Featured Articles

Traffic Management Systems for Expanding Shinkansen Network with Trouble-free Operation of Mutual Direct Trains

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OVERVIEW: In this time of global environmental problems and overcrowding in cities, the value of railways is being reappraised because of their role as a means of transportation that can handle large volumes with excellent energy efficiency compared to automobiles or aircraft. The Shinkansen is Japan's flagship high-speed railway, with a network that has been expanded in accordance with plans established by the Nationwide Shinkansen Railways Construction and Improvement Act. This has included steady progress on expanding the network over recent years, with the opening of the extension of the Hokuriku Shinkansen to Kanazawa in March 2015 and the launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto in March 2016. These two new Shinkansen services include mutual direct trains, meaning through-train services that operate over more than one railway company jurisdiction. While the operation of these services is more complicated than those that only involve a single company, they still need to ensure that the Shinkansen operates reliably and that passengers can enjoy trouble-free services. To achieve this, the Shinkansen traffic management systems need to support safe and reliable operation by ensuring that services match customer needs. Hitachi has been involved in developments and improvements to the Shinkansen traffic management systems that ensure the trouble-free operation of these mutual direct trains.

INTRODUCTION

RAILWAYS are a means of transportation that can handle large volumes with excellent energy efficiency compared to automobiles or aircraft, making them an important part of the social infrastructure. The Shinkansen is Japan's flagship high-speed railway and is known around the world for providing safe and punctual services. The Shinkansen traffic management systems, meanwhile, play a major role in ensuring this safety and punctuality.

The expansion of the Shinkansen network is being undertaken in accordance with plans established by the Nationwide Shinkansen Railways Construction and Improvement Act in 1973. This expansion has continued into recent years, with the Hokuriku Shinkansen between Nagano and Kanazawa commencing operation in March 2015 and the Hokkaido Shinkansen between Shin-Aomori and Shin-Hakodate-Hokuto in March 2016 (see Fig. 1).

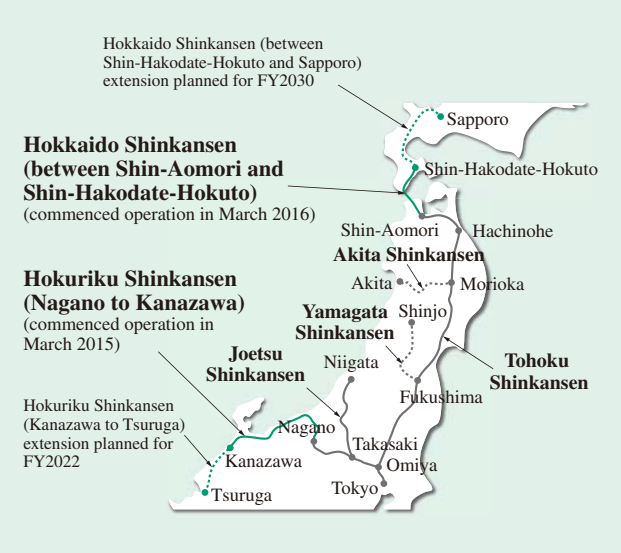

Fig. 1—Expansion of Shinkansen Network.
The expansion of the Shinkansen network brings significant benefits to industry and other parts of society by shortening travel times between regions.

These two new services include “mutual direct trains,” meaning through-train services operated jointly by two different railway companies. The opening of the extension of the Hokuriku Shinkansen to Kanazawa includes joint services run by East Japan Railway Company (JR-East) and West Japan Railway Company (JR-West), and the launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto includes joint services run by Hokkaido Railway Company (JR-Hokkaido) and JR-East. While the operation of mutual direct trains must take account of the borders between railway company jurisdictions, customers should be able to ride on the Shinkansen without having to concern themselves with such issues.

This article describes the computerized safety, maintenance and operation systems of Shinkansen (COSMOS) and the CYGNUS* traffic management systems used by the Shinkansen that have undergone further development and improvement to satisfy these requirements.

