Overview of Research and Development Activities Relating to Digitalization of Railway Operation Management and Future Outlook

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Various systems using Information Technology (IT) have been developed for automating or supporting train operation and traffic management. However, some tasks still depend on the experience and knowledge of dispatchers. For this reason, dispatchers are subject to significant pressure, not only for daily traffic management, but even more when dispatching operations in case of emergencies or disasters. Dispatchers who manage train operations and control traffic need to make quick decisions based on a large amount of information, so it is required to reduce the difficulty and load of dispatchers. Recent years have seen the development of systems for predicting and/or making decisions about train operations, using Information and Communication Technology (ICT), such as Artificial Intelligence (AI) and big data analysis, in order to alleviate the pressure placed on dispatchers and reduce the time required for resuming train operations after a disruption, based on information on passenger flow, operating conditions, weather conditions, etc. This paper introduces plans for R & D relating to train operation management support systems using ICT, to be included in the next multi-year RTRI master plan which will run from FY 2020, based on R & D conducted during the RTRI master plan which ran from FY2015 to Y2019.

Keywords: train operation control, demand forecasting, ICT, autonomous train operation, master plan

1. Introduction

While a range of operations, including train operation planning and control, have been systematized over the years, a significant number of tasks still rely on the experience and knowledge of dispatchers. This is made particularly obvious when disasters and other emergencies occur, and dispatchers are placed under tremendous pressure to make decisions about whether to suspend or resume train operations. To reduce this burden on dispatchers and shorten the time required for decision making, for things such as resumption of train operation, work is being conducted to develop a range of ICT-based systems to gather and share train operation information, for various purposes, including traffic prediction.

This paper overviews the research and development projects that were conducted during the five-year Master Plan ending FY 2019, and which support train operation control utilizing ICT, and then discusses related projects included in the next five-year Master Plan commencing FY 2020.

2. RTRI master plan

In January 2015, the RTRI Vision was released, entitled, “RISING: Research Initiative and Strategy - Innovative, Neutral, Global - We will develop innovative technologies to ensure the rail mode so that railways can contribute to the creation of a happier society”. As a result, three missions and strategies were established, to accomplish those missions. The three missions were: to intensify research and development activities so as to improve railway safety, technology and operation, responding to customer needs and social change; to develop professional expertise in all aspects of railways and, as an independent and impartial research body, to fulfill our tasks using the best science available in an ethical way; and, finally, to pioneer cutting-edge technologies for Japanese railways and become a world leader in the railway field. RTRI draws up a Master plan every five years, which is used for planning and carrying out projects each fiscal year, with a view to fulfilling the “Vision of RTRI”.

2019 was the last fiscal year of the Master plan “RESEARCH 2020” which started in FY2015. The results from this five-year period are being collated for evaluation. In the area of train operation control, systems utilizing information networks have been developed as outlined on several occasions including in the July 2019 issue of the RTRI REPORT.

April 2020 marked the starting point for the new Master plan “RESEARCH 2025” (which will run from FY2020 through to FY2024). This new Master plan sets out five basic principles: (1) Enhancing safety with an emphasis on improving resilience to natural disasters; (2) Developing innovative railway systems based on digital technologies; (3) Creating high-quality research outcomes by pursuing excellence across all fields of activity; (4) Enhancing the international presence of the Japanese railway technology; and (5) Creating a work environment to help the employees realize their full potential and undertake challenging tasks. Among these, research and development effort will focus on the policies (1), (2) and (3). Following principle (2), work involving digital technology in particular will be encouraged in all research and development fields to yield results that contribute to the realization of railway systems that can meet emerging customer and environmental needs.

The Master plan, also includes four research and development goals: “Improvement of safety,” “Cost reduction,” “Harmony with the environment” and “Greater convenience.” In addition, to ensure research and development is
as efficient and effective as possible, three guidelines were established: “Research and development for the future of railways,” “Research and development of technology for practical use” and “Basic research for railways.”

