AN ALGORITHM TO ESTIMATE TRAIN CONGESTION APPLICABLE FOR EVALUATION OF TRAIN RESCHEDULING PLANS

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Abstract: We propose a method to estimate the volume of passengers on trains for a given traffic rescheduling plan, so that we can calculate the evaluation indices of the traffic rescheduling plans from passengers' point of view. Our method is based on the combination of the Logit model and a simulation where train traffic and passengers flow are simulated simultaneously. Some of the characteristics of our estimation method is that the dynamic interaction between trains and passengers such as dwell times of trains are influenced by the number of passengers, can be simulated and the Logit model is built in to express passengers' choice of desirable routes. We conducted an experimental study using the real data and confirmed that there is no significant difference between the real congestion data and the value estimated by our method.

Keywords: train traffic rescheduling, evaluation method, passengers flow, simulation, Logit model

1. INTRODUCTION

In most urban railway lines in Japan, a number of trains are operated at intervals of three to four minutes. When train traffic is disrupted by an accident, for example, rescheduling operations are conducted to aim at restoring the delays of trains. This task is called train traffic rescheduling (traffic rescheduling, in short). On railway lines, especially on lines with heavy train traffic, a poor rescheduling plan imposes great inconvenience on a huge number of passengers. Thus, it is quite important to provide rescheduling plans of a good quality.

Disrupted traffic is rescheduled by experts called "train dispatchers". They forecast the future train traffic based on the original train schedule and the current situation, and prepare a traffic rescheduling plan by making a series of appropriate changes to the original schedule.

One of the problems in the current process of traffic rescheduling is that no quantitative evaluation methods for traffic rescheduling plans have been developed and traffic rescheduling plans are put into practice with no attention paid with regard to their qualities. Train dispatchers do their jobs based on their past experience and intuition. They do not employ a method to select the best plan after making a quantitative comparison to several rescheduling plans. Hence, no one knows whether the conducted rescheduling plan is the best.

We believe that a quantitative evaluation method has to be established in order to make the traffic rescheduling business more reasonable. It is extremely important that viewpoints of passengers' inconvenience are included in the criteria.

It is considered to be natural to adopt the total traveling time and the congestion of trains as the criteria of traffic rescheduling from the passengers' point of view. This means that a method to estimate the volume of passengers on each train for a given traffic rescheduling plan becomes necessary.

As for the methods to estimate the volume of passengers, the result of a research based on the notion of User Equilibrium Assignment (UEA) model is reported (Ieda *et al.* -1994). This research is based on the two conditions described below.

1. Trains exactly run by following the times prescribed in the train schedule.
2. Passengers have the information concerning the congestion of all trains and decide their behavior (choice of trains) so that the value of their utility becomes the maximum.

The first condition, however, do not hold in the situations where traffic has been rescheduled. When train traffic is disrupted, the number of passengers who get on and off trains sometimes becomes larger than usual, and this causes the dwell times of trains longer than those prescribed in the original train schedule. It is not appropriate to think train schedules are fixed and it is necessary to think that they are influenced by the number of passengers who get on and get off. In other word, a dynamic traffic environment where the flow of passengers and the train schedules interact each other has to be considered.

The second condition does not hold either. Although it is reasonable to assume that the second condition holds in the case of commuter transport where passengers iterate the same behavior everyday, it does not hold in the situation where train traffic is rescheduled. This is because traffic rescheduling plans differ from time to time and passengers cannot get the information about the traveling time and the congestion rate of the trains.

We propose a method to estimate the volume of passengers in each train for a given traffic rescheduling plan. In order to construct this method, we have to solve the following two issues.

1. Consideration of a dynamic traffic environment, i.e. a situation where the flow of passengers and the train schedule interact each other.
2. Consideration of passengers' behavior including the transfer between trains under the dynamic traffic environment.

In this paper, we introduce a dynamic traffic simulation model which can express the interaction between passengers and train traffic to solve the first issue. To settle the second issue, we devise a prediction method of passengers' behavior based on the Logit model, which is commonly used in the area of demand forecasting. Then, we have built it in our simulation model, which makes it possible to estimate the volume of passengers on trains under the dynamic traffic environment considering passengers' behavior.

