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AUTOMATIC GENERATION AND EVALUATION OF URBAN RAILWAY RESCHEDULING PLAN

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ABSTRACT

This paper describes the method to simulate and estimate futural train operation under the given constraint conditions and the method to evaluate train rescheduling plan from the viewpoint of passengers. And this paper also shows its automation algorithm for computers and evaluation result of real railway line's rescheduling plan with implemented program.

1. INTRODUCTION

It is very important to perform suitable train rescheduling when the train operation is disordered by train troubles, physical injuries, signal troubles, *etc*. Commanders of the railway reschedule the timetable by their experiences and intuition. The computer systems only show forecast of train diagram in case of executing commander's rescheduling plan. So reschedule planning is a heavy task for the commanders.

In train operation management system, futural train operation forecasting is important. The train operation depends not only on its vehicle's performance and track conditions, but also on signal conditions and other complicated constraint conditions. It is necessary to execute complex calculation, which includes drawing running profiles for simulating train operation accurately, by considering complicated constraint conditions. Such accurate simulation is, however, often not necessary. Simulation based on the standard running time between stations is sufficient.

First, this paper describes a method to simulate and estimate the futural train operation by graph theory, which is based on the standard running time between stations. Current train operation management does not care passengers but trains. Train operators trace trains' movement from the console, but do not trace passengers' behavior. Then this paper proposes passengers' behavior assumptions to realize a train operation that considers passengers' behavior. To do this, we describe the method of passengers' behavior simulation with the assumptions and the method to evaluate diagram from simulated passengers' behavior.

Finally, this paper introduces the system implemented these algorithms, and shows evaluation result of real railway line's rescheduling plan.

2. TRAIN OPERATION SIMULATION WITH PERT DIAGRAM

PERT(Program Evaluation and Review Technique) diagram is a method used to analyze and schedule mutually dependent works. Former research[1] applied it to train operation simulation. This method has merits of quickness and simplicity. This method occupies an important part of the implemented system. This section describes this method roughly.

2.1. A Graph Representation of Train Operation

It is necessary to make a graph that represents train operation firstly. Each node in the graph corresponds to each departure and arrival of each train at each station. Links represent constraints between these events. Links are created under the following conditions.

- The links which are created between each departure node and next arrival node of each train represent train running. The weights of the links are train's standard running time between the stations.
- The links which are created between each arrival node and departure node of each train represent train stopping. The weights of the links are train's standard stopping time at the station.
- The links which are created between each departure or arrival node and next train's departure or arrival node represent the order of train departure and arrival. The weights of links are minimum clearance time.
- The links which are created between each departure node and next same track using train's arrival node

