Train Operation Method Immediately After a Long Time Interruption
–Passenger Loss Time Minimization with Consideration of Passenger Flow Uniformity

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Abstract – It is an important factor for railway services to take proper train rescheduling under disrupted conditions. This paper discusses the rescheduling problem in the case of resumption of train operation, in which the train operation has been suspended by an accident for a long time. The authors propose a novel rescheduling method with consideration of passenger flow control. The proposed rescheduling problem has been formulated as a nonlinear optimization problem, and it has been solved by the simulated annealing method. Finally, the proposed methods are applied to a typical commuter line, and the efficiency of these methods has been verified through simulations.

Key Words – Rescheduling, passenger flow, simulated annealing method, intelligent passenger assistance system.

I. INTRODUCTION

Trains run based on the timetable that was constructed in advance from a comprehensive view of traffic demand. It is a precondition for passengers when they use the railway system that all trains are running as usual. However, in case of disruptions caused by a breakdown, bad weather and an accident resulting in injury or death, etc., it lowers the quality of train service rapidly. Therefore, it is an important task for passengers’ side as well as the operator to take proper rescheduling under disrupted conditions. Some studies have been conducted on the rescheduling problem for a single line in the past two decades. The main aim of these studies is to try to restore the usual timetable in a short time, and several practical systems have been developed.

In this paper, the authors will discuss the rescheduling problem from the viewpoint of reducing passengers’ loss time and passenger flow uniformity, in which the train operation has been suspended by an accident for a long time. And the efficiency of our proposal method that it can contribute to reduction of passengers’ loss time and passenger flow uniformity will be verified through several simulation results.

II. A PROPOSAL OF RESCHEDULING METHOD

A. Outline of This Research

Outline of this research is shown in Fig.1. Here, it must note that it should avoid such a situation that passengers are shut in the stopping trains when an accident happened. So the trains running between two stations should go forward to next station, so that all passengers in such trains get off at next station, and those trains should be rescheduled.

B. Problems of the Present Rescheduling Method

In order to decide a proper rescheduling plan with consideration of passenger demand, we must firstly catch the exact passenger demand information. Moreover, when the train operation is rescheduled in real time, it is also important how to inform the latest train schedule to passengers and the crew. As the present railway system, since system side can’t catch the exact passenger demand information, it arises that system side cannot evaluate a rescheduling plan quantitatively. Also, system side cannot provide individual real time guidance. Rescheduling plan has needed experience of experts who know the characteristics the line very well. Usually, experts combine several methods such as change of departure or arrival platforms, change of the train order, adjustment of headway, etc.

Such problems in the case of rescheduling mentioned above will be solved if IPASS, Intelligent Passenger Assistance System, proposed by our research group, can be realized in future [1]. The image figure of IPASS is shown in Fig.2. A passenger has a mobile communication terminal in his pocket or bag, and the transmitters-receivers are equipped at stations and trains. By the means of wireless communication between the terminal and a transmitter, the passengers can input their requests into their cards, and system side will give a response to them through the transmitters-receivers. Here,
brief description of three functions of IPASS is as follows.

1. Fare collection
2. Individual real time guidance
3. Acquisition of actual passengers’ information

**C. Proposal of Rescheduling Method with Consideration of Passenger Flow Uniformity**

The true purpose of train group control is not to make trains running orderly, but to carry passengers orderly. Both are close relationship in ordinary train operation, but after a big disruption, both can be different. Therefore, it is important to decide a rescheduling plan with consideration of passenger flow control.

Present train operators in Japan restart the identical operation pattern with a shorter headway after a long interruption, or slow down express trains so that they become local trains: it is a typical rescheduling strategy conventionally. Since a lot of passengers has accumulated at each station of the accident line at the resuming time, it cannot avoid that passengers concentrate in the first several trains. In other words, congestion rate of the first several trains cannot be help extremely high. Therefore, it is easy to cause confusion; it even brings about disruption again occasionally.

In order to improve the problem of the present rescheduling method, the authors proposed a novel rescheduling method. We define several trains as an objective train group as shown in Fig.3, and the main role of the objective train group is to carry the accumulated passengers at each station. Moreover, the skip stop scheduling method is applied to the objective train group. Therefore, the rescheduling problem can be resulted in definition of the operation pattern of the objective train group.