2. EVALUATION OF TRAFFIC RESCHEDULING PLANS

Traffic rescheduling plans should be evaluated from various aspects: for example, total delay time, time needed for restoration and the number of cancelled trains are considered to be major criteria. Among others, passengers' inconvenience should be a top priority. As the criteria considering passengers' inconvenience, it is natural to adopt traveling times of passengers and congestion of trains.

Figure 1 illustrates how traffic rescheduling plans should be evaluated from passengers' point of view. Gray lines denote the original train schedule. Let us assume that a train named Local 1 is delayed for some reason at Station 1. In this situation, there are two alternative rescheduling plans. One is to make all the trains run without giving any changes to the original schedule (Fig.1(a)). The other is to change the schedule to Local 1 so that it waits for the train named Express (drawn by thick lines) at Station 2 (Fig.1(b)). The purpose of this plan is twofold. One is to reduce the traveling time of the passengers from Stations 0, 1, 3 who are bound for Station 5. The other is to avoid Express being delayed. That is, if Express connects to Local 1 at Station 3, it will be more crowded than usual which probably makes its dwell time at Stations 3 longer. Which plan is quantitatively better?

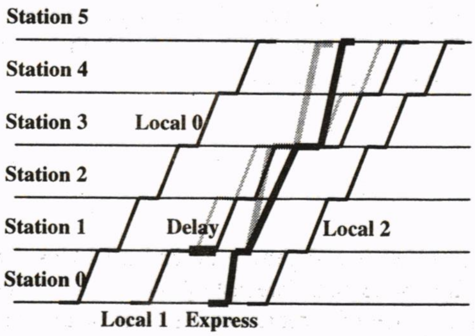

Fig. 1(a): Without any changes

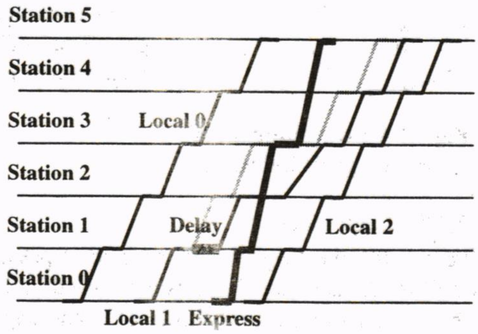

Fig. 1(b): Local 1 waits at Station 2

In order to evaluate these two plans, we have to solve the following two problems.

1. It is necessary to estimate the volume of passengers on each train for a given traffic rescheduling plan.
2. It is necessary to predict future train schedules considering the dynamic interaction between passengers and trains, such as increase of passengers make dwell times of trains longer.

We propose a passenger's behavior model which gives an answer to the first problem. This model is based on the Logit model, which is a model often used in demand forecasting, and can be applied to a situation where passengers decide their behavior as they like; such as to choose less crowded train, to transfer trains so that they can travel faster and so on. The detail of this model is discussed in section 3.1.

For the second problem, we have developed a simulator which can simulate both trains and passengers. The passengers' behavior model is installed in the simulator. The construction of this simulator is presented in section 3.2.

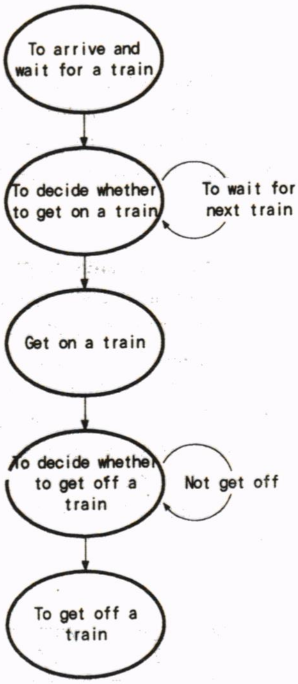

Fig. 2: A flow diagram of a passenger's behavior

3. ESTIMATION METHOD OF THE VOLUME OF THE PASSENGERS ON BOARD

3.1 Passengers' behavior model

(1) Overall construction of the model

We introduce a passenger's behavior model described in Fig. 2. Behavior of the railway passengers is considered to consist of the following five parts.

1. To arrive at a station and wait for a train
2. To decide whether to get on a train or not
3. To get on a train
4. To decide whether to get off or not
5. To get off a train

A passenger's behavior between his appearance at his starting station and arrival at his destination station is expressed by a combination of these five parts. For example, change of trains is expressed by a combination of "To decide whether to get off or not", "To get off a train", "To decide whether to get on a train or not" and "To get on a train".

