

PASSENGER FLOW ANALYSIS FOR TRAIN RESCHEDULING AND ITS EVALUATION

Shunichi Tanaka*¹, Kazumasa Kumazawa*² and Takafumi Koseki*³

*¹ Department of Information and Communication Engineering, Graduate School of Information Science and Technology, The University of Tokyo, tanaka@koseki.t.u-tokyo.ac.jp

*² Department of electrical engineering, Graduate School of engineering, The University of Tokyo, kumazawa@koseki.t.u-tokyo.ac.jp

*³ Department of Information and Communication Engineering, Graduate School of Information Science and Technology, The University of Tokyo, takafumikoseki@ieee.org

ABSTRACT

Train rescheduling during disrupted service is a substantially significant task for urban railway operators. This task typically depends on the experiences and personal decisions of the professional operators. The operators use neither systematic methodologies for modifying train schedules nor quantitative criteria for measuring the quality of the rescheduled plans. Thus, operators have requested assistance in the form of a computer-aided train-rescheduling program. The authors have created a computer-aided train rescheduling system that seeks to minimize passenger inconvenience. The method of passenger flow for train rescheduling is discussed for realistic analysis.

1. INTRODUCTION

Rescheduling train operation is often needed when train operation is disordered by various malfunctions or accidents. Main tasks for it are presently taken by train dispatchers with their experience and intuitions. It is very difficult, since there are many factors to be considered such as location of trains and rolling stocks, tracks and train layout, location of drivers, passengers' demand, and so on. Corresponding to high-speed and high-density train operation, dispatchers have requested an assistance system to make rescheduling train operation plans quickly and precisely.

The authors proposed a method to rate train operation plans quantitatively from the passengers' point of view. Based on it, the authors formulate an assistance system that chooses an appropriate method to modify a train schedule[1].

In this paper, the method of passenger flow analysis that is used for evaluating the rescheduling plan is introduced. Passengers tend to behave to decrease their discomfort, but the discomfort of congestion can be evaluated only after passenger flow is determined. That is to say, they cannot always behave with their minimum costs.

Therefore the multiple routes that has comparatively low costs are considered in passenger flow analysis, so that the passengers could select their routes stochastically.

2. TRAIN RESCHEDULING SYSTEM

This computer-aided train rescheduling system makes a rescheduling plan based on the information of delay and various restrictions. The system consists of two main parts, one is creating a train plan and the other is evaluating the plan. In the part of creating a train plan, change of train diagram and determination of train arrival and departure are executed. In evaluating the plan, estimation of passengers' behavior and calculation of evaluation indices are carried out. The train rescheduling plan is made by repeating process of adoption judgment of a new modification based on the evaluation indices. And the train rescheduling plan is presented to the train dispatchers. Fig.1 shows a composition of the computer-aided train rescheduling system.

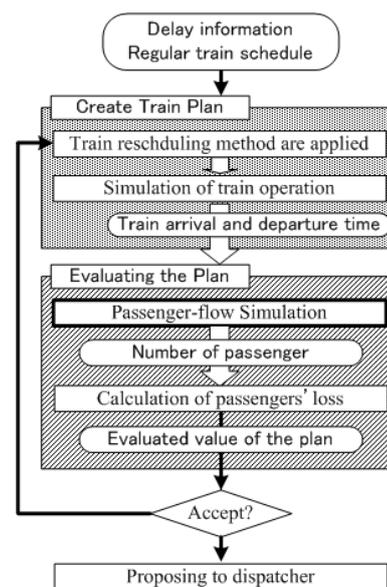


Fig.1 A composition of the computer-aided train rescheduling system

Table 1 Constraints for train operation

Constrains	Content
Regular schedule	A Train must not run earlier than regular schedule.
Regular running time	A train requires longer time defined by train type.
Regular Stopping time	A train must stop at a station for more than defined time.
Conflicting routes	A certain interval required between trains that routes conflict at a station.
Blockage	Trains more than defined number can't run at the same time between stations.

3. CREATION OF TRAIN RESCHEDULING PLAN

The part of creating train operation plan in the system receive a regular train schedule and information about delay, and try to apply train rescheduling method to meet the constraints for train operation as shown by Table 1.