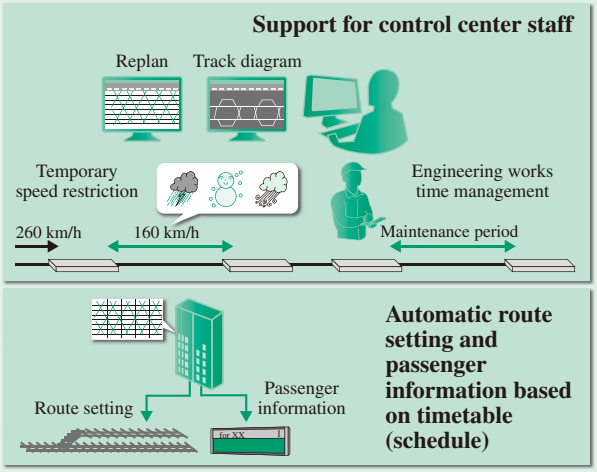

Fig. 2—Main Functions of the Traffic Management System. In addition to performing automatic control of train movements in accordance with the schedule, the system also provides functions that support the work of control center staff.

OVERVIEW OF COSMOS TRAFFIC MANAGEMENT SYSTEM

COSMOS provides comprehensive management for the Tohoku, Joetsu, and Hokuriku Shinkansen lines, covering everything from operational planning to traffic management, rolling stock management, and engineering works management. It was developed with the aim of upgrading the Computer Aided Traffic Control (COMTRAC) system installed when the Tohoku and Joetsu Shinkansen entered service in 1982 to a total system based on a new concept that could deal with the growing volume and changing nature of traffic, and commenced operation in 1995. The traffic management system in COSMOS serves as a comprehensive management system for traffic on the Shinkansen line and supports safe and reliable train operation that can cope with the increased complexity of Shinkansen operations that has resulted from operational practices that include high-speed, high-density services with the coupling and decoupling of rolling stock, diverse rolling stock configurations, and track extensions.

Traffic Management System

The traffic management system manages train operation over the course of a day. In addition to functions such as automatic route setting and passenger information that are based on the train schedules, it also supports the work of control center staff who need to coordinate traffic in accordance with changing operational circumstances when abnormal situations arise. Support functions for control center staff include a track diagram function for presenting information about actual operation, a replan function that supports same-day replan work, a temporary speed restriction function that sets speed limits based on railway line conditions, and engineering works time management that manages the times when the railway line is in use by trains and when it is available for performing engineering work (see Fig. 2).

One of the major features of the COSMOS traffic management system is train running prediction, which forms part of the replan function, and predicts future operation based on the train running result (actual data) and constants such as predefined basic running times (time between stations) and displays the results on operators consoles in table format. Train running prediction helps control center staff anticipate future operational circumstances and assists decision-making for same-day replan work.

Autonomous Decentralized System

The COSMOS traffic management system is an autonomous decentralized system in which a traffic management hub located at the control center is linked to automatic route setting at each station via a wide-area optic fiber network.

* A name coined from a combination of letters taken from “traffic control system,” “standard and narrow gauge,” “north of earth,” “united of operation and maintenance,” and “Hokkaido Shinkansen.”

In addition to control link redundancy and support for open networks that include a variety of different types of computers, autonomous decentralized systems can also adopt a hierarchical system configuration. Because this feature simplifies the retrofitting of new equipment, it can easily cope with the installation of station equipment, such as when a new station is commissioned.

DEVELOPMENT IN PREPARATION FOR OPENING OF THE EXTENSION OF THE HOKURIKU SHINKANSEN TO KANAZAWA

Overview of Opening of the Extension of the Hokuriku Shinkansen to Kanazawa

The Hokuriku Shinkansen commenced operation between Takasaki and Nagano in October 1997. The opening of the extension of the Hokuriku Shinkansen to Kanazawa added services between Nagano and Kanazawa, with direct trains between Tokyo and Kanazawa commencing from March 2015.

The two main features of the opening of the extension of the Hokuriku Shinkansen to Kanazawa are as follows.

The first is that it was larger than other new Shinkansen services added in recent years, adding approximately 240 km of railway line and seven stations.

The second is that two of its stations, at Iiyama and Joetsumyoko, fall under JR-East jurisdiction whereas the other five stations from Itoigawa to Kanazawa are in the JR-West jurisdiction. This means that the Tokyo-Kanazawa service of the Hokuriku Shinkansen is the first to involve mutual direct trains (see Fig. 3).

