Transport-related railway systems fall into two major categories. One of those is the transport planning system that plans arrangement of train operation, and the other is the transport management system that manages trains based on that arrangement.

JR East has developed and put into practical use the Integrated Railway Operation System (IROS) that prepares, transmits and manages the transport plan, the Autonomous decentralized Transport Operation control System (ATOS) that has the role of transport management for the greater Tokyo area and Programmed Route Control (PRC) per line or section for conventional lines outside that area. For the Shinkansen, too, we have put into practical use Computerized Safety Maintenance and Operation Systems for Shinkansen (COSMOS).

One of the important functions of the transport management system is to control train operation daily according to planned schedule. On the other hand, supporting quicker recovery to the normal schedule in case of train operation disruption due to mechanical failures or accidents is also a major function of the transport management system. But such support job is unfortunately not yet sufficiently systemized.

Thus, we are developing systems related to transport management. The aim of those is to minimize the effect on passengers and restore to the normal train schedule as soon as possible in operation disruptions.

The systems developed or under development include an operation rescheduling system that deals with train schedules, a vehicle operation rescheduling support system that deals with vehicle scheduling (use of vehicles), a crew operation rescheduling support system that deals with scheduling of drivers, conductors and other crew members, an operational notice transmission system that transmits scheduling change information and a shunting planning support system at depots involved in operation.

We have started actual use of some of those, such as the operational notice transmission system. We have also completed basic systems for the other systems, and development of those is entering the final phase.

In this article, I will first explain the “transport planning” related to train timetable revision and then the arrangement and processing measures of daily “transport management”. I will also present brief overviews of individual related systems.

### 2.1 Transport Planning

Transport planning consists of timetabling (train timetable) as the core of the plan, as well as items such as vehicle scheduling planning, crew scheduling planning and shunting planning. We collectively call those “transport planning” (Fig. 1).
Transport planning, especially timetabling, is a product for railway business, and the quality of the timetable greatly affects use by passengers. In order to prepare the timetable, we have to identify actual use by passengers and forecast future demand based on that. One type of data on the actual use by passengers is called “OD data (O: Origin, D: Destination)”. This shows the number of passengers from one station to another. A major urban area traffic census (the survey of the actual use of public transport) surveys time-of-day OD data. The all-line transport survey and the report of estimated number of passengers riding trains further identify the level of congestion of each train. Recently, we have been able to obtain the OD data using data of automatic ticket gates that read Suica and magnetic tickets and also look at the congestion level using the passenger load factor data measured by the deflection of air springs of each car bogie, allow us to survey congestion levels.

By making different analyses based on the OD data and the congestion level data obtained in those ways, we forecast the future demand. In other words, we forecast the transport volumes of line sections. Next, based on the forecast data, we consider the operation sections of trains, the required number of trans per time-of-day, customer service and other factors, making assessment of types of cars and the number of cars in a train set and travel time taking into account performance of the rolling stock. With that complete, we can finally start timetabling. The system we use for that is the Integrated Railway Operation System (IROS).

We prepare the train timetable, the vehicle operation plan and the crew operation plan using the scheduling system of IROS. The planners of each branch office prepare those in a dialog format on a monitor screen. With this system, the train data, the vehicle operation data and the crew operation data of all lines and sections of the JR East operation area have been compiled in a database under consolidated management.

The subsystem that delivers the prepared transport plan to crew offices, stations, maintenance depots and other locations is the schedule transmission system. In the past, the information of the transport plan was distributed to sections and depots involved as printed material called the “instruction paper for train operation”. By systemizing such operation information, we have become able to output not only the data to be picked up, but also the data forms that were prepared manually in the past.

In this way, now the transport plans that each branch office prepares are compiled on the database and transmitted to the depots involved.

### 2.2 Transport Management (in Normal Operation)

Based on the transport plan prepared with IROS, train timetable and the vehicle operation data are transmitted to ATOS for the greater Tokyo area and to PRC for lines in other areas.

Based on that timetable and vehicle operation plan data, the transport management system prepares the data required for entry to and exit from locations such as stations and depots, and it controls signals and switches at the specified time.

As explained above, in normal operation, cars are arranged and crews perform onboard duties based on the transport plan made out by branch offices. At stations, control devices connected to the transport management system determine routes for train operation (Fig. 2).