For decision on arrival or departure time of each train at each station under these constraints, the authors use graph theory as shown by Fig.2, and use PERT (Program Evaluation & Review Technique) for the longest path search algorithm to find the longest path to each node from the node expressing time origin.

4. EVALUATION OF THE RESCHDULING PLAN

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. The details about passenger flow simulation are described in the next section.

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.

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

$$L_1 = \sum_{i=1}^N t_i \quad (1)$$

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

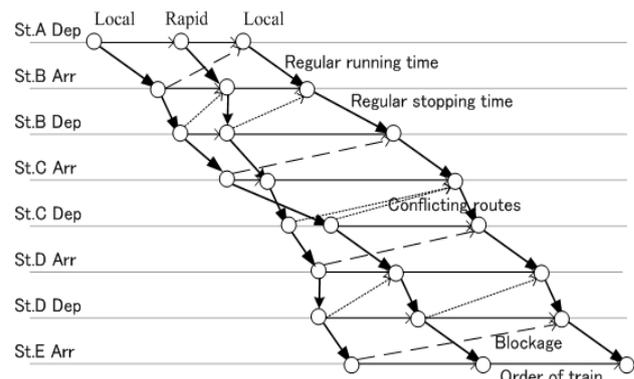


Fig.2 An example of a graph representing train operation

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.

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

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

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 Figure3[2]. Congestion loss is defined as follows:

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

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.

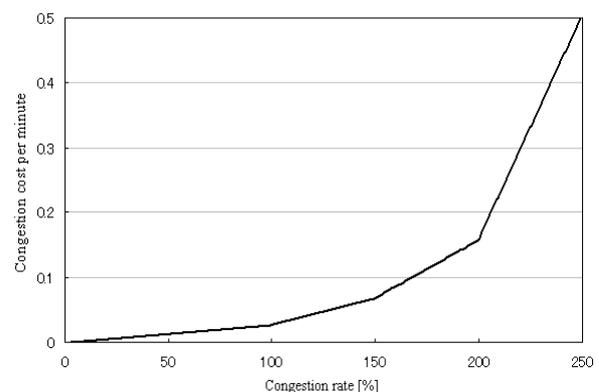


Fig.3 Relationship between congestion rate and congestion cost per minute

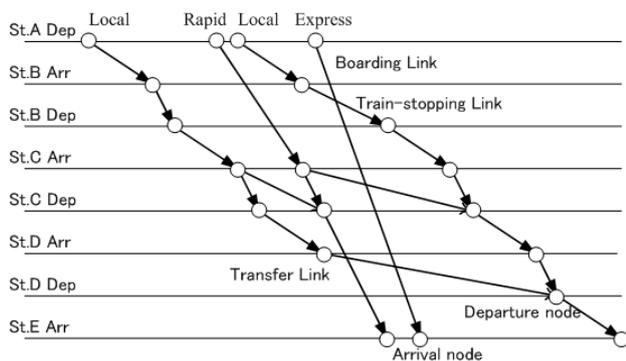


Fig.4 An example of a graph representing passenger flow

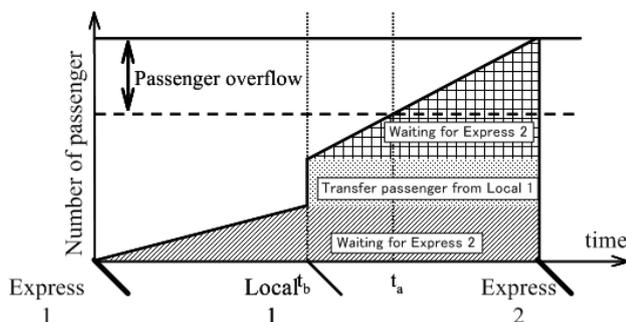


Fig.5 Model of passenger overflow

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

$$L = L_1 + L_2 + L_3 \quad (4)$$

5.PASSENGER FLOW ANALYSIS

5.1 Graph of passenger flow

Passenger flow analysis is based on graph theory. This graph consists of nodes and links. The nodes show arrival and departure of each train at each station, and the links show boarding, train stopping, and transfer. Boarding links and train-stopping links contain time, and transfer links contain total of time and discomfort as weight of links. The example of passenger flow graph is shown in Fig.4.