(2) The Logit model

We employ the Logit model to predict passengers' choice of getting on and off trains. The Logit model is a model that is often used in the area of demand forecasting (Ono *et al.* -1988). This model gives a probability of a passenger's choice of a route among a set of available routes (Please note that a route means choice of trains, i.e. change of trains is also included). This model is based on an assumption that a passenger chooses the most desirable route for him/her.

The probability of a passenger's choice of a route R (Prob. (R)) is expressed by the following formula, when there are two available routes, Route A and Route B, and their utility for the passenger is U_A and U_B respectively.

$$Prob.\ (Route\ A) = \frac{e^{U_A}}{e^{U_A} + e^{U_B}} \quad , \quad Prob.\ (Route\ B) = \frac{e^{U_B}}{e^{U_A} + e^{U_B}} \ .$$

In these formulas, e denotes the base of natural logarithm.

Utility of a route means how desirable the route is for a passenger. Desirability is considered to consist of three factors, namely, the traveling time, the time needed for change of trains and congestion. Thus, utility of a route R (U_R) is expressed by the following formula:

$$U_R = a\,(\text{Pseudo traveling time}) + b\,(\text{Necessary time to change of trains})\ , \qquad (1)$$

where a and b are parameters. Congestion is included in "Pseudo traveling time" using the following formula which expresses congestion by a measure of traveling time reported in Ono *et al.* (1999)

$$\text{Rate of additive traveling time} = (\text{Congestion rate})^{\beta}, \quad (2)$$

where α and β are parameters. Then, we have Pseudo traveling time as below;

$$\text{Pseudo traveling time} = \text{Traveling time } (1 + \alpha\,(\text{Congestion rate})^{\beta}. \quad (3)$$

3.2 Combination of train traffic simulator and passengers flow simu lator

As an estimation method of the volume of passengers, we use simulation. We believe simulation is the most appropriate way to express the dynamic interaction between train traffic and passengers. Actually, our simulator is a combination of the two simulators; one is a train traffic simulator and the other is a passengers flow simulator. They share a memory where the train schedules are stored and these two simulators work hand in hand exchanging messages and simulate the dynamic traffic environment formed by trains and passengers (HIRAI-1998). The configuration of the simulator is depicted in Figure 3.

The train traffic simulator simulates movement of trains based on the train schedule. The simulator is designed based on a Colored Petri-net model. It has several characteristics such as it always produce physically feasible simulation results, automatic traffic rescheduling algorithms can be installed and so on. For the details of the train traffic simulator, see Tomii *et al.* (1997) and Sakaguchi *et al.* (1996).

The passengers flow simulator simulates the flow of passengers. First, it estimates the number of passengers who appear at stations based on the appearance rate which is calculated from the given OD (Origin-Destination) data. When a train arrives at a station, it estimates how many of the passengers at the station get on the train. Passengers decide whether they should get on or not based on the passengers' behavior model presented in the previous chapter. Moreover, please note the two points. If a passenger's destination station is passed by the train, he / she does not get on the train. The capacity of trains is also taken into account, that is, passengers which exceed the capacity of trains are not allowed to get on.

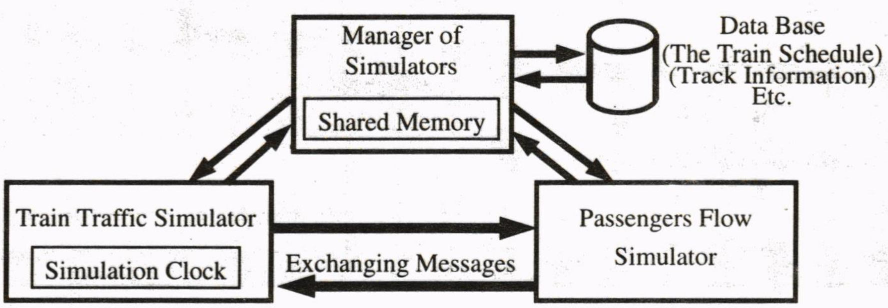

Fig. 3: A Configuration of the simulator

The passengers flow simulator estimates the number of passengers who get on and get off and calculate the necessary dwell times, which is transferred to the train traffic simulator, thus the dynamic interaction between passengers and train traffic is simulated.

