On the busy railway lines in the metropolitan area, accidents involving injury or death and accidents at railway crossings cause major disruptions in railway traffic. When such a disruption in railway traffic occurs, the dispatcher modifies operations by cancelling train runs or through pendulum (shuttle) operations in order to restore the system to the normal train schedule. However, due to the large number of trains in operation and the flow of passengers that cannot be forecast, an extended period of time is sometimes required before the train schedule returns to daily, thus resulting in service deterioration.

Given these circumstances, JR East is gradually introducing the Tokyo Area Transport Management System ATOS (Autonomous Decentralized Transport Operation Control System) in the metropolitan area in order to automatically provide information to passengers and control train routes. However, information is still transmitted to the crew and control train routes. Moreover, a "Crew Operation Rescheduling Support System" that supports crew operation rescheduling and a "Mobile Information Terminal for Train Crew" that directly transmits information from the dispatcher or the crew manager individually to the crew are currently being developed. In this current development initiative, by conducting comprehensive tests combining these systems on the Chuo Sobu Line, the effectiveness of the various systems upon disruption of the train schedule was verified.

**Keyword**: Operational changes, operation rescheduling, ATOS, packet communication, job cards, wireless LAN

## 2 Operational Changes Transmission System

### 2.1 Current Status of Operational Changes

In order to modify operations as planned, the crew needs to be informed of the plan by the dispatcher. For example, if operation is to be suspended midway on a line, not only the driver of the train, but also the train conductor who makes the announcement to passengers on the train will need to be informed in advance. Transmitting such important matters regarding changes in the train schedule from the dispatcher to the crew is called "operational changes." Currently there are two methods of making this operational changes. One is for the station personnel to hand over an "Operation changes Ticket" that directly transmits information from the dispatcher or the crew manager individually to the crew and the other is for the transmission to be made through direct conversation between the dispatcher and the crew using a train wireless system. However, both these methods are manual and thus time consuming.
2.2 Development Overview

2.2.1 Development Objectives and Concept

In order to modify operations as planned and thus reduce the time required to restore the train schedule to normal, the current labor intensive and time consuming operational changes described above needs to be done as smoothly as possible.

For this reason, the system was developed along the lines of the following concepts.

1. Automatically generate and transmit information when there is an event to be transmitted without the need for any new input from the dispatcher;
2. Confirm that the operational changes was actually transmitted and received by the crew;
3. Make use of existing equipment such as ATOS and the monitor in the driver's cab;
4. Make use of generic communication technology rather than create a dedicated communication infrastructure.

2.2.2 System Overview

This system is divided into wayside and on-board equipment (Fig. 2).

The wayside equipment automatically extracts and edits operational changes based on the modified operation data that has been input into ATOS from the operational changes server, automatically designates the target train (IP address), and transmits the information via a dedicated line to an all purpose communication network.

NTT DoCoMo’s packet communication network has been adopted as the means of transmitting information between the wayside and on-board equipment. The reason for adopting the packet communication network is because this system makes it possible for the wayside to be in communication with each individual train at all times. In addition to the advantage that it is possible to immediately transmit any information generated, the operating cost of the system is based on an inexpensive metered rate.

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**Fig. 1: Methods of Operational changes**

**Fig. 2: Principal Functions of the Operational Changes Transmission System**
The data received by the packet reception terminal in the on-board equipment are displayed on the monitor after protocol conversion. Other than operational changes, passenger information (status of operation of railway lines in the vicinity) may be transmitted to the train via the same route.

2.2.3 Major Functions of the Operational Changes Transmission System

(1) On-board Equipment/Train Number Management Function
A table for management of correspondence between the train number and the train composition number is formulated in the operational changes server. By constantly collating the train composition number, terminal IP address, train number, and train position received from the on-board equipment upon change in train status (such as when pendulum (shuttle) train operation is in effect or the crew has been changed), with the train number and position on the tracks that is stored in the ATOS equipment, the trains to which information are to be sent are positively identified (Fig. 3).

(2) Monitoring Function for Confirming Receipt
The on-board equipment sends a “transmission completed” response to the wayside equipment after receiving data. Furthermore, there is a receipt button on the monitor panel that has the function of sending the “receipt confirmed” response to the wayside equipment when the crew pushes this button.

On the other hand, the wayside equipment has a transmission and receipt confirmation monitoring table in the operational changes server to store “transmission completed” and “receipt confirmed” responses allowing confirmation of the status using the display. Moreover, if “transmission completed” or “receipt confirmed” is not effected within a given time, an alarm is activated or the operational changes is automatically resent to enhance the reliability of data transmission (Fig. 4).

