With the recent development of systemization of the operation management system, tasks of the dispatchers have been reduced during normal times. However, support by the system for train traffic rescheduling planning tasks for returning to the regular train schedule at the time of transportation disruption has not shown much progress.

Although some traffic rescheduling support systems that would solve conflicts (changes due to avoid danger or change in train order) generated during the course of traffic rescheduling have been developed so far, the important parts of traffic rescheduling such as cancellation of train runs, changes in reversal of direction points in pendulum operations, extra train departures, and temporary vehicle storage in the car depot have not yet been systemized. Furthermore, use of these systems resulted in partial traffic rescheduling instead of complete traffic rescheduling; therefore, trains have sometimes been delayed even further, providing unsatisfactory results.

Therefore, we decided to develop a system that could execute comprehensive and collective train traffic rescheduling by predicting train schedules through the use of previous train schedules that are continuously sent from the existing operation management system while also taking into consideration the current status of train use by passengers based on such predictions. In this development stage, its basic algorithm and simulator were developed. The man-machine interface for train schedule evaluation was also developed.
delayed even further, providing unsatisfactory results. Also, crew district offices and car depots used to work with the command section to manually check crew and vehicle schedules. Systems to support rescheduling (crew deployment rescheduling support system, and vehicle operation rescheduling support system) were developed, but since rescheduling of train operations by the command section was only partial, information was conveyed piecemeal, resulting in insufficient effectiveness.

In response to this, we determined to develop a train traffic rescheduling system that would create train adjustment plans including rescheduling of crews and vehicles, and that would facilitate recovery of train schedules. This system was designed to capture information such as planned schedules, past train operations, and planned changes, predict and display the train operation status based on the above-mentioned information, and execute comprehensive and collective train traffic rescheduling while taking the current status of train use by passengers into consideration should transportation disruption occur (Figure 1). In this development stage, its basic algorithm and simulator were developed. The man-machine interface for train schedule evaluation was also developed.

2 Development overview

2.1 Selection of a model district

Development of this system targets districts within the ATOS (Autonomous Decentralized Transport Operation Control System) area that already have or will have the train schedule prediction functions. In order to create a general-purpose system that can be used in any district, we selected the Chuo line (rapid transit) (between Tokyo and Takao) as a model district because application of the new system seemed relatively difficult on this line.

2.2 Train traffic rescheduling algorithm

During the course of the system development, we developed an algorithm to accurately calculate the volume of service use by passengers and to obtain an appropriate traffic rescheduling suggestion based on that calculation result. This system accurately calculates the volume of service use by passengers for each “area,” defined by a time range and a location between two stations, by calculating the number of passengers who waited at a station until train operation restarted and the number of passengers who could not get on a particular train since it was too crowded. Then, the system calculates the number of trains (transportation capacity available for passengers) in that particular area based on the predicted schedule. Based on the information obtained, the system identifies the areas that are expected to have insufficient transportation capacity and then creates a traffic rescheduling suggestion in order to improve the transportation capacity of that area. In this way, it will become possible to adjust train operations in such a way that optimum transportation capacity will be secured for the passengers who have to wait at a station in case of an extended transportation disruption causing trains to stop for a certain period of time. At the same time, delayed trains are thinned out in order to recover from the delay. By doing this, it will become possible for the system to create a train operation suggestion that will eliminate the delays while maintaining the transportation capacity.

2.2.1 Train schedule evaluation logic

Based on the local train traffic volume inspection data for the entire line, the evaluation logic for quantitatively evaluating the train schedule was created as follows:
1) Five time ranges were created based on the changes in time-specific transportation capacity such as rush hours (Figure 2)
2) Each time range defined in 1) above was further divided into units of 30 minutes each.
3) Areas between stations were defined based on the differences in use of services by passengers.
4) Each “area” defined by the time range and the area between stations is the unit of analysis evaluation.
5) In order to evaluate the number of trains that were operated within

![Fig. 2: Area Division](image)
each area, the number of trains in excess of or below the requirement is obtained based on the number of passengers who were unable to get on a train since it was too crowded (Figure 3).

6) In order to evaluate train operation intervals within each area, discrepancies in operation intervals are calculated between the actual train schedule and the estimated train schedule.

7) In order to evaluate delays of trains within each area, the longest delay and the total hours of delays caused by all trains in that area are calculated.

8) The train schedule for each area is evaluated based on the values obtained (the number of trains in excess or below the requirement, the amount of extended time between train operations, and duration of train delays).

2.2.2 Optimization algorithm method

The hill-climbing method was used to obtain train traffic rescheduling suggestions due to the enormous number of possible combinations and complexity of the problem. The hill-climbing method in this development is an approach to find a totally optimal solution from multiple points in order to avoid the problem being resolved with locally optimal solutions.

2.2.3 Basic algorithm

Based on train schedule prediction and train schedule evaluation results, the optimal train traffic rescheduling (changes in direction
reversal points in pendulum operations, cancellation of train operations, and so on) is carried out and then a train traffic rescheduling suggestion is made. This adjustment will be carried out during train schedule recovery or train schedule estimation. This algorithm is shown in Figure 4.

2.3 Man-machine interface

Train traffic rescheduling plans simulated by the train traffic rescheduling function can be assessed by using the color display function and the radar chart display function. The color display function uses various colors to show the status of service use by passengers. For example, crowdedness of trains or the existence of passengers who could not get on a particular train and thus had to wait for other trains on the platform will be displayed in various colors. This function allows easier understanding of the service use by passengers. The radar chart display function uses a radar chart to display the overall or partial evaluation of a train schedule based on various evaluation indices, allowing easier understanding of the evaluation results.

