Train Rescheduling Algorithm Which Minimizes Passengers' Dissatisfaction

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Abstract. Although computer systems which assist human experts in rescheduling disrupted train traffic is being practically used recently, they are not so helpful in decreasing the workload of human experts. This is because they are lacking in intelligence such as to automatically make rescheduling plans. In this paper, we propose an algorithm for automatic train rescheduling. Firstly, we propose to use passengers' dissatisfaction as a criterion of rescheduling plans and to regard the train rescheduling problem as a constraint optimization problem in which dissatisfaction of passengers should be minimized. Then we introduce an algorithm for train rescheduling designed as a combination of PERT and meta-heuristics. We also show some experimental results of the algorithm using actual train schedule data.

1 Introduction

In Japan, railways play the most significant role both in urban and intercity transportation. In fact, trains are operated every couple of minutes in many cities carrying a massive amount of commuters and even in Shinkansen high speed railway lines where trains run at the maximum speed of 300km/h, hundreds of trains a day are operated every three to four minutes [1]. Thus, it is strongly desired for railways to provide those people with a stable and reliable transportation.

Although Japanese railways are known to be the most punctual in the world, sometimes train traffic is disrupted when accidents, natural disasters, engine troubles happen. In order to restore the disrupted traffic, a series of modification of the current train schedule is done. This task is called "train rescheduling [2, 3]."

Recently, computer systems which help human experts in charge of train rescheduling (they are called train dispatchers) began to be put in a practical use. These systems, however, are lacking in a function to automatically make rescheduling plans.

Hence, train rescheduling is totally left to train dispatchers, and this is a heavy burden for them.

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In order to break through such a situation, it is required for train rescheduling systems to be equipped with an advanced function of automatic rescheduling.

To make train rescheduling plans, however, is an extremely difficult task [4]. Details will be described later in Chapter 2 but to name a few; objective criteria of rescheduling plans are diverse depending on the situations; it is a large size and complicated combinatorial problem in which hundreds or sometimes thousands of trains are involved; an urgent problem solving is required etc.

In this paper, we propose to treat the train rescheduling problem as a constraint optimization problem and introduce an algorithm which quickly produces a rescheduling plan. To this aim, we have to settle the following two issues.

1. To establish objective criteria of rescheduling plans.
2. To develop an algorithm which quickly produces a near optimal rescheduling plan.

To settle the first issue, we propose to use passengers' dissatisfaction as objective criteria of rescheduling plans. For the second issue, we introduce an algorithm combining PERT (Program Evaluation and Review Technique) and simulated annealing. This algorithm quickly produces a rescheduling plan in which passengers' dissatisfaction is minimized.

We analyze situations where passengers would complain and accumulate them in a file called a Claim File. Situations when passengers complain would be different depending on the characteristics of lines, times when accidents happened, severity of accidents etc. Thus, we prepare different Claim Files reflecting those characteristics and select an appropriate one before rescheduling plans are made. As mentioned earlier, criteria of rescheduling should be decided case-by-case basis, and we try to concur this problem by providing Claim Files appropriate for the situation.

This idea makes it possible to develop an intelligent algorithm which automatically produces a rescheduling plan, which was not realized in conventional works.

The overall structure of the algorithm is based on a combination of simulated annealing (SA) and PERT. One of the key idea of this algorithm is that SA does not explicitly deal with the departure/arrival times of trains and they only decide the outline of the schedule such as cancellation of trains, departing orders of trains etc., and the PERT technique calculates the arrival and departure times of trains so that there occur no conflict among them. This idea makes it possible to enormously reduce the search space of SA and get an algorithm which works quite fast.

In our algorithm, train schedules are expressed by Train Scheduling Networks, which is a kind of PERT networks. Then we propose an efficient rescheduling algorithm using a property that passengers' complaint relating with delays of trains could be eliminated by modification of the Train Scheduling Network focusing only on the critical paths in it.

We have implemented the algorithm on a PC and evaluated its effectiveness through several experiments using actual train schedule data. Then we have confirmed that our algorithm works good enough to produce rescheduling plans which are practically usable.

2 Train Rescheduling Systems: State of the Art

2.1 Why Train Rescheduling Is Difficult?

Methods of schedule modification employed in train rescheduling are shown in Table 1. We have to note that a combination of these methods are taken, not only one of them is used.