5.2 Conventional model

Passengers would get on train in order to assure that their discomfort become minimum. As a result, passengers' routes are described as routes from start nodes to destination nodes with minimum cost. In the preceding study[3], the shortest paths from each departure node to arrival node are calculated with Dijkstra's algorithm.

However, congestion is not considered in this passengers' discomfort. Congestion cannot be used as a barometer of passenger flow analysis because congestion is determined after decision of passenger-flow.

For this reason, passengers in the simulation tend to choose rapid trains as compared to local trains. Therefore

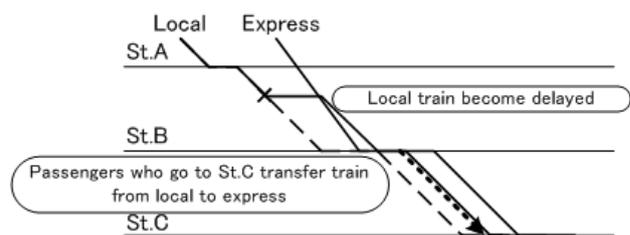


Fig.6. Change of passenger flow

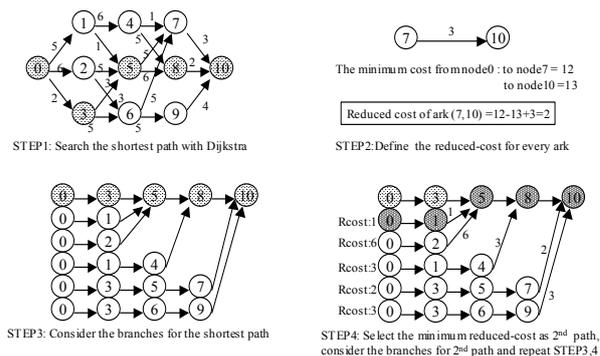


Fig.7 the flow of MPS algorithm

passengers could get on more than capacity of the train as shown in Fig.5. This caused violence of causality. The passengers' behavior was not correctly estimated and evaluation criteria could not be accurately calculated.

If each passenger overflow is independent, passengers who cannot get on the train can adjust their travel plans after the next train leaves the station. But under the circumstances that more than one passenger overflows have relationships, it is very difficult to calculate the passenger-flow accurately.

Moreover, all passengers might transfer the train even if their discomforts show a slight decline as shown in Fig.6. It is not realistic that behavior of all passenger is drastically affected by slight differences in the discomfort, and passenger overflow occurs because many passengers are concentrated in a rapid train.

6.MULTIPLE PATHS OF PASSENGER FLOW

6.1 Introduction of k -th paths algorithm

K -th shortest paths algorithm was developed for finding a path between two nodes such that the sum of weight of its constituent edges is k -th smallest. MPS algorithm[4] is one of the k -th shortest paths algorithm. The flow of this algorithm is shown in Fig.7.

In the graph of passenger flow proposed by us, nodes represent destination and arrival of the trains. Calculation of multi-paths from one destination node to arrival node can find only the paths with the same train at the start station and the same train at the goal station. This method