2.3 Field Test on the Chuo Sobu Line

2.3.1 Test for Confirming Basic Functions (Fiscal 2000)
Wayside equipment and on-board equipment (two trains) were temporarily installed in order to confirm such basic functions as “automatic editing and automatic transmission of operational changes” and “display on the train monitor” as well as to confirm whether or not there were omissions in the transmitted information. The transfer of information between the equipment and the basic functions were all in good order. Moreover, with respect to transmission time, the average time from input into ATOS until display on the on-board monitor was 14 seconds. Thus data transfer that is exponentially faster than the current method of providing operational changes has been achieved.

2.3.2 Test of Data Transmission and Receipt (Fiscal 2001)
(1) Overview of the Test
Since the packet communication network mentioned above is a public communication network, it was necessary to confirm whether or not the system could be used for operational changes. For this reason, test equipment was installed on a test-train and for about four months transmission and receipt of simulated data to and from the wayside equipment which was connected to the DoPa network was repeated every 30 seconds and the status of packet error was...
(2) Results of the Test and Observations

The error rate was calculated based on the transmission and receipt of about 130,000 units of data and the average error rate was found to be 0.22% and the fact that this was not affected by the position of the train, time period, or speed of the train was confirmed.

Error Rate (%) = \( \frac{\text{Number of Erroneous Data}}{\text{Total Number of Data}} \) x 100

2.3.3 Overview of Monitor Run (fiscal 2002 to 2003)

Positioning this initiative as the final test prior to actual introduction, "confirmation of data generation and data transmission" and "user evaluation such as on the ease of use" will be tested in actual situations of disrupted traffic.

In the test, the on-board equipment will be installed on all trains of the Chuo Sobu Line and wayside equipment will be connected to the ATOS of the Chuo Sobu line. Moreover, the crew and dispatcher will handle this system in parallel with the legacy operational changes. The test is divided into two terms and currently, data from the first term and the responses to a questionnaire are being analyzed.

3 Vehicle operation rescheduling support system

3.1 Current Status of Vehicle operation rescheduling

In order to operate trains, vehicle such as rail-coaches need to be allocated to a train schedule and adjustments made to enable operation as a train. Such a plan for using vehicles is called vehicle operation and this is produced in cycles of approximately one day. On existing lines, daily operation allocation is determined at the various vehicle depots taking maintenance plans into consideration.

When a disruption occurs in train operations, vehicle operation will differ significantly from the plan as a result of the operations being modified. Depending on the way changes are made, situations occur in which vehicles scheduled for inspection do not enter the vehicle depot, or vehicles end up being put into service even though they should not enter service due to issues such as difference in the model of the train etc. For this reason, the dispatcher and the verification duty staff at the vehicle depot will need to check these factors and make modifications to avoid such situations. Moreover, at the vehicle depot, a plan for returning to the original monthly operation plan will be made from the following day forward in order to conform with the inspection schedule. These tasks are done manually at both the dispatchers office and the vehicle depot and at times this leads to delay in restoring the train schedule to normal or delay in returning to the original operation plan after the train schedule has been restored to normal. For this reason, a system for supporting these tasks has been developed.

3.2 Development Overview

In addition to obtaining information on train allocation or inspection schedules from the integrated railway operation system (rolling stock management system), this system obtains information from ATOS on changes that cause disruption to the train schedule such as cancellation of train runs or pendulum (shuttle) operation. Moreover, from the operational changes transmission system that is being developed separately, the system obtains the train composition number and location information that correspond to the train number. The system is comprised of two functions, the 'operation rescheduling function' and the 'operation return function' and these functions are provided based on the information obtained and such limitations as train model constraints (Fig. 5).
Due to the limitations on train operations such as train connection and disconnection and the fact that there are two vehicle depots, the Chuo Rapid Line was targeted for development.

3.2.1 Operation rescheduling function
The operation rescheduling function is displayed in a simplified train diagram and provides a function for monitoring vehicle location in real time, outputting the day’s alerts with respect to operations and suggesting operation rescheduling. Since these functions monitor the vehicle composition number allocated to the various trains, in addition to information that can be obtained from the vehicle management system and ATOS, they make use of information from the operational changes transmission system. The operational changes Transmission system has a scheme whereby the train number, vehicle composition number, current train location, kilometer post, and the course route number of the driver of the train are obtained in succession from the on-board equipment. By constantly obtaining this information, it is possible to track information on operational changes outside the ATOS district or when trains of an unplanned train composition leave the depot.