In order to represent the interaction between the number of passengers who get on and off and the necessary dwell time, we analyze experimental data performed in Railway Technical Research Institute, Japan. Then, we have the following formula:

$$\begin{aligned}&\text{Necessary time for getting on and off}\\&\quad = c + p\,(\text{the number of passengers getting on at a door})\\&\qquad + q\,(\text{the number of passengers getting off at a door})\\&\qquad\quad + r\,(\text{the number of passengers on board})\ , \qquad (4)\end{aligned}$$

where c, p, q and r are parameters obtained from the experimental data. Comparing the necessary time with a train's resultant dwell time, the longer time is adopted as the dwell time of the train. Then, the simulator can represent dynamic delay caused by passengers' getting on and off.

Fig. 4 shows an overview of our simulator. The background window shows diagram of the original train traffic schedule together with the simulation results. The front windows show the congestion rates, the volume of passengers on trains and stations.

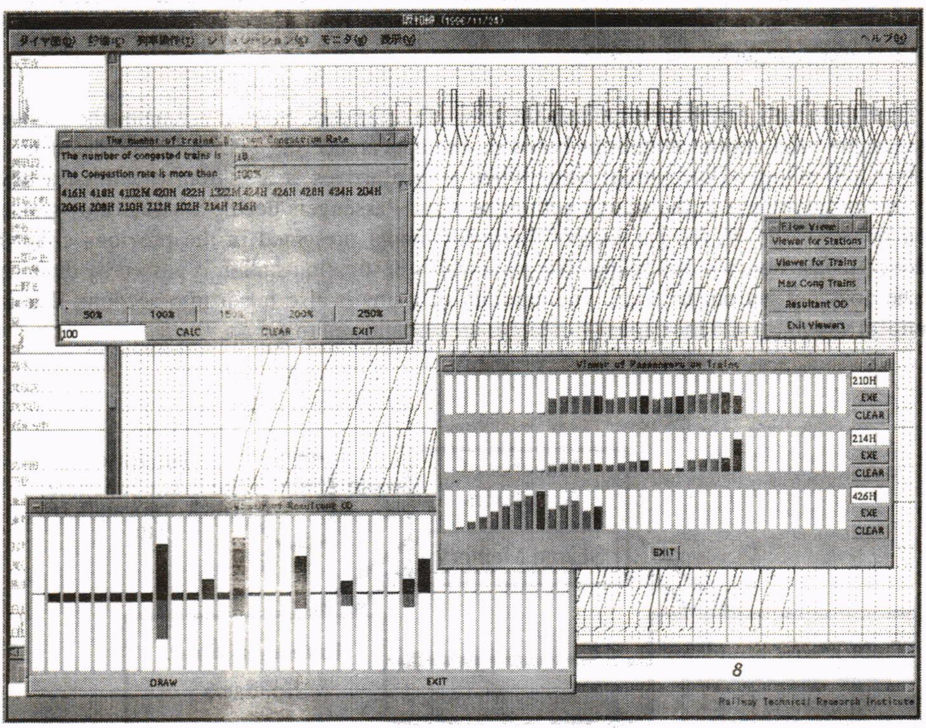

Fig. 4: An Overview of the simulator

4. EXPERIMENTAL RESULTS

In order to verify the effectiveness of our method, we conducted an experiment using real data. We obtained the OD data and the actual congestion data from a railway company. We estimated the congestion by applying our method to the given OD data, and compared the real congestion data with the estimated value.

The target railway line is a commuter line near Osaka, the second largest city in Japan. There are 26 stations along this line as depicted in Figure 5. During the morning rush hour, a lot of passengers commute to Station 26, which is located in the downtown of Osaka. The distance between Station 26 and Station 1 is about 35 km and it takes 35 minutes for the fastest train to run between these two stations. Seven types of trains are operated in this line and they differ in stopping patterns and running times. Local trains often let express trains pass at Station 10 and Station 14, hence passengers transfer between local trains and express trains there.

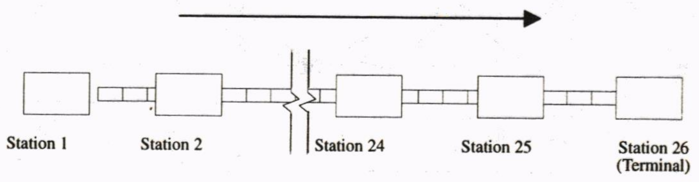

Fig. 5: Layout of the railway line

The target time is from 7:00 to 7:30, the morning rush hour. We estimated the congestion of the trains when they arrive at Station 26. The actual congestion data were collected on a day when the train traffic was normal (not disrupted).