An example of the skip stop schedule as shown in Fig.3, it can be found that two or three successive trains share-serving stations in order to keep cruising speed and increase the transport capacity consequently. This scheme can realize the high frequency and high-speed train operation [4].

**III. FORMULATION FOR RESCHEDULING PLAN**

**A. Basic definition**

The first state of an objective train group can be defined by vector $d$

$$ d = (d_0, d_1, \cdots, d_{n-1})^T $$

Where $n$ is the number of stations of the accident line, $d_i$ is the number of trains, which depart from station $i$.

And the operation patterns of the objective train group can be expressed as

$$ P = \begin{bmatrix}
  p_{00} & p_{01} & \cdots & p_{0n-1} \\
  p_{10} & p_{11} & \cdots & p_{1n-1} \\
  \vdots & \vdots & \ddots & \vdots \\
  p_{m-10} & p_{m-11} & \cdots & p_{m-1n-1}
\end{bmatrix} $$

Where $m$ is the total number of trains. $p_{ij}$ is defined as the following:

$$ p_{ij} = \begin{cases}
  0 & \text{train } i \text{ doesn't stop at station } j \\
  1 & \text{train } i \text{ stops at station } j
\end{cases} $$

**B. The objective Function**

One of the most important things after a long time interruption is to minimize an extension of passengers’ travel time occurred by an accident. Therefore, we define the objective function on rescheduling problem for minimizing passengers’ total loss time. Then, the rescheduling problem can be resulted in an optimal operation pattern problem, and it is described as the following:

Determine $p$

So that $T_{loss}(P) \rightarrow \min$

Subject to

$$ p_{i0} = 1, \quad p_{0n-1} = 1 \quad (i = 0, 1, \cdots, n - 1) $$

$$ x_{ij} \leq x_{\max} $$

Equation (4) means that all trains must stop at its station of origin and terminal station. If a train's congestion is over than its maximum capacity, so that no passenger can get on it. This constraint condition is represented by equation (5). Where, $x_{ij}$ is the congestion of section $j$ of train $i$, $x_{\max}$ is the maximum permissible congestion.

**C. Evaluation Functions**

In this study, from a viewpoint of reducing passengers’ loss time with consideration of passenger flow uniformity,
we give two evaluation functions for a rescheduling plan.

Total passengers’ loss time is given by

\[ T_{\text{loss}} = \sum_{i=1}^{N} [(t_i + t_i') - t_i] \]  

(6)

Where, \( T_{\text{loss}} \) is the total loss time, \( t_i' \) is the real time needed of passenger \( i \) to finish his travel. Assuming passenger \( i \) can take a nonstop train to get to his destination, and the needed time is \( t_i \). And \( N \) is total number of passengers who use the object train group.

Next, evaluation of passenger flow uniformity, in other words, evaluation of trains’ congestion uniformity among an object train group is calculated by

\[ C = \sum_{i=0}^{n-2} \sum_{j=0}^{n-1} \frac{1}{u_i} (c_{ij} - \overline{c_i})^2 \]  

(7)

Where, \( C \) is the sum of variance of each section’s congestion, \( u_i \) is the total number of train pass the section \( i \). \( c_{ij} \) is effective congestion of train \( j \) of section \( i \).

And \( \overline{c_i} \) represents the average effective congestion of section \( i \).

In order to calculate the evaluation value of a rescheduling plan, passenger flow has to be estimated, namely, it needs to estimate the number of passengers in each train and each section. In this paper, it is assumed that passengers’ behavior for completing their trips is described as follows:

1. passengers always choose trains at originating and transfer stations which can get to their destinations in the shortest travel time,
2. passengers randomly arrive at their originating stations,
3. if there are more than two routes with the same time needed, passengers always choose one path with the least transfer times.

It is easy to estimate the number of passengers in each train and each section based on these passengers’ behavior assumptions, OD table and each passenger’s chosen path.

We have applied the Bellman’s algorithm to search the shortest path for a passenger to finish his travel in this study [3].