When the train dispatcher or the control operator plans to modify train operations and any random train diagram line is selected at any random position, the diagram line of the train that will be subject to change upon arrival at a station will be drawn and the content of alert to be provided to each train upon change of operation (failure of train scheduled for inspection to enter the depot, operation limitation due to difference in train model, etc.) will be anticipated and displayed. Through this, it is possible to reschedule train operations giving consideration to vehicle operation.

In the congested sections particularly in the Tokyo area, it is difficult to reschedule train operations in a way that gives complete consideration to vehicle operation and in such areas the rescheduled operation prioritizes maintaining the transportation capacity and urgently restoring the train schedule to normal. Warning from the perspective of vehicle operation that are generated from this kind of rescheduling of train operation are displayed as red train diagram lines. Whether or not warning will be displayed may be set separately by such items as inability to carry out predeparture inspection, inability to carry out regular inspection, trains that should not be put into service being put into service, inability to apply to the following day’s planned operation, and a train composition or freight train being allocated outside its assigned area. If red display is selected for the train diagram line, the content of the warning may be confirmed and a suggestion to reschedule train operation in order to resolve the warning situation will automatically be made. If there is are multiple warning, the content of the warning to be resolved may be selected and automatic suggesting executed. The scope for which a suggestion to reschedule operations is made is from the point at which modification has already been implemented to the point at which the warning is actually generated. The content of the suggestion may be a change in pendulum (shuttle) operation, change in train operation, change in departure from a vehicle depot, or change in entry to a vehicle depot (Fig. 6).

After the train schedule returns to normal, the check function may be used to confirm the number of vehicles on the track either in the vehicle depot or station and the number scheduled to be on the track based on the original plan.

![Fig.6: Rescheduling of Operation (Function for Warning, Suggesting Rescheduling)](image-url)
3.2.2 Operation Return Function

The operation return function is displayed in an operation table format whereby the train composition number is represented by the vertical axis and the date is represented by the horizontal axis and it allows a suggestion to be made for returning to the original monthly operation plan in order to synchronize the plan to the inspection schedule from the following day forward.

This function obtains the record of alteration (final operation) for the day on which disruption of the train schedule occurred that was made as a result of rescheduling of operations from the operation rescheduling function. From the status of this record, the function automatically suggests a return to the original operation plan by altering the combination of operation from the following day forward. It is also possible to automate the suggestion only on a part of the suggested plan for returning to the original operation for which an amendment is desired or to make such amendment manually. Moreover, it is possible to check the suggestion or the amended suggestion in terms of failure to allocate a train to operation or recovery of predeparture inspections.

The task of returning to normal operation is an issue that involves train allocation for several days' operations and as the scale of the problem increases, the volume of calculation required increases exponentially. Various methods for resolving the optimization problem have been studied in various fields and in this development effort, several methods were verified in the algorithm review stage. The 'order of degree of freedom' model was adopted as a system that provides an approximate solution within a short period of time. The order of degree of freedom model is a planning method whereby in the allocation of resources for operation, the operation is categorized by the level of the degree of freedom and allocation is made successively from the group with a low degree of freedom. This is a system that provides the final solution using few steps. When this method is applied to the problem of returning to the originally planned operation, the level of the degree of freedom is, from the lower level, operation such as regular inspection, overnight operation, and day trip operation respectively.

Moreover, in the case of the Chuo Rapid Line, there are two depots, the Musashi Koganei Electric Car Depot and the Toyoda Electric Car Depot. In the past, vehicles assigned to a given vehicle depot were returned to that vehicle depot and substitution was undertaken only when the vehicle entered the vehicle depot. However, with this system, in order to restore planned operation as efficiently and rapidly as possible, an algorithm whereby the two vehicle depots freely make use of the other's vehicles and operation and substitution is made between the vehicle depots has been employed (Fig. 7).

3.3 Verification Test

The prototype system was verified without connecting to ATOS, the operational changes terminal, or the rolling stock management system and was carried out offline using data from an actual accident to confirm the processing speed. For the most part, satisfactory results were obtained for the various functions and with respect to the processing speed, it was confirmed that processing may be undertaken without any time lag.

Currently, an online field test is being carried out on the Chuo Sobu Line where the operational changes transmission system is being tested in order to verify the effectiveness of this system during actual disruption of the train schedule. Test terminals have been installed at the Tokyo Central Dispatcher Office and the Mitaka Electric Car Depot and the Narashino Electric Car Depot, which are the depots where the vehicles for the Chuo Sobu Line are stationed, and tests began in June 2003. To date, there have been about 10 cases of schedule disruption and the functioning of the system is satisfactory for the most part in the various locations (Fig. 8).
4 Crew Operation Rescheduling Support System / Mobile Information Terminal for Train Crew

4.1 Current Status of Crew Operation Rescheduling
As in the case of vehicle operation, crew such as the driver and conductor must be allocated to a train. In crew duty scheduling in such busy lines as those in metropolitan Tokyo, day trips or one night stays are the principal patterns. The route of the crew begins at the assigned depot and ends upon return to the assigned depot after completion of one work cycle.

