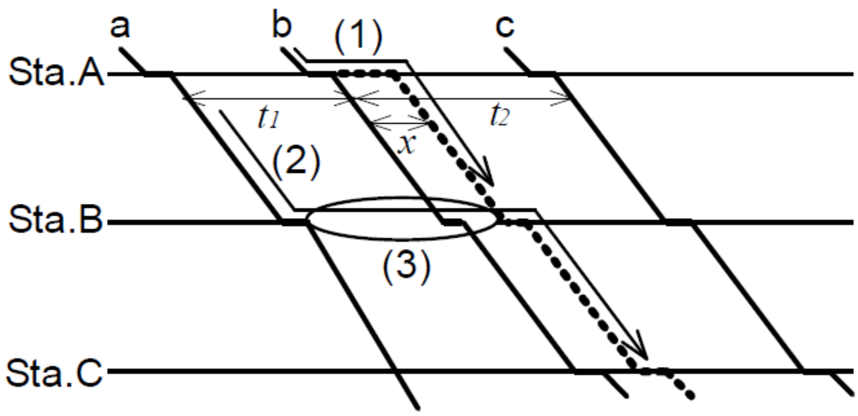


Figure 6: Change of passengers’ discomfort

(1) Passengers who get on the train and pass the station A

The passengers' traveling time increase by increase of stopping time at station A. Assuming that increase of stopping time is done for *x* seconds, loss time is increased as follows.

$$T_1 = \begin{cases} P_k(x-\tau_{sk}) & (x-\tau_{sk}>0) \\ 0 & (x-\tau_{sk}\leq 0) \end{cases} \quad . \tag{5}$$

where P_k is number of passengers going to station *k*, τ_{ik} is margin time from station A to *k*.

(2) Passengers who transfer to the train on the way

Loss time is increased as follows in this type of passengers.

$$T_2 = \begin{cases} Q_{nk}(x-\tau_{sk}) & (x-\tau_{sk}>0) \\ 0 & (x-\tau_{sk}\leq 0) \end{cases} \tag{6}$$

where Q_{jk} is number of passengers going from station *j* to *k*, τ_{jk} is margin time from station *j* to *k*.

(3) Passengers who enter from the station, where the dwelling time has been increased, and from its following stations, and who aim to go to further stations

The authors use a model that each passenger appears at his/her starting station uniformly. The loss time changed by increase of stopping time is, therefore, shown in formula 7.

$$\begin{aligned} T_3 &= (S_3+S_4)-(S_1+S_2) \\ &= (\frac{1}{2}p_{jk}t_{1j}^2+\frac{1}{2}p_{jk}t_{2j}^2)-\left[\frac{1}{2}p_{jk}\left\{t_{1j}+(x-\tau_{sj})\right\}^2+\frac{1}{2}p_{jk}\left\{t_{2j}-(x-\tau_{sj})\right\}^2\right] \\ &= p_{jk}\left\{(x-\tau_{sj})^2-(t_{2j}-t_{1j})(x-\tau_{sj})\right\} \end{aligned} \tag{7}$$

where p_{jk} is number of passengers going from station *j* to *k* per second. There are passengers whose boarding train is changed from *c* to *b* by the increase of stopping time. Their loss time difference is calculated in formula 8.

$$T_4 = \begin{cases} p_{jk}(x-\tau_{sk})(t_{\alpha jk}-\tau_{jk})-t_{\beta jk} & (x-\tau_{sk}>0) \\ 0 & (x-\tau_{sk}\leq 0) \end{cases} \tag{8}$$

The summation of passengers' loss changed by the increase of stopping time is calculated in formula 9.

$$\Delta T(x) = \sum_{k=s+1}^{N} T_1 + \sum_{j=1}^{N-1}\sum_{k=j+1}^{N} T_2 + \sum_{j=1}^{N-1}\sum_{k=j+1}^{N} T_3 + \sum_{j=1}^{N-1}\sum_{k=j+1}^{N} T_4 \tag{9}$$