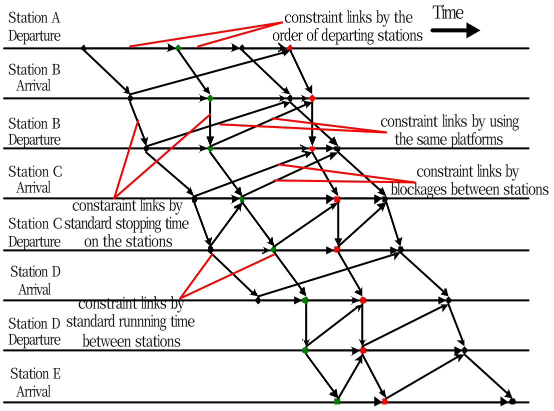

Fig. 1 The graph structure represents train operation

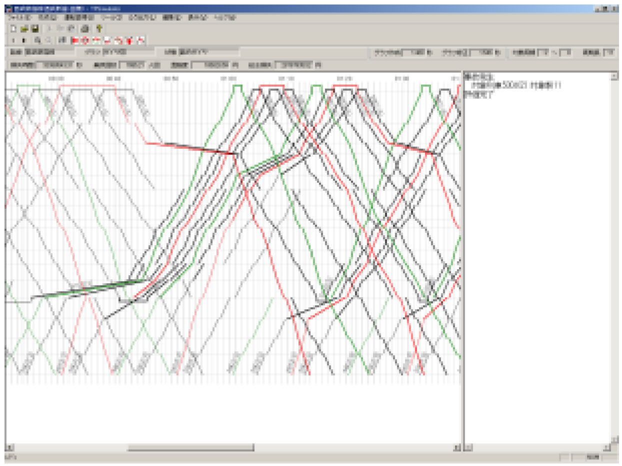

Fig. 2 The simulated train operation diagram

represent constraints using the same track. The weights of links are the minimum clearance time.

- The links between the stations, which are created between each arrival node and its former station's departure node of *n* times later train represent block constraints. *n* is the number of block sections between the stations. The weights of links are zero.
- The links which are created between root node and each departure and arrival node of each train at each station represent regular train operation. The weights of links are regular departure or arrival time at the station.

An example of the graph made by mentioned above conditions is shown as Fig. 1. Links represent regular train operation is omitted in Fig. 1.

2.2. PERT Diagram Calculation

Once the graph is created, each train's departure and arrival time at each station is calculated automatically by the method of PERT diagram. First, topological order of every node should be calculated. And occurring time of the event which is represented by each node is calculated in ascending order of its topological order by adding up incoming links' weight and occurring time of the event which is represented by precedent nodes.

2.3. Reconstruction of the Graph when Rescheduled

When a train diagram is rescheduled, the graph is reconstructed. After the graph is reconstructed, PERT diagram is recalculated and then a new train operation time is obtained. Train accident is simulated by changing concerning links' weights. Changing shunting station or track or used train fleet is represented by changing the connection of the links. Starting an extra train or canceling a scheduled train is represented by adding or removing the nodes and the links.

The simulated train operation diagram disordered by an accident is shown as Fig. 2

3. TRAIN DIAGRAM EVALUATION FROM THE VIEWPOINT OF PASSENGERS

Currently rescheduling plan is often evaluated by the total time of delay of the trains. This method is simple but treats all trains equally regardless of the number of their passengers. This section proposes about passengers' behavior assumptions. This section also describes passengers' behavior simulation method with the assumptions and evaluation method from the viewpoint of passengers.

3.1. The Point of Evaluation

To evaluate the train diagram from the viewpoint of passengers, the total of passengers' loss is selected as the evaluating value. The ideal for passengers are

1. There is no waiting time at the departing station. The train to ride will come as soon as the passenger comes to the station.
2. The riding train runs directly to the destination as fast as possible.
3. There is no passenger in the train excluding himself.

The total of passengers' loss from this ideal state is selected as evaluation value. The evaluation value has three parameters and all of them are converted to loss of money.

<u>Loss time.</u> The necessary time to the destination is passengers' major interest. The difference between the time required in actually and the ideal time is defined as 'Loss time'. The time required in actually includes loss time such as train delay, waiting time at the departing station and transferring station. The evaluated equation is following.

$$L_1 = w \times \sum_{i=0}^{N} \left(t_i' - t_i \right) \qquad (1)$$

N : The number of passengers.
t_i' : i-th passenger's required time in actually.
t_i : i-th passenger's ideal required time.
ω : Time to money conversion factor.

Time to money conversion factor is about fifty yen per minute in urban area obtained by income approach method[2].

Transfer count. The number of transfer is counted as loss because transfer bothers passengers. Here, one transfer is set to equal to two minutes loss time. The evaluated equation is following.

$$L_2 = 2 \times w \times \sum_{i=1}^{N} r_i \qquad (2)$$

N : The number of passengers.
r_i : The count of i-th passenger's transfer.
ω : Time to money conversion factor.