Train rescheduling is quite a difficult work. Major reasons of this are as follows:

(1) It is difficult to decide an objective criterion of rescheduling which is uniformly applicable. Criteria for rescheduling differ depending on various factors such as severity of accidents, time when the accident occurred, characteristics of the line such as whether it is a commuter line or an intercity railway line etc. To give an example, although delays of trains are usually considered to be undesirable, regaining the schedule is not so significant in railway lines where trains run with short intervals and it is considered to be more important to prevent the intervals from becoming too large. The criteria should be even different depending on the time accidents have happened. During the rush hours in the morning, to keep the constant intervals between trains is considered to be more important than to reduce delays, whereas in the afternoon, it is most important to regain the schedule before evening rush hours and sometimes a considerable number of trains are cancelled.

Table 1. Methods of rescheduling

Method	Contents of modification
Cancellation	To cancel operation of trains
Partly cancellation	To cancel a part of operating area of trains
Extra train	To operate an extra train which are not contained in the original schedule
Extension of train	To extend the operating section of a train
Change of train-set operation schedule	To change the operation schedule of a train-set
Change of track	To change the track of a train in a station
Change of departing order	To change the departing orders of trains (often, change the station where a rapid train passes a local train)
Change of meeting order	To change the meeting orders of trains (either in single track line or at a station where two lines come together)
Change of stop/pass	To make a train stop at a station which it was originally scheduled to pass
Change of train types	To change the type of a train (to change a rapid train to a local train, etc.)

(2) Train rescheduling is a large size combinatorial problem. In urban areas, the number of trains involved often reaches hundreds or even thousands. Moreover, in Japan, train schedules are prescribed by a unit of fifteen seconds (in urban lines, the time unit is five seconds). In making train rescheduling plans, we have to

determine departure/arrival times and tracks for each train, whether to cancel trains or not etc. This is quite a complicated and large size problem difficult to deal with. As a matter of fact, when trains are delayed about one hour, the number of required schedule modification sometimes reaches several hundreds.

(3) A high immediacy is required. Since train rescheduling plans are made in order to modify the schedule of trains which are running at that time, they have to be made quickly enough.

(4) All the necessary information cannot be always obtained. Some of the information necessary to make better rescheduling plans are; how crowded trains are/will be, how many passengers are/will be waiting for trains at stations, how many passengers will emerge at stations and so on. Under current technology, however, it is quite difficult or almost impossible to get or estimate such information.

To sum up, the train rescheduling problem is a so called ill-structured problem which is large size, complicated and whose criteria are full of ambiguity.

2.2 Problems of Current Train Rescheduling Systems

Since train rescheduling is such a difficult job, assistance by computer systems have been longed for, and nowadays train rescheduling systems are being practically used. Although they have a function to predict future train schedules, the problem is that they are very poor in automatic rescheduling. They only have a function to suggest changes of departing orders of trains and do not have a function to use other rescheduling methods of Table 1. So, to make rescheduling plans is totally left to train dispatchers.

The reason why current train rescheduling systems are lacking in intelligence is due to the reasons mentioned in 2.1. That is, objective criteria of train rescheduling are diverse and it is impossible to cope with it by a single criterion, thus a framework in which computers bear a routine work and human experts take charge of decision making is employed.

But train rescheduling systems developed under this framework is not useful to decrease the workload of dispatchers.

(1) It is often a time consuming work to input a large number of schedule modifications by hand. Sometimes, their inputs are too late to change the schedule.
(2) Current rescheduling systems adopt an algorithm to iterate a local change of schedules, hence they are lacking in a viewpoint to get a globally optimal solution.

3 Evaluation of Train Rescheduling by Passengers' Dissatisfaction

3.1 Previous Research on Evaluation of Train Rescheduling

In order to regard the train rescheduling problem as a combinatorial optimization problem, we first have to clarify objective criteria of the problem.

Until now, following ideas are proposed as the criteria [5-8].

(1) Delay time of trains should be minimized.
(2) Number of cancelled trains should be minimized.

(3) Time required until the train traffic is normalized should be minimized.
(4) Passengers' disutility should be minimized.
(5) Gaps of the service level between one which passengers expect and one passengers actually receive should be minimized.