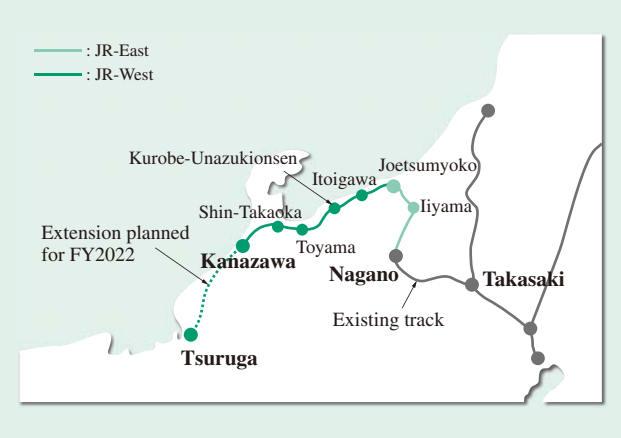

Fig. 3—Opening of the Extension of the Hokuriku Shinkansen to Kanazawa.
The Hokuriku Shinkansen services between Tokyo and Kanazawa that commenced in March 2015 include the operation by JR-East and JR-West of mutual direct trains. The newly opened railway line extends for approximately 240 km and includes seven new stations, with Joetsumyoko Station being the boundary between the two railway companies. The two stations on the Tokyo-side (Iiyama and Joetsumyoko) are under JR-East jurisdiction and the five on the Kanazawa-side (Itoigawa, Kurobe-Unazukionsen, Toyama, Shin-Takaoka, and Kanazawa) are under JR-West jurisdiction.

System Configuration

The opening of the extension of the Hokuriku Shinkansen to Kanazawa required the implementation of a traffic management system that could deal with these mutual direct trains.

Accordingly, the COSMOS traffic management system previously used only at the JR-East control center was upgraded to operate under a single system/dual control centers configuration (the two control centers being those of JR-East and JR-West respectively). This involved upgrading and retrofitting traffic management servers and operators consoles at the JR-East control center, and retrofitting operators consoles at the JR-West control center. In addition, new automatic route setting was installed at all of the new stations from Iiyama to Kanazawa.

These upgrades and retrofits enable the COSMOS traffic management system to perform comprehensive management of the entire lengths of the Tohoku, Joetsu, and Hokuriku Shinkansen lines.

Development of Functions Required for Trouble-free Operation of Mutual Direct Trains

The advantage of the single system/dual control centers configuration is that it enables the two railway companies to centrally manage their respective Shinkansen schedules and other information on the same system. However, because their control centers also manage operation of Shinkansen services within their own jurisdictions, the system also needs to provide trouble-free operation of mutual direct trains and ensure that checking is performed reliably within their own jurisdictions. New functions were developed to satisfy these requirements.

One example of such a new function is the cross-checking of same-day replan.

Because the respective control centers have different jurisdictions, the control centers must notify each other whenever a schedule change is made to mutual direct trains that cross the borders between railway company jurisdictions, and the schedule must be updated accordingly. Furthermore, after the replan, the changes must be validated by both companies.

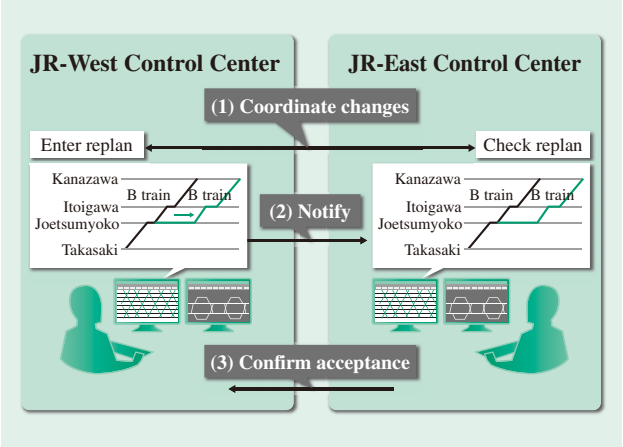

Fig. 4—Cross-checking of Same-day Replan.
A same-day replan for mutual direct trains can be performed reliably by having the two systems perform their respective checks.