Congestion rate. To evaluate congestion rate, non-linear human feeling factor against congestion rate[2][3] is introduced. The evaluated equation is following.

$$L_3 = w \times \sum_{j=1}^{n-1} \sum_{k=1}^{H_j} \left\{ f_c(c_{jk}) \cdot q_{jk} \cdot t_{jk} \right\} \qquad (3)$$

n : The number of stations.
ω : Time to money conversion factor.
H_j : The number of trains stop at station j.
c_{jk} : Congestion rate between station j and its next station on train k.
q_{jk} : The number of passengers between station j and its next station on train k.
t_{jk} : The required time between station j and its next station on train k.
f_c : Non-linear human feeling factor against congestion rate shown in Fig. 3.

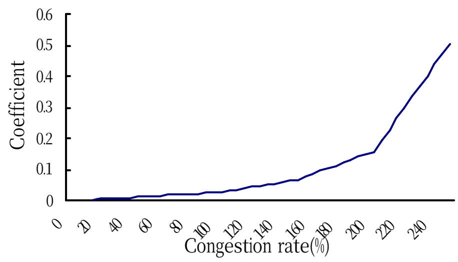

Fig. 3 Characteristic curve of the human feeling factor against congestion rate

3.2. Passengers' Behavior Assumptions

To calculate this evaluating value, it is necessary to know passengers' flow. In real railway, current and past passengers' flow can be determined by automatic ticket gates or weight sensors equipped with coaches. But in computer simulation or to forecast futural passengers' flow, it is necessary to decide passengers' flow. For this reason, a passengers demand table forecasted based on past result is needed. In this research, we use following assumptions.

1. A passenger does not move in the opposite direction.
2. A passenger selects his/her path whose evaluation value for him/her is least.
3. A passenger selects the path whose required time is least, if there are multiple paths whose evaluation value in 2. are the same.
4. A passenger selects the path which transfers at the station nearest to the destination, if there are multiple paths whose evaluation value in 3. are the same.
5. And a passenger selects the path, which reaches to transfer station first, if there are multiple paths whose evaluation value in 4. are the same.

Passengers generally do not mind timetable in an urban railway, and they come to their departing station uniformly. Paths for every passengers are decided uniquely the assumptions mentioned above.

3.3. Passengers' behavior simulation

From the assumptions mentioned above, passengers' flow can be calculated. It is efficient for this calculation to use Dijkstra algorithm. To use Dijkstra algorithm, the graph structure that represents passengers' behavior should be created. Each node in the graph represents passengers' getting on the train or getting out of the train at the station. Links are created under the following conditions.

- The links which are created between each node that represents passengers' getting on the train at the station and node that represents passengers' getting out of the train at the next station represent passengers' moving with the train. The weights of the links are the time required.
- The links which are created between each node that represents passengers' getting out of the train at the station and node that represents passengers' getting on the train at the station represent passengers' continuous riding on the train at the station. The weights of the links are the stopping time at the station.
- The links which are created between each node that represents passengers' getting out of the previous train and node that represents passengers' getting on the train of the next train represent passengers' transfer at the station . The weights of the links are time-transfer conversion coefficient.

The created graph is shown in Fig. 4.