2.3.1 Color display

On the train schedule screen, areas defined by duration and stations are displayed in different colors in accordance with the number of passengers who wait for trains as seen in Table 1. When the ratio of passengers aboard the train is over 200% of the nominal riding capacity of that train and it is thus difficult for more passengers to get on it, then the train schedule is drawn in reddish color to indicate warning. Difficulty for passengers to board a particular train is expressed by darkness of the color (Figure 5). Also, display of the areas defined by duration and stations can be easily switched by clicking on the on-screen button. Display of inbound line information, outbound line information, and information for both directions can also be switched in the same manner.

2.3.2 Radar chart display

Train schedule evaluation items were determined based on the basic elements of railway services such as safety, reliability, comfort, and punctuality. Among these, safety must include signal safety when being evaluated; therefore, evaluation items in this evaluation were based on reliability, comfort, and punctuality. Reliability means that the transportation capacity satisfactory to the passengers is secured and can be evaluated in terms of the number of trains operated. Comfort means that the time necessary for passengers to wait for a train at the station or the time necessary to board a train stays within the time range which is considered appropriate. Punctuality means that the time of departure or time of arrival for passengers aboard trains stays within the time range which is considered appropriate. The last two can be evaluated based on operation intervals, stop time, and travel time between stations. In this development, we set the following four items as the train schedule evaluation items, and enabled these items to be displayed on a radar chart (radar display area can be easily changed) (Figure 6).

<table>
<thead>
<tr>
<th>Table 1: Displayed Colors</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of passengers waiting for a train</td>
</tr>
<tr>
<td>Below the number of projected passengers</td>
</tr>
<tr>
<td>From the number of projected passengers to less than 3,000 passengers</td>
</tr>
<tr>
<td>From 3,000 passengers to less than 3,750 passengers</td>
</tr>
<tr>
<td>From 3,750 passengers to less than 4,500 passengers</td>
</tr>
<tr>
<td>From 4,500 passengers to less than 5,250 passengers</td>
</tr>
<tr>
<td>From 5,250 passengers to less than 6,000 passengers</td>
</tr>
<tr>
<td>From 6,000 passengers to less than 6,750 passengers</td>
</tr>
<tr>
<td>From 6,750 passengers to less than 7,500 passengers</td>
</tr>
<tr>
<td>From 7,500 passengers to less than 8,250 passengers</td>
</tr>
<tr>
<td>From 8,250 passengers to less than 9,000 passengers</td>
</tr>
<tr>
<td>9,000 passengers or more</td>
</tr>
</tbody>
</table>
station in accordance with the planned train schedule
Evaluation objective: understanding of riding comfort for the passengers
(4) Travel time between stations
Evaluation criteria: time necessary for a train to run between two stations in accordance with the planned train schedule
Evaluation objective: understanding of riding comfort for the passengers

2.4 Train traffic rescheduling simulator
The simulation was made possible by incorporating the train traffic rescheduling algorithm described in Section 2.2 and the man-machine interface function described in Section 2.3 into the train traffic rescheduling simulator (Figure 6). We carried out simulation with the model case and examined its effectiveness.

2.5 Verification test
The following five types of disruption information were inputted in the test:
1) Time when disruptions in inbound / outbound lines occurred: 12:35:00
2) The first deterred inbound train: 1162H Starting point of inbound operation deterrence: Kokubunji station Estimated time for resumption of inbound train operation: 13:30:00
3) The first deterred outbound train: 1275H Starting point of outbound operation deterrence: Mitaka station
4) Estimated time for resumption of outbound train operation: 13:30:00

The flow of tasks from input of the disruption information to acquisition of a train traffic rescheduling suggestion, return to the regular train schedule, and post-adjustment evaluation was carried out, and we were able to check the flow on the train schedule screen. In this example, 387 traffic rescheduling such as suppression of train departures and delaying of train departures were carried out as the initial step. Then, operation of a total of 20 trains was cancelled, and accordingly, changes were made in reversal points in pendulum operations in order to recover from the delay. Including such direction-reversal point changes and operation cancellations, a total of 309 traffic rescheduling were made.

For the train schedule status after the rescheduling, when the estimated number of trains to be operated was evaluated against the number of trains required to be operated, the required transportation capacity was secured for passengers waiting on platforms. Also, the total delay was reduced from 142 hours and 2 minutes before the rescheduling to 54 hours 29 minutes after the rescheduling. Therefore, we were able to confirm appropriateness of application of the algorithm to the actual train schedules and its effectiveness.

3 Development results
1) We were able to develop an algorithm that automatically creates train traffic rescheduling suggestions comprehensively and collectively with the passenger flow as the main concern.
2) We were able to develop a man-machine interface that would
allow us to understand the passenger status (color display and radar chart display functions).

3) By implementing the functions listed in 1) and 2) above and conducting the verification test, we were able to confirm a certain level of effectiveness in early train schedule recovery during transportation disruptions and improved customer satisfaction.

4 Conclusion

The basic algorithm, man-machine interface, and simulator were developed in this development project. In FY2005, we have been developing a system that generates traffic rescheduling suggestions that supports all necessary procedures including actual rescheduling by developing an interface between the vehicle operation rescheduling support system and the crew deployment rescheduling support system. We are also developing an algorithm with even higher accuracy.