### 3 Transport Management in Train Schedule Disruption

#### 3.1 Operation Rescheduling

In normal operation, routes are controlled and trains are operated as specified by the timetable. But in accidents or mechanical failures, trains stop and operation is disrupted.

The dispatcher’s office that is responsible for transport management makes changes in the transport plan to adjust to the situation. For example, it issues instructions to turn back at a certain station or cancels operation of some trains to secure as much transport capacity as possible. After restarting operation, it takes actions to return the operation schedule to normal as soon as possible. We call this work "operation rescheduling".

In current operation rescheduling work, dispatchers collect information such as on the severity of the accident, the passenger congestion level and the on-site situation, and prepare the rescheduling proposals in a short time based on experience and knowledge. At the same time, they coordinate the scheduling of vehicles and crews with personnel such as individual dispatchers and sections involved, and input such change information in the
transport management system. This change input instantly revises the train timetable. Based on that, route control and guidance displays of individual stations are automatically changed too.

But, such timetable change data is not automatically delivered to stations and crew offices. Rather, it is transmitted by dispatchers via means such as fax from the dispatcher’s offices. So, the operation rescheduling plan is prepared based on the experience and knowledge of dispatchers. At present, rescheduling support and proposals by the system are not made (Fig. 3).

3.2 Operational Notice
When route and track change or turn-back operation is required for running trains due to operation rescheduling, that change has to be notified to the drivers and conductors. We call this an “operational notice”. Stations handling train operation control prepare “operational notice cards” based on the change information via means such as fax from the dispatcher’s office and hand the cards to the crew members of the trains involved. On the lines sections without train operation control staff, such notification is made via train radio. In both methods, time and labor is required to enter the “notice receipt cards” or to confirm the change by repetition.

3.3 Operation Plan for Vehicle and Crew Rescheduling
When the train timetable is changed due to operation rescheduling, the operation of vehicles and crew is changed greatly from the original schedule. We call this arrangement for the earliest return of the vehicles and crew to the original route the “operation plan for vehicle and crew rescheduling”.

Crew offices prepare the change plan for onboard duty route based on the change information via means such as fax from the dispatcher’s office and advise that change to the crew members involved. We call such work for crew “crew operation rescheduling” and for vehicles “vehicle operation rescheduling”. At present, dispatchers and persons in charge at crew offices do this work with cooperation and coordination, but no support or proposal is given by the system.

4. System Support for Early Restoration to the Normal Timetable

As explained above, we currently perform transport work ranging from transport planning to daily transport management using the system in normal operation. But, once operation disruption has occurred, almost no system support for early restoration to the normal timetable is given. Dispatchers prepare change plans and input those to the devices for transport management. The situation is the same in other railway companies.

In order to recover from operation disruption earlier, we must quickly and appropriately implement the following five jobs.

1) Accurately identify the on-site situation
2) Prepare the rescheduling plan appropriate to that situation
3) Confirm the arrangement of vehicles and crew according to the rescheduled timetable
4) Input the rescheduling plan to the devices for transport management
5) Immediately transmit the change information to persons and sections involved

So, why has such an important job series not been systematized yet?

Detailed information cannot be obtained only by means such as train radio from crew members and image data from stations to give an accurate picture of the on-site situation. Systematization of operation rescheduling planning is also difficult because we have almost no written material on knowledge such as experience and knowledge of dispatchers and because operational conditions are quite different by line section. As for vehicle and crew operation, we actually cannot make appropriate change plans to ensure passenger transport just after operation restart because we cannot completely identify (trace) the locations of each vehicle and crew member after rescheduling arrangement by dispatchers. Another reason lies in the hardware environment to build such a support system, such as CPU processing speed, problems with the GUI and insufficient research in application of algorithms (combinatorial optimization problem).

As shown in Fig. 4, we have systematized the above five jobs into three systems—operation rescheduling system and a crew operation rescheduling support system for moving trains and a vehicle operation rescheduling support system for static trains. Each system has its own system configuration and software environment to build such a support system, such as CPU processing speed and information transmission transmission system for rural lines to support operational notification such as the rescheduling timetable and operation rules. Now I will introduce overviews and features of each of those systems (Fig. 4).

4.1 Operation Rescheduling System
When the train schedule is disrupted due to rolling stock failure or injury accident, dispatchers have to make many operation
rescheduling arrangements in a short time. In places where many trains are operated such as in the greater Tokyo area, schedule recovery to normal might be delayed without appropriate and quick operation rescheduling.