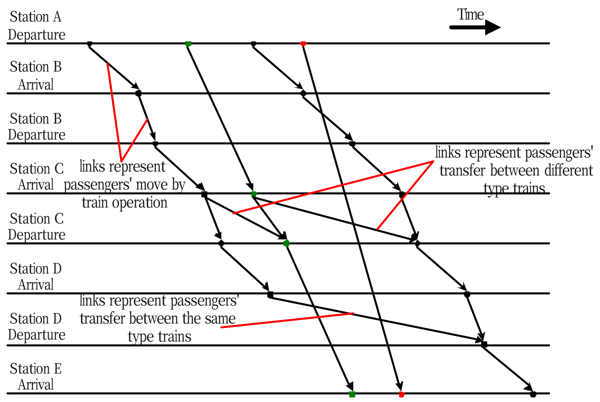

Fig. 4 A graph represents passengers' behavior

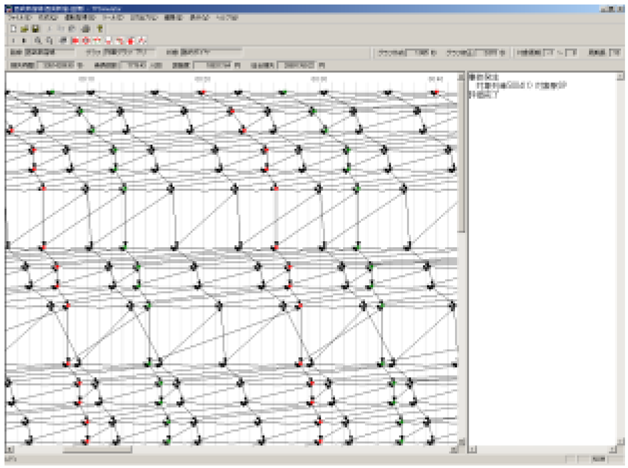

Fig. 5 The graph used to simulate train operation

With this graph, the path on which total of link weight is least can be easily calculated by applying Dijkstra algorithm from each node that represents passengers' getting on the train. From the assumptions, the passengers will select the path that has the smallest evaluating value, that is, the path which is decided by Dijkstra algorithm.
After the paths are enumerated, unnecessary paths that do not meet the assumptions are rejected. Passengers are distributed to each remaining path in proportion to path's interval. The number of passengers who ride on each train can be estimated with this method and evaluation value for train diagram can be calculated.
To reduce calculated amount, the number of links should be minimized. Minimizing the number of links which represent passengers' transfer has an instant effect on reducing calculated amount. Transfer links between the same class train can be omitted, because no passenger will transfer from local/express train to another local/express train in the same line. But pattern of stopping stations and train's destination should be cared because omitting transfer links may cause ignorance of capable transfers.

4. IMPLEMENTED SYSTEM

We have implemented program which uses the method mentioned above. The program has graphical user interface (GUI). Generated diagram and the graph used for generating the diagram are shown graphically. And evaluation value for the diagram is automatically calculated and shown. The diagram simulated by the program is shown in Fig. 2. The graphs that represent the train operation and the passengers' behavior are shown in Fig. 5 and Fig. 6, respectively.

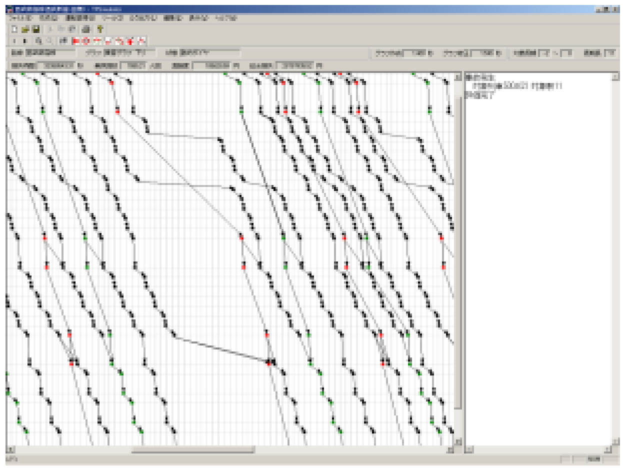

Fig. 6 The graph used to simulate passengers' behavior

5. SIMULATION OF REAL RAILWAY LINE

With this program, we have simulated real railway line. This section describes the model of simulation and evaluation result.

5.1. Model of simulation

We have selected Shinjuku line of Seibu railway corporation from Seibu-Shinjuku to Tanashi as the model. This line connects the suburbs with the central Tokyo. Major parts of passengers are commuters. Seibu-Shinjuku station and its next station Takadanobaba are in the center of city and are the destination for major parts of passengers. About five hundred thousands passengers use these two stations per day. Model selected section of this line is all electrified and double tracked. Map of this section is shown in Fig. 7.