When the train schedule is disrupted, due to rescheduling of operation, the crew duty scheduling and train assignments are also changed to reflect the rescheduled operation plan. When the originally assigned crew of a train cannot arrive in time due to delay in the schedule, the dispatcher or the crew manager at the crew depot may assign reserve crew or the crew of trains whose runs have been cancelled. These rescheduling are made with due consideration to rest time and overnight stays but any delay in making the arrangements will result in confusion in services. Moreover, contact with crew who have left the train must be made by telephone via station personnel or manager at the crew depot. When the station is in a state of confusion, contact with the station staff may not be possible and the crew may not be located, so that there may be cases in which transmitting information becomes time consuming. From the above situation, in order to support the work required for crew duty scheduling upon disruption of the train schedule, the location of the crew must be tracked, crew operation rescheduling must be automatically suggested based on tracking of the crew’s location, and information on the changes must be communicated to the crew.

4.2 Development Overview
The prototype system for the Crew Operation Rescheduling Support System and Mobile Information Terminal for Train Crew are being developed for drivers on the Chuo Sobu Line. As with the field test for the Vehicle Operation Rescheduling Support System, by using the test environment of the operational changes transmission system, it is possible to obtain train schedule information that has been input into ATOS and information on the driver that is transmitted from the train.

The prototype system is configured as follows. The Crew Operation Rescheduling Support System (hereafter referred to as "support system") and the crew information management server (hereafter referred to as "server") are installed in the Tokyo Central Dispatcher Office and connected to the operational changes terminal of the operational changes transmission system. The depot terminal and access point to the wireless LAN (hereafter referred to as AP) are installed in the Nakano Electric Car Depot and Narashino Transport Depot to which the drivers of the Chuo Sobu Line are assigned. On the other hand, wireless LAN APs are installed at Nakano Station and Tsudanuma Station, which are the standby stations for the drivers and these are connected to the network. Moreover, the mobile information terminals were selected so that they may function both with the packet communication network and wireless LAN (Fig. 9). When actually using this system, the flow begins with the crew reporting to work and moves on to the tracking of the crew, warning, suggestion for rescheduling with respect to crew duty scheduling in the event of disruption in the train schedule, and transmitting the information on the change to the crew duty scheduling that has been suggested. The status of development and testing will be explained.
4.2.1 Tracking the crew's location

Upon reporting to work, a crew member registers the course number and fixed address of any given PDA unit in the server by inputting the course number for which the member is responsible on that date and transmitting this information. The box diagram of the course number that has been input is confirmed using a browser and the data (course table data including the affiliated depot and course number, timetable information of the train's scheduled roster) (hereafter referred to as "job data") equivalent to the job card (IC card) used in the drivers cab monitoring equipment are downloaded into the PDA. When the crew member carrying the PDA departs the crew office, the condition in the server will change to "in transit." When the crew member enters the AP area of the wireless LAN in the station standby office, the server will show "standby" under the "station standby office" display. When the crew member boards the train for which he or she is responsible, the departure data stored in the PDA is transmitted to the on-board monitor via the wireless LAN. At this point, the on-board monitor equipment is in the same state as if the job card that is currently in use had been inserted in the equipment. When the train number is set at the on-board monitor, the packet wireless equipment that is installed on the train transmits the train number and the course number of the crew member via the operational changes terminal to the server in succession. Thus the status at the server will change to "driving" (Fig. 10).

Tracking a crew member who is on duty via the job card that is currently in use has been confirmed to be workable for the most part. Generally good results have also been obtained in the operation upon reporting to work and detection of position using the wireless LAN (Fig. 11). However, there are issues that remain such as the consumption of electricity by the PDAs through the use of the wireless LAN. One wireless LAN AP unit was installed on the train to confirm the transmission function and good results were obtained such as in terms of the transmission time.