We set the parameters a and b in Equation (1) as – 0.1 and – 0.2 respectively. These values are introduced in Ono *et al.* (1988), based on a discussion about the utility function when the Logit model is used. The parameters α and β in Equation (2) are set by the congestion disutility as depicted in Figure 6. This is introduced by Ono *et al.* (1999).

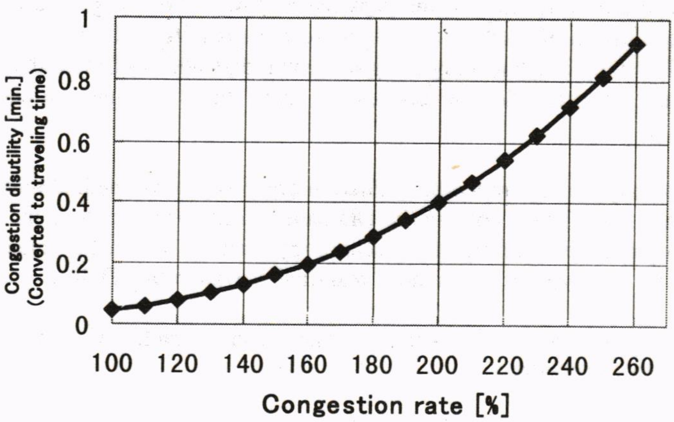

Fig. 6: Congestion Disutility Function

We set the parameters concerning the time for getting on / off trains, namely, c, p, q and r as –0.35, 0.65, 0.37 and 0.16 respectively. These figures are obtained by applying regression analysis to the data gathered by conducting experiments in RTRI.

The results of the experiment are shown in Figure 7. It seems that these two data look similar. In order to confirm the similarity between them, we conducted a t-test, a commonly used statistical test. Then we got a conclusion that the hypothesis that there is no difference between these two data cannot be rejected, which in other words, means that the two data can be considered to be close enough.

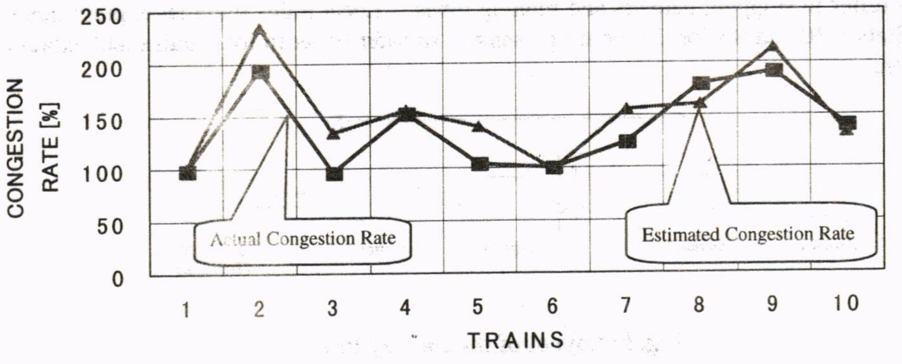

Fig. 7: Results of the Experiment

5. CONCLUSIONS

We have introduced a simulation method to estimate the volume of passengers on each train for given traffic rescheduling plans. This method is a combination of train traffic simulator and passengers flow simulator with a built-in passengers' behavior model based on Logit model. One of the characteristics of our method is that it is possible to express the dynamic interaction between the train traffic and the passengers flow. We can get various kinds of indices useful for evaluation of rescheduling plans from the results of the simulation. Also, we have conducted an experimental study using the actual data and confirmed that there is no significant difference between the real congestion data and the value estimated by our method.

There still remain a couple of future works. First, in order to put our method into a practical use, we have to investigate how to obtain the OD data, which form a part of the input data. We believe that the advance of information technology, such as automatic ticket inspecting and train operation control systems, will realize real time provision of OD data.

Second, we would like to enhance our method so that it can be applied not only for a single railway line but a railway network.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to Mr. Toshiyuki AOKI and Mr. Koji ONO for providing the valuable comments and the data necessary to develop our simulator.

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