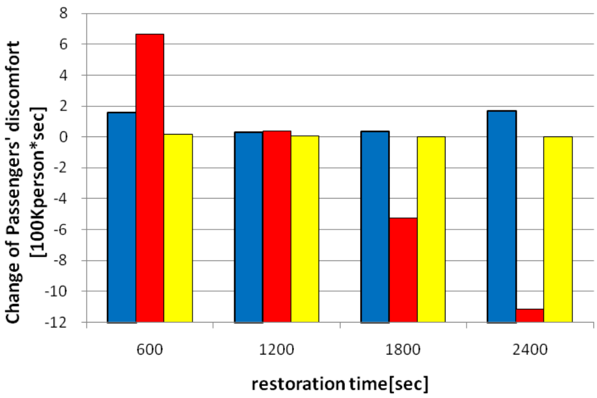
3.3.2 Change of passengers' discomfort on every tentative pattern

In each tentative pattern, we search the trains that increase their stop time in every station, and we calculate change of passengers' discomfort based on formula 9. The pattern with the least change of passengers' discomfort is determined as the tentative operation plan.

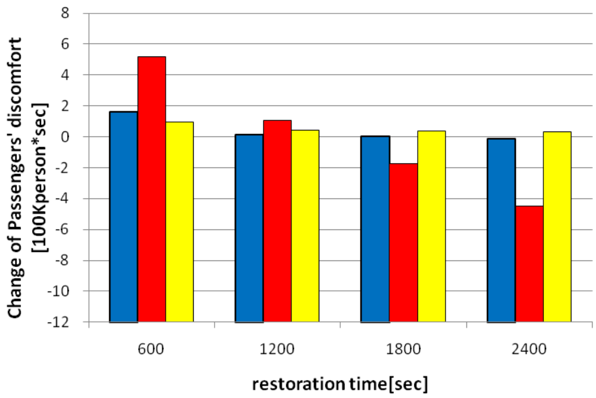
3.3.3 Simulation of tentative operation patterns

The tentative plan is applied in the model-line. Model-line contains 24 stations and quadruple tracks, and 2 local trains, 1 rapid train, 1 express train per an hour. 16 kinds of accident conditions, 4 places and 4 restoration times, are set in this simulation. Figure 7 shows change of passengers' discomforts in 3.3.2 on each tentative plan. And Figure 8 shows the evaluation values in three hours when each tentative plan is actually applied and train rescheduling is executed.

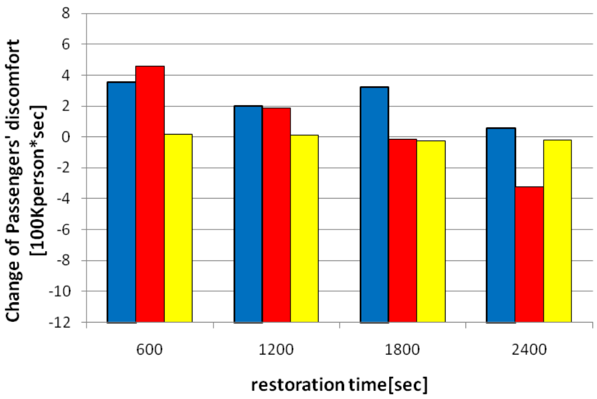
(c)