None of these criteria, however, are satisfactory, because situations when train rescheduling is conducted are diverse. For example, an idea to use delay times of trains is not appropriate when a number of trains are cancelled. The more trains are cancelled, the less the delay would be, but passengers suffer from inconvenience, because trains are crowded and frequency of trains decreases. The idea to use the number of cancelled trains as a criterion has an opposite problem. Although it is true that cancellation of trains sometimes inconvenience passengers, this is the most effective method to restore disrupted schedule. Thus, it is often desirable to cancel appropriate number of trains and to normalize schedules especially when an accident happened before evening rush hours. Passengers' disutility and gaps of service level seem to be promising as the criteria from passengers' viewpoint but they are quite difficult to measure with existing technology.

3.2 Evaluation of Train Rescheduling Based on Passengers' Dissatisfaction

In this paper, we propose to use "passengers' dissatisfaction" as an objective criterion for train rescheduling. The background of this idea is as follows:

(1) Situations when train rescheduling is done are quite diverse and it is not a good idea to use a single criterion such as the total delays of trains, number of cancelled trains etc.
(2) Criteria for train rescheduling have to be set up from passengers' viewpoint, because in a situation where train schedules are disrupted, passengers' viewpoint is far more important than that of railway companies.
(3) At the present time, it is unrealistic to use the disutility of passengers because to estimate how much passengers will be inconvenienced is extremely difficult.

Table 2. Passengers' dissatisfaction

Dissatisfaction	Contents
Delay	A delay of an arrival of a train exceeds a certain threshold. A delay of a departure of a train exceeds a certain threshold.
Stoppage times	An increment of a stoppage time of a train exceeds a certain threshold.
Running times	An increment of a running time of a train exceeds a certain threshold (often occurs when a train is kept waiting before it arrives at a station because its scheduled track is occupied by some other train).
Frequency	An interval between trains exceeds a certain threshold.
Connection	Connection of trains usually kept is lost.

We first scrutinize in what cases passengers would complain considering conditions such as severity of accidents, characteristics of railway lines etc. Then these cases are accumulated in a file called the Claim File. Before our rescheduling algorithm starts, it chooses the most suitable Claim File.

Types of passengers' dissatisfaction we consider in this paper are shown in Table 2.

A weight is put to each dissatisfaction taking its content such as amount of delays etc. into account. We calculate an evaluation measure for a given rescheduling plan as a weighted sum of each dissatisfaction contained in the plan. We call this evaluation measure “dissatisfaction index.”

From an alternative view, passengers’ dissatisfactions defined above can be regarded as “constraints” to be satisfied. In this sense, we can say that we treat the train rescheduling problem as a sort of constraint optimization problem to find a schedule which observes the constraints defined in the Claim File as much as possible.

4 Train Rescheduling Algorithm Which Minimizes Passengers’ Dissatisfaction

4.1 Overall Structure

Recently, for combinatorial optimization problems, a category of algorithms called meta-heuristics are attracting attention. There are many applications of meta-heuristics for scheduling problems which seem to have something common with the train rescheduling problems.

Table 3. Types of arcs in Train Scheduling Networks

Type	Meaning	Weight
Train	Operation of trains	Running time
Stoppage	Time necessary for passengers to get on and off at a station	Stoppage time
Train-set	Time needed to turn over	Turn over time
Track	Conflict of tracks	Minimum interval between trains
Departure	Departing orders of trains	Minimum interval between trains
Arrival	Arriving orders of trains	Minimum interval between trains
Number of trains	Maximum number of trains allowed to exist between stations	Minimum interval between trains
Crossover	Conflict of routes in a station	Minimum interval between trains
Schedule	Scheduled time of each train	Scheduled time

Table 4. Schedule modification methods reflecting arc types

Arc Type	Method of schedule modification
Departure	Exchange departing orders of trains which correspond to the both end nodes of the arc.
Arrival	Exchange arriving orders of trains which correspond to the both end nodes of the arc.
Track	Change a track of the train which corresponds to either end of the arc.
Train-set	Change the schedule of the train-set which corresponds to the arc.
	Cancel the train which corresponds to the arc.

Since a fast algorithm is required for the train rescheduling problems, we decided to apply the simulated annealing, which is one of the meta-heuristic algorithms.

The overall structure of the algorithm is shown in Fig. 1 and details will be introduced in the following sections.