D. Search of the Optimal Operation Pattern

Optimizing an objective function is to find the best solution. Assuming that the total number of station of an objective train group except stations of origin and terminal stations is \( y \), the number of possible operation pattern will be \( 2^y \), that means even for a simple model, a large number of operation patterns can be chosen. It will take too much time to find the best solution by investigating all possible patterns. Therefore, a quasi-optimization method is required to solve our rescheduling problem. Simulated Annealing method is consequently applied to this problem as an attempt.

Neighborhood of an operation pattern \( p \) is defined as follows. Firstly, \( p \) can be rewritten

\[ p = (p_{0\alpha}, p_{0\alpha+1}, \ldots, p_{1\alpha}, p_{1\alpha+1}, \ldots, p_{w-1}\alpha) \]  

(8)

as a binary bit string with a length of \( m \times n \). Next, three continuous bits among equation (8) will be chosen. Then, according to a probability decided by heuristic, the order of those bits will be reversed or those bits will be mutated.

Renewing the temperature is based on the following equation (9),

\[ \text{New Temperature} = \alpha \times \text{Temperature} \]  

(9)

where, \( \alpha \) is the temperature gradient.

IV. SIMULATION

We conducted a simulation using a typical commuter line model in order to verify the effectiveness of the proposed method.

A. Commuter Line Model

Fig. 4 shows a typical commuter line’s train diagram with 15 minutes period. There are two local and one express trains in one period. Each train is composed of 10 cars. Capacity of a car is 144 persons. Running time between two successive stations is given as 2 minutes.

The demand per one minute is summarized in Table 1. It can be found that the demand from station 1-6 to station 7 is much more than between other pair of stations.

One case of rescheduling is assumed as follows. The train departed from 0 station at 11:21 stopped at station 1 by an accident at 11:24. Also, there are no substitute routes for all passengers to get to their destination. 30 minutes later after the accident happened, train operation service was restarted at 11:54.
B. Simulation Results

The simulation parameters were set as follows. The initial temperature value is 4000.0, temperature gradient $\alpha = 0.9$. If the temperature is less than 1.0, then the iteration is over. The maximal permissible congestion and the number of train of an object train group are 1.8 and 5, respectively.

Fig. 5 shows the train diagram of the best operation pattern obtained by SA. This diagram indicates the tendency that different trains carry the passengers at different stations to the terminal station 7 as a nearly direct service. For example, the train, which departs from station 1 at 11:54, plays a role for carrying the passengers at stations 1 and 6 to station 7. On the other hand, the train, which departs from station 0 at 11:54, does a role for carrying the passengers at station 0 and 3. Such a carrying form will contribute to reduce passengers' loss time and avoid that extremely high congestion of several specific trains caused by concentration of passengers to them.

Total loss time of proposed method and the present rescheduling method is plotted against the evaluation values for congestion uniformity in Fig. 7. Here, we chose all-local pattern as shown in Fig. 6, which is widely used after train operation restarted, as the present rescheduling method. Also, in order to illustrate the correlation between two evaluation values (6) and (7), evaluation values of 100 quasi optimization patterns are also plotted in Fig. 7. It can be found that, as a tendency, the total loss time decreases with an increase in evaluation value of congestion uniformity. Total loss time of the best operation pattern by proposed method is 34.5% of the all-local pattern, and the sum of variance of each section's congestion of the best pattern and all-local pattern are 0.44 and 1.07, respectively. Moreover, the average calculation time to find the best optimization solution from an initiation pattern was only 260 milliseconds.

Consequently, it may be concluded that our proposed method is very efficient. Also, it is possible to put our proposed method to a practical use.

V. CONCLUSIONS

Based on a precondition introducing a highly information system, Intelligent Passenger Assistance System (IPASS), into railway system, this paper has proposed a novel rescheduling method in the case of train operation resuming immediately after a long interruption. The evaluation function for rescheduling plans has been established. In order to find the best solution of the objective function, as an attempt, the simulated annealing was applied to solve the optimization problem. As simulation results, it was found that our proposed rescheduling method could contribute greatly to reduction of passengers’ loss time and passenger flow uniformity.

REFERENCES