Trains cannot be operated at higher speed like automobiles to make up for delays. The train timetable is set based on the maximum speed for each line section and train, and travel time is also specified (with some margin time). Thus, in order to restore the timetable to normal, we often use the methods such as train service cancellation and turn-back operation of trains to make up for the delay.

While cancellation and turn-back of many trains allows restoration to the timetable earlier, many passengers have to wait long at stations and trains will become highly crowded. That will increase dissatisfaction of passengers. What’s worse is that getting on and off at stations will take longer, thus worsening the delay.

In this context, we have to rely on the knowledge and skill of experienced dispatchers to determine the stations and trains to reschedule by service cancellation and turn-back.

We have developed a system to support operation rescheduling work of dispatchers. That system forecasts the timetable at the time a couple of hours ahead according to the timetable results accumulated in existing PRC, and displays an warning for locations that might be a cause of longer delay based on such forecast.

Such a support system that displays limited warnings can solve the delay at the specific time and location. But the arrangement by the system sometimes causes other delays at other locations, increasing total delay. That is because the system can determine the arrangement for early timetable recovery only based on the partial rationality, not take into account the total timetable.

Train timetable can be implemented only when vehicles and crew are available. An operation rescheduling proposal that doesn’t take into account operation of those trains and crew cannot stand as operation rescheduling and may have to be redone. In some cases, such loss of time by redoing the proposal even worsens the delay.

We have thus proceeded with development of a system that supports operation rescheduling planning and works in conjunction with the vehicle and crew management support system.

The major advantages of the system are that it considers…

1) Operation rescheduling that takes into account use by passengers
   - Taking into account transport capacity of the time of day based on the passenger volume of each train
2) Operation rescheduling based on the policy of dispatchers
   - Designating the time to timetable restoration
3) Operation rescheduling that takes into account scheduling of vehicles and crew
   - Checking vehicle inspection and line sections on which drivers are approved to drive
4) Operation rescheduling planning from operation restart to timetable restoration
   - Total operation rescheduling planning instead of partial planning

With those advantages, the system can suggest overall well-balanced operation rescheduling plans (Fig. 5).

4.2 Operational Notice Transmission System

The operational notice transmission system is a system to automatically prepare the information necessary to operational notification and display that on the cab monitor of the trains involved without manual work. That operation is done based on the change information that dispatchers input to ATOS for operation rescheduling. Its function goes beyond transmission of information.

The advantage of the system is that dispatchers can monitor using a timer function whether or not trains receive the transmitted information and crew members read that information. Furthermore, the system can give a warning when necessary to ensure transmission of information and the crew’s check of that information. We have also developed an overlooking prevention function to call attention of drivers to the cab monitor at the specified location before the location where to apply the operational notice based on the importance of operational notices.

An operational notice transmission system has been put to practical use on the Chuo line and the Sobu local line, and we are now proceeding with deployment of that in the greater Tokyo area along with the introduction of digital train radio for conventional lines. Along with deployment those line sections, we have improved the function to notify of operation limitation information such as information on rain and wind from the disaster prevention information system (PreDAS) (Fig. 6).

For line sections outside the greater Tokyo area, we have developed an operational notice transmission system for rural lines to immediately give the operational notices related to speed limitations due to rain and wind. The system is based on the operational notice transmission system developed for the greater Tokyo area and supports operational notification work for rural lines without operation management devices such as ATOS and also without
monitors on cars. Crew members identify the location of trains with a mobile terminal and the operational notices are also displayed on that terminal. Functions such as reception confirmation are equal to the one of the system for the greater Tokyo area. For the communication infrastructure, it uses public lines the same as mobile phones use (Fig. 7).

4.3 Operation Rescheduling Support System
As the operation rescheduling support system, we have developed a vehicle operation rescheduling support system and a crew operation rescheduling support system.

4.3.1 Vehicle Operation Rescheduling Support System
In case of train timetable disruption, vehicle scheduling and planning is greatly changed from the original by the operation rescheduling by dispatchers. In some operational rescheduling (to restore to the operation schedule on that day), the time of timetable restoration might be delayed and the operational rescheduling on the days after (to restore to the original monthly vehicle management schedule) might take longer time. In light of that situation, we have developed a system that supports disrupted operation rescheduling, giving information required for vehicle scheduling to dispatchers and persons in charge of the sections and depots involved and making proposals on rescheduling plans.