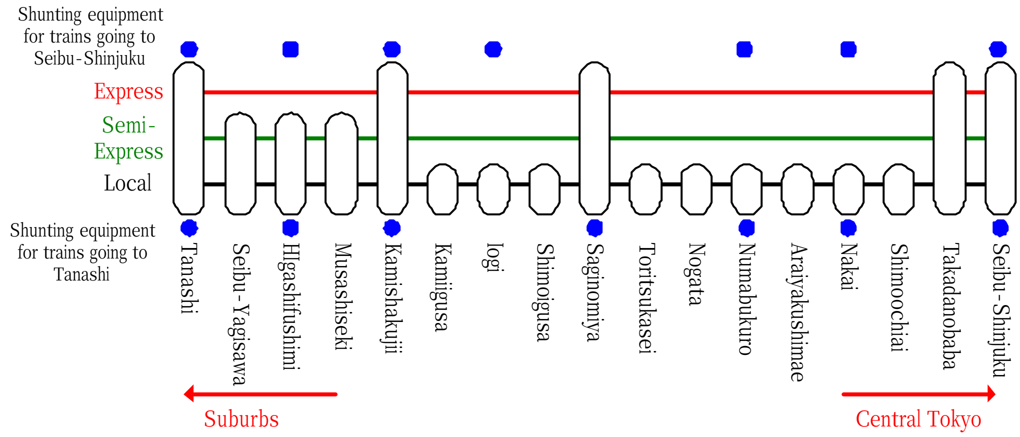

Fig. 7 The map of Seibu Shinjuku line

The model diagram is based on daytime diagram of Seibu Shinjuku line. In the model diagram, one express train, one semi-express train and three local trains run for each direction every twenty minutes. The model of demand of passengers is also based on daytime demand in Seibu Shinjuku line.

In rescheduling simulation, initial delay is set to local train. The model of accident is minor trouble in the train. The train involved in the trouble can not move for specified time. The other trains can move but can not take over the involved train.

5.2. The Method of Rescheduling

There are various methods of rescheduling. In this research, we use two methods of rescheduling. The one is changing shunting stations and the other is changing train class. Changing train class is often done by changing express train into local train. This is done to make easy to guide passengers when train operation is confusing.

On the contrary, in this research, we use the method of upgrading train class. That is, changing local train into express train. We use this method because in city-suburbs connecting line such as Seibu Shinjuku line, major parts of passengers' destination is the station in the central city. When the train operation resumes, there are a lot of waiting passengers. And destination of major parts of them is in the central city. So operating extra express trains to the central city will reduce loss time of them. This method is rare, but is simulated to measure the effect of evaluation from the viewpoint of the passengers.

5.3. Simulation Result Diagram

In this simulation, train trouble is set to the local train at Kamiigusa station for twenty minutes. Diagram with no rescheduling after the accident is shown in Fig. 8. Diagram with changing shunting station is shown in Fig. 9. Diagram with upgrading train class is shown in Fig. 10