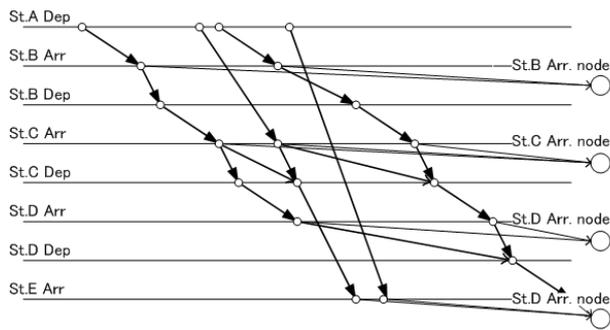


Fig.8 Introduction of the station arrival nodes

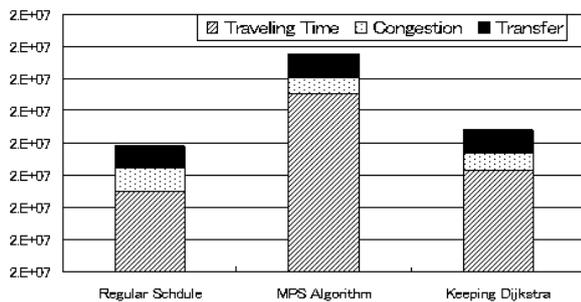


Fig.9 Comparison of passengers' loss

cannot find an effective solution.

The node that brings train arrival nodes of each station is introduced as shown in Fig.8. With the search for the multi-paths from the train departure node to station arrival node, effective multiple paths can be found.

6.2 Keeping the result of Dijkstra's algorithm

As another method, keeping the result of Dijkstra's algorithm can be considered. In conventional graph of passenger flow, Dijkstra's algorithm can find the paths from one train-destination node to multiple train-arrival nodes at one station. In conventional method, the paths except for the shortest path are discarded. By keeping these paths, the information would be useful for multi-path search though there is no guarantee of k -th shortest paths accuracy.

6.3 Probability of passenger flow

Two methods to find multi-paths are introduced. The number of passengers that use each path is determined with disaggregate demand model as follows:

$$P_i = \frac{\exp(-\theta C_i)}{\sum_{j=1}^n \exp(-\theta C_j)} \quad (5)$$

where P_i is probability that passenger select the path i , and θ is parameter of Logit model, C is discomfort of traveling time and transfer, and N is the number of paths. Passengers act under this probability.

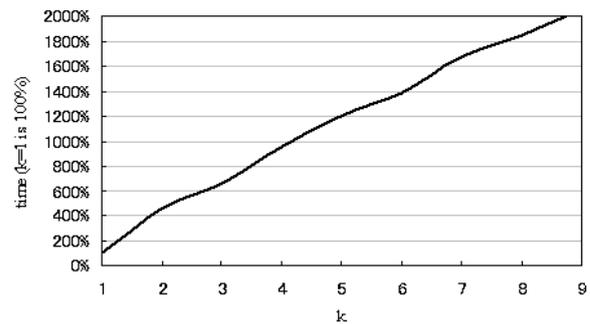


Fig.10 Calculation time of MPS Algorithm

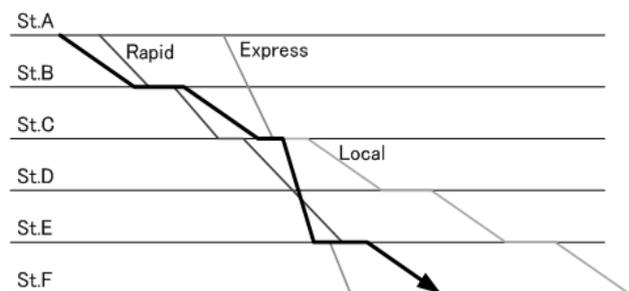


Fig.11 The example of inappropriate path

6.4 Effect of multiple paths

Both k -th path algorithm and keeping the result of Dijkstra's algorithm reduce the discomfort of congestion although the discomfort of traveling time and transfer is increasing as shown in Fig.9. The total passengers' loss is increasing, but the gap of the number of passengers between rapid and local trains has been mitigated.

Based on calculation time, the method of keeping the result of Dijkstra's algorithm is about the same time as finding only single path. On the other hand, the method of k -th path algorithm requires time as k increases. Fig.10 is relationship parameter k and calculation time on certain train network.

7.CONCLUSION

Considering multiple paths in passenger flow analysis ultimately results in the numerical increase of passenger penalty function. But the problem in the analysis only with single path can be eliminated. On finding the multiple paths, an inappropriate path could sometimes be found as shown in Fig.11. Such paths must be removed from the candidates.

One of the methods for more realistic passenger flow analysis to include planning time in the analysis for explicit consideration of causality[5]. The combination of these method and multiple paths would result in more useful evaluation of the passenger flow in practice.

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