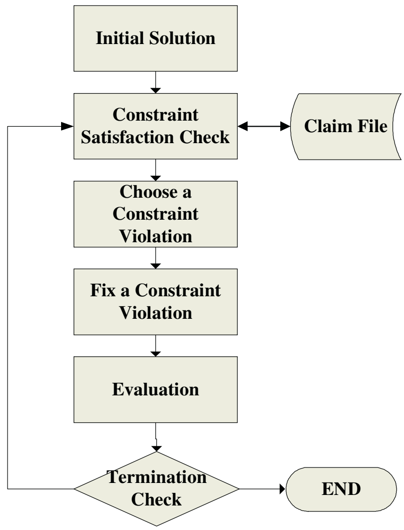

Fig. 1. Structure of Algorithm

4.2 Train Scheduling Network

We first introduce a network called a Train Scheduling Network (TSN) which is a kind of the PERT network. TSN is constructed as follows [9, 10]:

Node : a node is constructed corresponding either to an arrival of a train at a station or a departure of a train from a station. We also prepare a start node, which is used to express scheduled times of trains.

Arc : Chronological constraints between two nodes are expressed by an arc with a weight. The weight is the minimum time required for the two events of the both ends of the arc occur consecutively. Details are depicted in Table 3.

4.3 Details of the Algorithm

(1) Initial solution
The train schedule left as it is (namely, without giving any modification) is set as the initial solution. Let $S :=$ initial solution.

(2) Constraints satisfaction check
Check the schedule S whether the constraints defined in the Claim File are satisfied and if not, pick out all the portions in S which violate the constraints.

(3) Choose a constraint violation to be fixed.
Choose randomly a portion of S which violates a constraint.

(4) Try to fix a constraint violation and generate a new schedule.
- Identify critical paths to the node which violates constraints in the Train Scheduling Network constructed from *S*.
- Collect train-set, track, departure and arrival arcs in the critical paths.
- Apply modification of the train schedule as described in Table 4.
- Let *S*' := newly generated schedule.

(5) Evaluation of the newly generated schedule
Calculate the dissatisfaction index of *S*' (we denote this $|S'|$) as $\sum w_i f(i)$, where $f(i)$ is the number of violated constraint of type i and w_i is its weight.

(6) Decide whether to accept the newly generated schedule.
If $|S'| < |S|$ then let $S := S'$. Otherwise, let $S := S'$ with a probability $exp(-\Delta/t)$, where $\Delta = |S'| - |S|$ and t is the *temperature* decided based on the idea of the simulated annealing [11].

(7) Termination
If no improvement is observed during a prescribed iteration steps, the algorithm terminates and outputs the best schedule ever found. Otherwise, go to Step (2).

4.4 An Example of the Execution Process of the Algorithm

We show an example to show how the algorithm works using Fig. 2-5. Fig. 2 is a train schedule in which the departure of Train 3 from Station A is delayed (Train 3') for some reason and the departure of Train 1 from Station B is also delayed because it is scheduled to wait for Train 3 there. We set this schedule as the initial solution of our algorithm (Please note that Fig. 2, 4, 5 are drawn in the so called *train diagram* style, where the horizontal axis is the time axis and movements of trains between stations are depicted by diagonal lines).

Fig. 3 is the Train Scheduling Network created from the schedule of Fig. 2. The description inside each node means "Train-Station-departure/arrival." To avoid the figure becomes too complicated, weights of arcs are not shown.

Let us assume that the delay of the arrival of Train 1 at Station C is chosen as a constraint violation to be fixed. Critical paths from the node "Train1-StationC-arival" are looked for. In this case, the critical path is "1-C-*a* -> Track arc -> 4-C-d -> Train-set arc -> 3-C-*a* -> Train arc -> 3-B-*d* -> Stopage arc -> 3-B-*a* -> Train arc -> 3-A-*d*."

All the Track arcs and the Train-set arcs in the critical path are collected and one of them is chosen at random. Let us assume that the Track arc is chosen. Following the procedure in Table 4, either the track of Train 3-4 or that of Train 1-2 at Station C is to be changed. Let us assume that the track of Train 3-4 is changed to Track 2 (see Fig. 4). Iterating the similar process, the departing order of Trains 1 and 3 at Station B is changed and we get the schedule of Fig. 5.

5 Results of Experiments and Evaluation of the Algorithm

We have implemented our algorithm on a PC and evaluated its effectiveness.