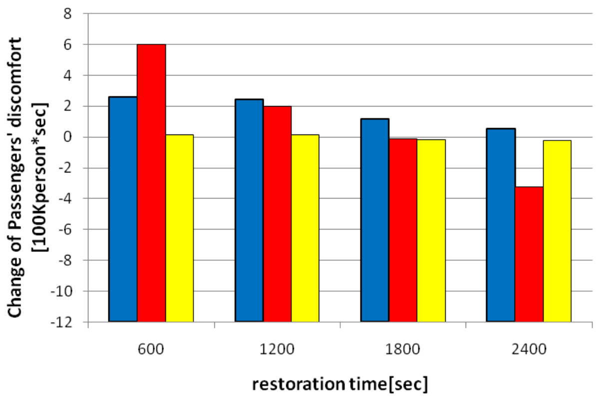
(a) Location A



(d) Location B

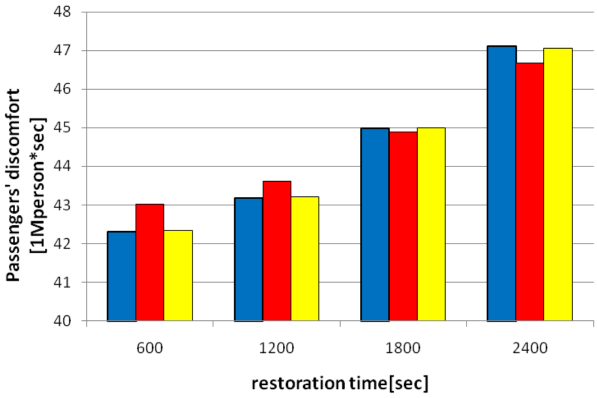


(b) Location C

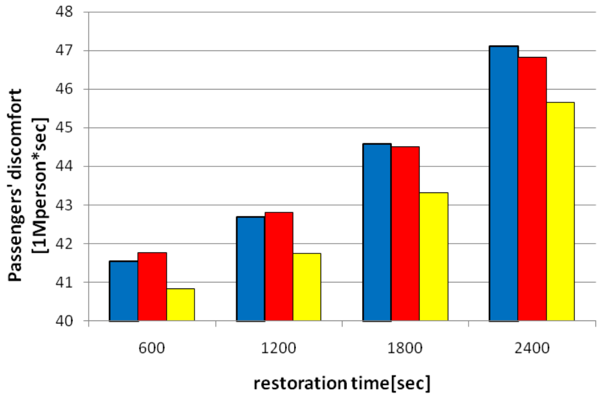


(d) Location D

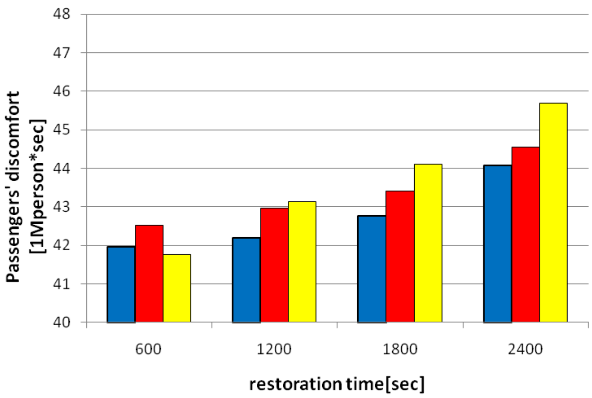
Figure 7: Changes of passengers' discomforts on a model-line



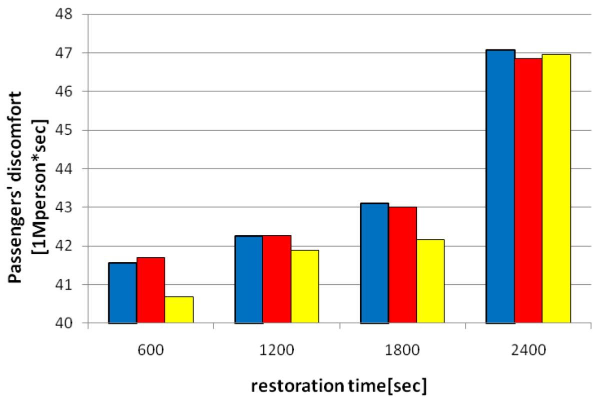
(a) Location A



(b) Location B



(c) Location C



(d) Location D

Figure 8: The evaluated criteria when each tentative plan is actually applied in the model-line

In most patterns, the magnitude relations in Figure 7 are corresponding to those in Figure 8.This shows that the method to select tentative pattern can estimate the best tentative pattern before the methods of train rescheduling are applied.

4 CONCLUSIONS

We have proposed to insert the tentative diagram between accident time and start of executing a carefully proposed rescheduling plan. Case studies using an example of commercial urban line and information of real passengers' flow show that the proposed method to select and apply a plan from preliminary prepared tentative operation plans is effective and useful in practice.

In this simulation, the authors considered only one direction. The influence for another directional train is not included in the evaluation. So it is necessary to improve making the rescheduling plan.

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