With that support system, we can constantly monitor train numbers and train set numbers corresponding to those. For timetable disruption, we have added two functions to the system. Those are the operation rescheduling function and the monthly operation rescheduling function. The former is the function to output operational warnings of the day (checks such as non-allocation with vehicles and return for inspection) and make suggestions to avoid those based on limitations by type of car and required inspection. The latter is the function to make suggestions to restore to the original monthly operation schedule. We have developed the system on the Chuo line and the Sobu local line. Some of the functions are planned for introduction to the Chuo rapid line at introduction of the digital train radio for conventional lines (Fig. 8).

4.3.2 Crew Operation Rescheduling Support System
Drivers, conductors and other necessary crew members have to be allocated to trains. In train timetable disruption, allocation of crew members is changed due to operation rescheduling, for example, the train to which a crew member is allocated with on-board duty is changed. Dispatchers in charge of scheduling and railway driver and operation management offices the depot make arrangement for and instructions to other crew members or allocation change when the original crew member cannot arrive in time to the next allocated train due to train delay. After timetable restoration, they also arrange rescheduling to restore the changed route to the originally scheduled one. Any delayed or overlooked arrangement might worsen the transport disorder. A crew operation rescheduling support system is thus a system to check crew arrangements, give warnings if necessary and make proposals of crew management rescheduling to prevent overlooked arrangements.

That support system consists of four major functions.

1. The fourth function, though optional, is the function to transmit the timetable to cab monitors using wireless LAN technology. Crew members of JR East carry a portable timetable and an IC card (a work schedule card) to perform operation jobs. But, when instructed to change onboard duty allocation in operation disruption, they do not have the timetable for the newly allocated trains. Thus, at present, we send the necessary portable timetable via fax to the crew office or the station where the crew members involved are waiting and hand that to the crew members.
the rescheduled onboard duty to the PDA using the mobile terminal network. The crew members involved can see the rescheduled route and the timetable of the newly allocated trains on the PDA. Furthermore, they can transmit the new timetable to the cab monitor and display that by making operation of the PDA in the cab.

The development of this system is at the final stage. We are now proceeding with verification tests for early start of practical use (Fig. 9).

5 Shunting Planning Support System

I have explained the system to support early timetable restoration to normal in case of operation disruption as transport management of the trains running on commercial lines. Now I will introduce the system to support shunting work at rolling stock depots that is related to transport management both in normal operation and in disruption.

Shunting of cars for inspection, cleaning and watering is carried out every day at rolling stock depots. The daily work schedule (entry to and exit from the depot and change of line) is prepared for extra repairs and cleaning on the day before the work, while a rough schedule is determined at revision of the timetable. Such schedule planning is quite complicated, because it has to take into account conditions such as the track where cleaning and washing is possible, the number of cars that can be pooled and in-depot constraints such as routing and crossing obstruction.

When the scheduled work is changed due to operation disruption that day, immediate rescheduling is required. Thus, experienced personnel at the depot prepare shunting plans.

Shunting planning is a combination optimization problem involving preparing the routing order of tracks to enter while meeting specified conditions. That is necessary since each train set (car) has to have required inspections and cleaning within the time from entry to exit. Solving that problem with brute force requires huge volume of calculation involving much time, or no solution may be found in the worst case. We have thus used constraint logic software as the efficient solving technology.

The support system developed has the following three functions.

1) Basic shunting planning function
   • Preparing basic shunting plans at each timetable revision while meeting required conditions
2) Daily shunting planning function
   • Preparing daily shunting plans of the days of work. Manual work is possible for partial correction. This is used for rescheduling in case of operation disruption.
3) Form function
   • Outputting shunting order plans and exit lists

6 Future Development

The Research and Development Center of JR East Group is carrying out development with an aim of creating a next-generation greater Tokyo railway system. In future greater Tokyo area transport, we will need to offer flexible transport according to use by passengers and provide timely and appropriate information to passengers, both in normal operation and in operation disruptions. We are thus aiming for transport trusted by passengers, using the next generation transport management and operation control system, a subsystem of the next generation greater Tokyo area railway system, based on developed component technologies.

Reference:
1) Tomii, Fukumura, Sakaguchi, Hirai: Scheduling Algorithms for Railways, NTS, 2005