(1) Data used in experiments

We selected a line in Tokyo urban area, which is about 40 km long and has 19 stations. We used a schedule of a whole day of this line which contains 564 trains. Time unit in making the timetable is fifteen seconds.

(2) Claim File

We created a Claim File considering delays at major stations, loss of connections, decrease of frequency of trains etc, which contains 265 records.

(3) Experiments

We have conducted experiments assuming two types of accidents: the first is a case in which a departure of one train is delayed due to an engine trouble and the second is a case in which a train is disturbed between stations due to an accident at a level crossing. We have conducted experiments ten times for each case.

(4) Results

We have confirmed that our algorithm produces a rescheduled plan which is practically usable in each trial. Since the space is limited, we only show the results of the first case. Fig. 6 is a schedule without rescheduling. Fig. 7 is an output of our algorithm (train schedules of two hours are shown). Observing Fig. 7, we can know that it was made by canceling an appropriate number of trains, changing tracks and departing orders of trains etc. The total number of modifications was thirty. Dissatisfaction index (DI) of the schedule in Fig. 6 is 942 and is reduced to 153 in Fig. 7.

Time needed for execution was approximately one minutes using a PC (Pentium 3.06 GB).

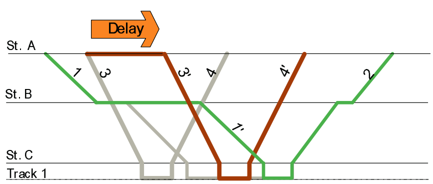

Fig. 2. Delayed schedule

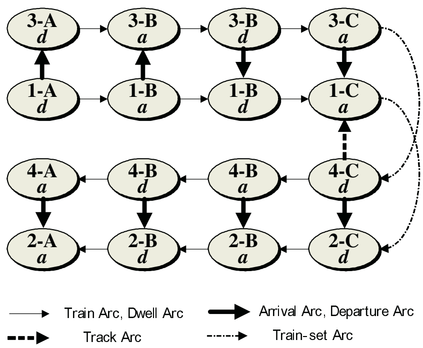

Fig. 3. Train Scheduling Network

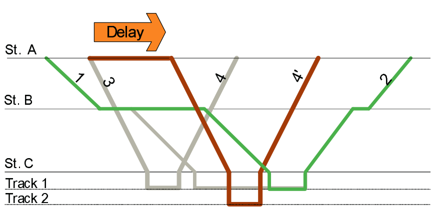

Fig. 4. Change of track

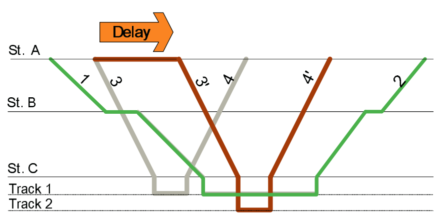

Fig. 5. Change of departing order

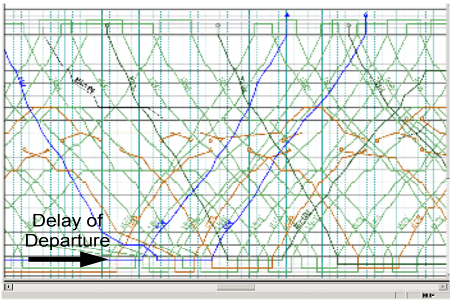

Fig. 6. Without rescheduling. DI=942

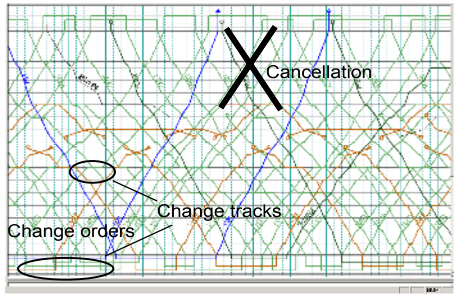

Fig. 7. Result of rescheduling. DI=153

6 Conclusions

We have proposed an idea to use passengers' dissatisfaction as the objective criteria of train rescheduling problems and introduced an efficient algorithm combining PERT and simulated annealing. This algorithm has a function to automatically make rescheduling plans for disrupted train traffic. Some of the characteristics of this algorithm are; it works quite fast and it supports versatile methods of rescheduling including cancellation, change of train-set operation schedule, change of tracks etc.

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