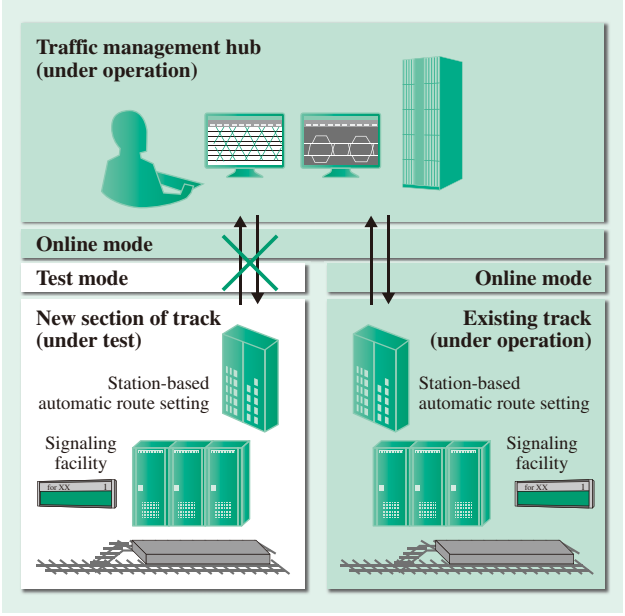

Fig. 5—Connection Control Based on Autonomous Decentralized Configuration.
Equipment under test is able to coexist with equipment under operation by taking advantage of the support that an autonomous decentralized configuration provides for staged implementation.

To achieve this, a cross-check notification technique for sending pre-adjusted replan details from the control center where they were entered to the other control center was developed that took advantage of the single system/dual control centers configuration. This ensures that checking is performed reliably using the system when a schedule change occurs for a mutual direct train that crosses the borders between railway company jurisdictions (see Fig. 4).

Other newly developed functions that helped achieve trouble-free operation of mutual direct trains included sending notification to the other control center about control operations associated with temporary speed restrictions and company-specific control restrictions for the operators consoles.

Field Testing

New signaling facilities were installed for the opening of the extension of the Hokuriku Shinkansen to Kanazawa. Accordingly, testing was conducted aimed at ensuring safety in preparation for full-scale system operation, including signaling facility testing and testing of connections between signaling facilities and station-based automatic route setting.

The challenge facing these tests was that the traffic management hub to which the station-based automatic route setting being tested was connected was under operation, meaning that the overall system needed to include both equipment that was under operation and equipment under test.

To deal with this, the testing took advantage of autonomous decentralized system functions that support staged system implementation for the connections between the traffic management hub and station-based automatic route setting. Testing was completed despite the presence of both equipment that was under operation and equipment under test by using a test mode (in which the link to the traffic management hub is disconnected) when testing station-based automatic route setting in conjunction with the signaling facility, and using an online mode (in which the link to the traffic management hub is connected) for central connection testing and system switchover (see Fig. 5).

DEVELOPMENT FOR LAUNCH OF THE HOKKAIDO SHINKANSEN TO SHIN-HAKODATE-HOKUTO

Overview of Launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto

The Hokkaido Shinkansen to Shin-Hakodate-Hokuto was launched in March 2016, adding new services between Shin-Aomori and Shin-Hakodate-Hokuto (and approximately 149 km of railway line and three stations) and providing direct service between Tokyo and Shin-Hakodate-Hokuto.

The two main features of the launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto are as follows.

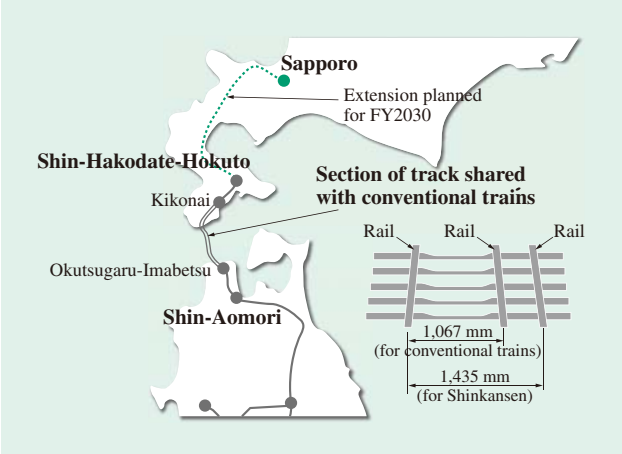

Fig. 6—Track Used by New Hokkaido Shinkansen that is Shared with Conventional Trains.
This was the first time for a Shinkansen line to share dual-gauge track with a conventional line. The Shinkansen and conventional trains are able to share track by laying an additional rail for Shinkansen use next to the narrower-gauge track used by the existing Tsugaru Kaikyo Line.