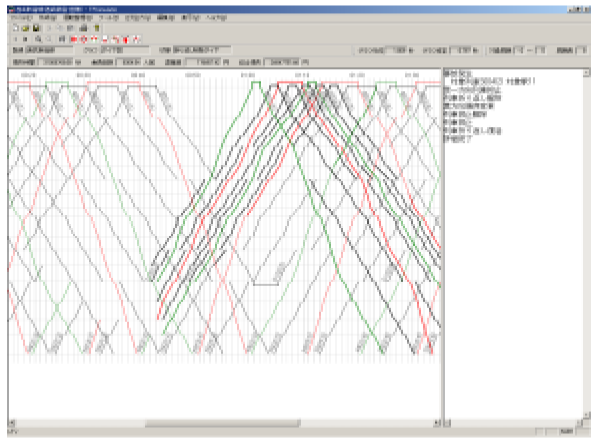

Fig. 8 Diagram with no rescheduling

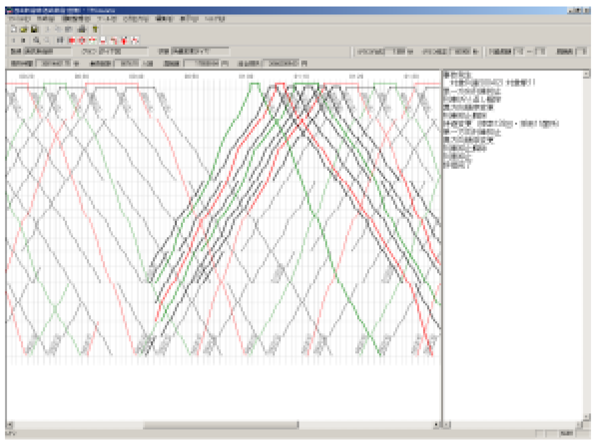

Fig. 9 Diagram with changing shunting station

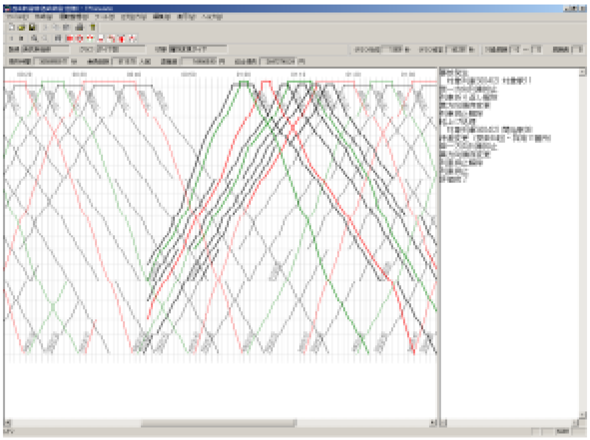

Fig. 10 Diagram with upgrading train class

5.4. An Evaluated Result

An evaluated result is shown in Fig. 11. Loss time is major part of total loss of passengers. Congestion does not have major effect on total loss because daytime passengers' demand is specified in this simulation . Changing the shunting stations reduces the loss of passengers. Upgrading train class furthermore reduces loss of passengers.

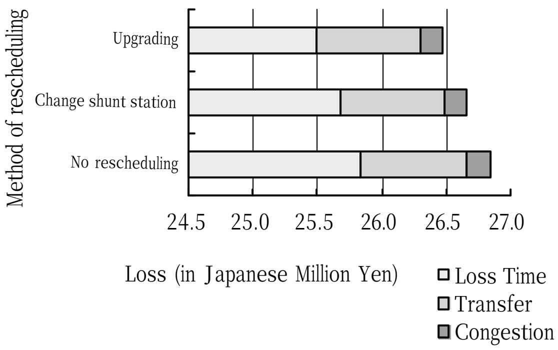

Fig. 11 An evaluated result

6. CONCLUSIONS

This paper shows the method of train operation simulation and simulation of passengers' behavior with graph theory and simulation result of real railway line.
Evaluation value from the viewpoint of passengers will be useful for operators training and their assistance. And this evaluation value will be also useful for developing computer automation system.
In this paper, only total evaluation value is shown in Fig. 11, but each passenger's loss and behavior can be also demonstrated in this system. The operator can understand whose loss is the largest and can take care of them.
A practical advantage of this method is the efficiency in developing a system. A system developer can use ready-made libraries by using graph theory's algorithm. The amount of its computational load has already been estimated, *i.e.* it has been proven that it is efficient. We can easily separate data structure from his main algorithm in the application with graph theory. This separation improves system maintainability.
The advantage of the user side of this system is real time performance. Also he can easily understand the internal behavior of the system through a user-friendly graphical representation.
On the contrary, PERT diagram is not suitable for a simulation such as links' weight is dynamically changing. Train operation simulation method with PERT diagram cannot deal with signal conditions or stopping time disturbance influenced by the number of passengers. If such accuracy is needed, PERT diagram cannot be used. The evaluation value from the viewpoint of passengers proposed in this paper will be still useful even in such a situation.

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