4.2.2 Issuing warning and Suggested Rescheduling to Crew Operation

When a train is delayed due to such incidents as impairment in transport, the support system predicts the train schedule taking into
consideration the station platform number and schedule for pendulum (shuttle) operation. Based on this predicted schedule, the system identifies trains that will not be in time for the next scheduled run and it issues a warning. Moreover, in the event that a rescheduling of operations such as cancellation of a run or change to pendulum (shuttle) operation is input into ATOS, the system identifies any contradictions in the crew duty scheduling and issues a warning. Warnings are also issued when there are trains that have not been allocated due to rescheduling of operations or when the final destination of a train differs from the final destination that was planned under the original schedule. In order to resolve circumstances leading to such warnings, the system automatically calculates suggested operation reschedulings based on information obtained from the server such as the current location of the crew. The suggestion to reschedule operation is made starting with issuing a warning with the highest priority and continues processing the suggestion for the next warning reflecting the content of the suggestion that was made for the prioritized warning. In the event there are multiple suggestions for a single warning, the suggestion with the highest priority is adopted. This process is repeated until the final suggestion is output. The content of the suggestion may be the station at which pendulum (shuttle) operation is effected, the connection or disconnection of a course at the station at which the crew is replaced, or the assigning of a reserve crew. The suggestion takes into consideration special conditions in the district such as the method of replacement at the station where pendulum (shuttle) operation is to be implemented and the section in which crew may man a train within the crew district in order to return operations to the originally planned course.

The information on train schedule changes that causes the information on the crew’s performance to be reflected in the train schedule diagram are being processed without problem and output of the anticipated train schedule and warnings is generally satisfactory. (Fig. 11) With respect to the function for rescheduling operations, when a simple disorder pattern was input, usable results were output, but further improvement in the algorithm is required.

4.2.3 Transmission of Information on Changes in Operation

When the final decision has been made on changes in crew operation rescheduling suggested by the support system, the changed information is transmitted to the server and downloaded to the home page of related courses and PDAs and the departure data is updated. The server inputs e-mail for making the transmission to the related course into the mail server and trigger messages are sent to relevant PDAs. The PDA that receives the trigger message will automatically power itself on and the mail client will start up to receive the e-mail message. When the e-mail is received, an alarm will sound, the transmission message will be displayed and the latest box diagram after the change will be displayed using the Web address in the content of the e-mail message. When the content of the change is confirmed, the latest job data is downloaded (Fig. 12). The server also manages the status of transmission of e-mail messages and status of confirmation by the crew. This may also be confirmed using the browser of the depot terminal.

It has been confirmed that push-type mail could be sent in a seamless manner even to trains that are moving or crew who are in transit.
The transmission time involves between 3 to 5 seconds from final decision of changes in operation to start up of the PDA, but since there are cases in which between 1 and 2 minutes are required before the e-mail message is received, improvement is still required.

With respect to the operational changes transmission system, through tests that have been performed up to fiscal 2001, it has been confirmed that the adoption of this system will speed up and achieve labor saving in the task of making operational changes and that there are no problems associated with using the public wireless network. Moreover, the monitor run that is currently being carried out will analyze whether or not there are problems in data transmission and reception during disrupted operations and on the ease of use for the crew. In addition to this, it is believed that changes in operations and revision of regulations for putting the system into practical use and final discussions with the various departments on the method of operation will be required.

With respect to the vehicle operation rescheduling support system, the field test that is currently being conducted has been positively received by the end users and it has been confirmed that the direction of the system is correct and that it is adequately feasible. In the future, in order for the system to be adaptable to routes where train connection and disconnection are frequent or different models of rolling stock are used in parallel, improvement of the algorithm is planned.

The crew operation rescheduling support system and the mobile information terminal for train crew have been confirmed with respect to the fundamental functions and issues that need to be resolved have been identified for each of these functions. With respect to the crew operation rescheduling support system, improvement in the algorithm will continue and the result of the suggestion that has been output will be evaluated including the user. Moreover, the man-machine interface of the crew mobile information terminal for train crew will be improved and through field tests using several PDAs, greater depth will gradually be achieved.

Systems for transmission information and rescheduling operations are being developed in model line as explained above and in the future a "Train Traffic Rescheduling System Considering Vehicle and Crew Operation" that has an integrated automatic suggesting function that takes into consideration train schedule anticipation and operation will be developed and connected to a total operation management system.

5 Conclusions

With respect to the operational changes transmission system, through tests that have been performed up to fiscal 2001, it has been confirmed that the adoption of this system will speed up and achieve labor saving in the task of making operational changes and that there are no problems associated with using the public wireless network. Moreover, the monitor run that is currently being carried out will analyze whether or not there are problems in data transmission and reception during disrupted operations and on the ease of use for the crew. In addition to this, it is believed that changes in operations and revision of regulations for putting the system into practical use and final discussions with the various departments on the method of operation will be required.

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