The first is that it uses the existing Seikan Tunnel linking Honshu with Hokkaido, and is the first Shinkansen line under the Nationwide Shinkansen Railways Construction and Improvement Act to share dual-gauge track with a conventional line (the Tsugaru Kaikyo Line) (see Fig. 6).

The second is that the new services between Shin-Aomori and Shin-Hakodate-Hokuto run on the Hokkaido Shinkansen line operated by JR-Hokkaido while the services between Tokyo and Shin-Aomori run on the Tohoku Shinkansen line operated by JR-East. This means that services between Tokyo and Shin-Hakodate-Hokuto now involve mutual direct trains jointly operated by JR-Hokkaido and JR-East.

System Configuration

The launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto required the implementation of a system that can manage traffic on the new Hokkaido Shinkansen line. The challenge was that, whereas the Shinkansen has exclusive use of sections of track previously managed by COSMOS, the Hokkaido Shinkansen line also has conventional trains running on shared track that includes the Seikan Tunnel. Given the difficulty of using COSMOS to manage schedules for conventional freight trains with very different operating practices, a decision was made for the JR-Hokkaido jurisdiction to develop a new integrated Shinkansen system (CYGNUS) for the Hokkaido Shinkansen line that is separate from COSMOS, and that can perform integrated management of both the Shinkansen and the conventional trains that run on shared track.

The CYGNUS traffic management system that manages train operations in the JR-Hokkaido jurisdiction over the course of a day is a centralized system that locates automatic route setting and support functions for operations control at the control center. Display of information about the status of operations along the entire length of the Hokkaido Shinkansen line, automatic route setting, and scheduling are all performed on the traffic management hub. The CYGNUS traffic management system also has functions for engineering works management, with the procedures for entering, starting, and completing a job being performed on the system.

Development of Functions Required for Track Shared by Shinkansen and Conventional Trains

The CYGNUS traffic management system required the development of new functions for handling configurations (the sharing of track by Shinkansen and conventional trains) that were not covered by the previous Shinkansen traffic management system.

One of these was the integrated departure sequencing function. The CYGNUS traffic management system manages lines used by the Shinkansen and conventional trains as separate sections of track. However, the challenge was that decision-making for automatic route setting becomes more complicated if the departure sequence for shared sections of track where lines used by the Shinkansen and conventional trains come together from these different sections of track are handled separately. In response, decision-making for automatic route setting of Shinkansen and conventional trains entering from these different sections of track was made simple by only integrating the departure time order for the departure sequence of Shinkansen and conventional trains on shared sections of track.

A second example is Shinkansen prioritization. The fact that sections of track are shared by Shinkansen and conventional trains means there is a risk that disruptions to the conventional trains' schedules will also disrupt the Shinkansen schedule. Accordingly, functions were developed to give priority to maintaining the punctual operation of the Shinkansen.

Shinkansen prioritization is broadly divided into two functions. The first is a train running prediction function that issues a warning prompting the control center staff to replan when it detects that a delay to a

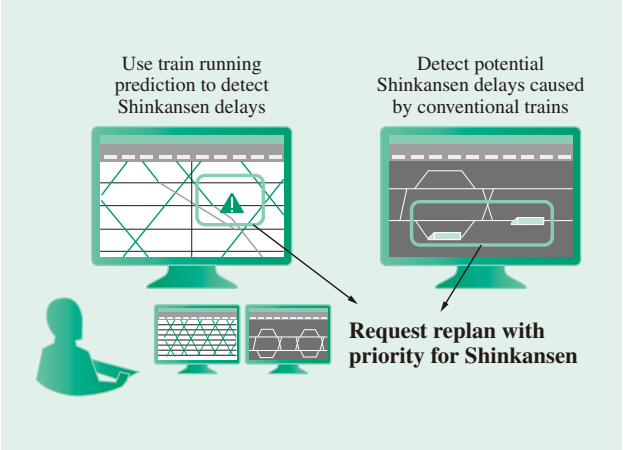

Fig. 7—Shinkansen Prioritization.
By giving priority to Shinkansen mutual direct trains, this manages operation in such a way that delays to conventional trains do not cause delays to the Shinkansen.

conventional train will cause a delay to the Shinkansen. The second function prevents the conventional train from proceeding and prompts the control center staff to replan when it detects that a delay to a conventional train will cause a delay to the Shinkansen based on the predicted time at which the trains will arrive at their next stations (see Fig. 7).

By prompting control center staff to replan, Shinkansen prioritization ensures the punctual operation of the Shinkansen and manages operation in such a way that delays to conventional trains do not cause delays to the Shinkansen.

Interoperation between CYGNUS and COSMOS Traffic Management Systems

To ensure the trouble-free operation of the Shinkansen, the policy adopted when the Hokkaido Shinkansen commenced operation was to use COSMOS to ensure the consistency of schedules along the entire length of the Shinkansen line between Tokyo and Shin-Hakodate-Hokuto, including the section under the jurisdiction of JR-Hokkaido. The following two points describe the interoperation between the CYGNUS and COSMOS traffic management systems in accordance with this policy.

(1) Scheduling

In accordance with the above policy, COSMOS manages the Hokkaido Shinkansen schedules along the entire length of the Shinkansen line between Tokyo and Shin-Hakodate-Hokuto, while CYGNUS manages the schedules for the Shinkansen and conventional lines between Shin-Aomori and Shin-Hakodate-Hokuto that are under the jurisdiction of JR-Hokkaido. During scheduling, COSMOS generates the schedules for the entire length of the Shinkansen line between Tokyo and Shin-Hakodate-Hokuto and CYGNUS receives the schedule for the section of track under the jurisdiction of JR-Hokkaido from COSMOS and coordinates this with the schedules for conventional train services.

COSMOS traffic management system predicts the schedules between Tokyo and Shin-Hakodate-Hokuto so that it can ensure the consistency of schedules along the entire length of the Hokkaido Shinkansen line between Tokyo and Shin-Hakodate-Hokuto. Because train running prediction (schedule prediction) uses train running results as well as basic running times and other predefined constants, the COSMOS traffic management system requires train running results for the JR-Hokkaido jurisdiction. Meanwhile, because the CYGNUS traffic management system manages traffic in the JR-Hokkaido jurisdiction, same-day train running results from this section of track are kept by the CYGNUS traffic management system. Accordingly, having COSMOS ensure the consistency of schedules along the entire length of the Hokkaido Shinkansen line was achieved by having the CYGNUS traffic management system send the train running results for track in the JR-Hokkaido jurisdiction to the COSMOS traffic management system so that the COSMOS traffic management system can predict the schedules between Tokyo and Shin-Hakodate-Hokuto based on these received train running results.

(2) Engineering works time management

On sections of track managed by COSMOS, the switchover from train operation to the maintenance period (the time reserved for engineering work such as track maintenance) occurs after the final Shinkansen train has gone. To this end, the COSMOS traffic management system manages the train operation and maintenance periods at each station and in the intervals between stations (called the “engineering works time management function”). To ensure trouble-free management, the transition to the maintenance period is based on acquiring notification that the last Shinkansen trains have passed or stopped from the stations.

Similarly, the basis of the approach to engineering works time management on the Hokkaido Shinkansen follows the same concept as used in the past. Because the CYGNUS traffic management system also has to deal with conventional trains, the transition to the maintenance period can only take place after all train traffic has finished, including conventional trains. However, because late night and early morning

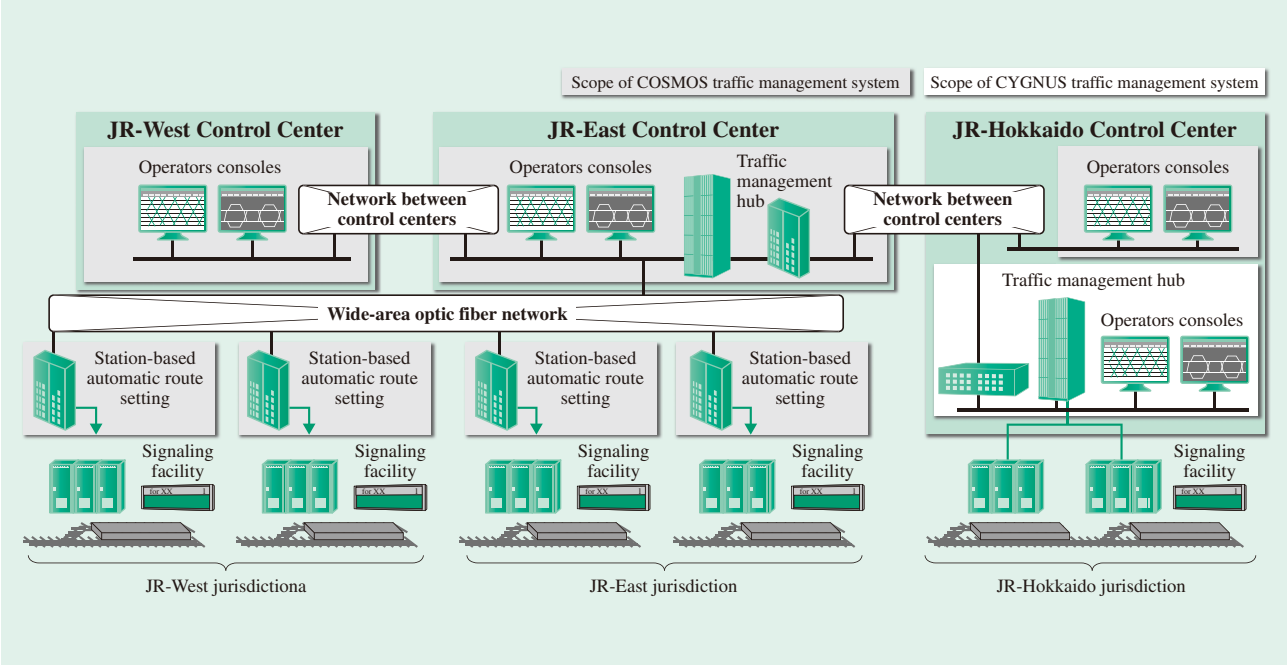

Fig. 8—Overview of Shinkansen Traffic Management System after Hokkaido Shinkansen Commences Operation.
The COSMOS and CYGNUS traffic management systems work together to support safe and reliable Shinkansen operation. The COSMOS traffic management system has a configuration that is distributed between stations and manages Shinkansen traffic across the jurisdictions of both JR-East and JR-West. The CYGNUS traffic management system has a centralized configuration and manages both Shinkansen and conventional train traffic on lines under JR-Hokkaido jurisdiction.

conventional train services run on the sections of track that are shared with conventional trains, the finish time for train traffic on the COSMOS and CYGNUS traffic management systems is very different.

To deal with this, an engineering works time management function that works in accordance with actual operation was implemented by having an end time for Shinkansen traffic on track under JR-Hokkaido jurisdiction, and having the CYGNUS traffic management system send notification that the last train has passed or stopped to the COSMOS traffic management system to notify the COSMOS traffic management system that Shinkansen traffic has finished on track under JR-Hokkaido jurisdiction.

Field Testing

As noted above, the sharing of sections of track with conventional trains is a major feature of the launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto. This was also a challenge during the field testing phase.

As past extensions to the Shinkansen network have involved the laying of new track, signaling facility testing and the connection testing of signaling facilities and system equipment have been conducted independently of existing services. With the launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto, however, the presence of both existing equipment for the conventional line and new equipment for the Shinkansen on sections of track shared with conventional trains imposed the restriction that Shinkansen equipment could not be operated while the conventional line equipment was in use.

Accordingly, on-track trials of the Shinkansen were conducted by switching over to the Shinkansen equipment during the short period during the night when conventional trains are not running. An effort was made to ensure quality efficiently by testing the CYGNUS traffic management system in conjunction with this testing of signaling facilities.

CONCLUSIONS

This article has described the developments and improvements to the COSMOS and CYGNUS traffic management systems made for the recent opening of the extension of the Hokuriku Shinkansen to Kanazawa and the launch of the Hokkaido Shinkansen to Shin-Hakodate-Hokuto.

Since the opening of the extension of the Hokuriku Shinkansen to Kanazawa in March 2015, the COSMOS traffic management system has operated under a single system/dual control centers configuration to support

the operation of Shinkansen lines that include the newly opened section of track that spans JR-East and JR-West. Similarly, the COSMOS traffic management system, which is distributed between stations, and the centralized CYGNUS traffic management system have worked together to support the safe and reliable operation of the Shinkansen since the commencement of operation of the Hokkaido Shinkansen in March 2016 (see Fig. 8).

In the future, the intention for the Shinkansen traffic management system is to proceed with initiatives such as the incorporation of new technology and service improvements, and to work on technical developments that ensure safe and reliable transportation.

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