3. Research and development in the master plan ending FY 2019 and major results

In the FY2015-FY2019 master plan, six laboratories belonging to the Signalling & Transport Information Technology Division carried out R&D on a combined total of 97 subjects (some of which are essentially the domain of other divisions), of which 28 subjects were related to train operation control, demand forecasting and other areas in the transport and commercial fields. Figure 1 shows the breakdown of the subjects undertaken by the three pillars of research and development: “Research and development toward the future of railways,” “Research and development of technology for practical use” and “Basic research for railways.”

This section outlines some of the major achievements obtained in train operation control, demand forecasting and other areas from R&D under the Master plan “RESEARCH 2020” that are not featured in the February 2020 issue of the RTRI REPORT.

![Number of the R&D subjects undertaken by the laboratories of the Signalling & Transport Information Technology Division under the “Research 2020” master plan](image)

3.1 Enhanced SPEEDY features

SPEEDY [1], was developed to automatically generate speed profiles required for the calculation of station-to-station running times, and has been used for numerous research and development purposes and by a number of railway operators. To keep pace with continuing advances in information technology and broadening range of applications using speed profiles, SPEEDY has been upgraded into a highly scalable system. At the same time, review of its headway computation logic made the system capable of computing practical headways [2, 3]. Specifically, the improved representation method for track data enables the setting of gradient, curve and other details for passing tracks. In addition, to enable computation for a range of operating conditions, the system is capable of computing headways to work with speed profiles with specific details of tracks and operating methods (Fig. 2). The system has been used widely not just for the computation of station-to-station running times but also for the computation and study of headways (minimum time distance to the preceding train, minimum allowable time interval for catching up, minimum allowable time interval for succeeding, headway limited by crossover structure).

3.2 Prediction of train operations using real-time information

To support decision making for when train delays arise and appropriate remedial actions are needed whilst maintaining proper headways, a method capable of predicting train delays and vehicle occupancy rates several tens of minutes in advance using a neural network was developed (Fig. 3) [4]. Conventional methods for such applications have limitations in terms of usability including fixed pre-conditions and many parameters that must be set appropriately. The method using a neural network can output predictions with a small number of preset parameters once the network is put through a learning process of historical train operation and occupancy data and then given data on the actual train delay and occupancy up to the current time. It was found that, with no significant disruptions, the method had a delay prediction error of 30 seconds or less in 86 of any 100 predictions. The method still needs be refined however, before being added to train operation control systems. The train operation prediction method is also seen as an underlying technology for autonomous train operation and control, which is discussed in section 4 of this paper.

3.3 Demand forecasting methods

To support transport demand forecasting, quantitative evaluations of business strategies and rail services, economic efficiency evaluation and other efforts, a method was developed for evaluating demand fluctuations every 50 minutes based on demand on trunk lines with multi-mode

![Example of train headway diagram created by upgraded SPEEDY](image)

![Prediction of train delays using a neural network](image)
route alternatives, historical Shinkansen ridership records and other data [5]. In addition, a system was developed for predicting the occupancy rate of individual trains based on predicted demand fluctuations to help arrange extra trains. Furthermore, a method was developed for estimating station catchment areas on local trunk lines for limited express trains, which has been difficult to estimate using conventional methods (Fig. 4) [6]. Using this method, railway operators can now study transport and related business strategies for the use of limited express trains in their prefecture. The methods outlined above have already been used by a number of railway operators.

4. Research and development in the next master plan

This section outlines the research and development program for the future of railways included in the next master plan “RESEARCH 2025” centering on autonomous train operation and control.

4.1 Research and development toward the future of railways

Based on the predicted outlook for railways, RTRI hopes to develop activities that can be applied in practice in about twelve years. In order to guide work towards this goal, RTRI drafted six research targets aimed at meeting the needs of railway operators and adapt to emerging social trends:
1) Enhance resilience against extreme weather disasters;
2) Autonomous train operation and control;
3) Save on manual labor through digital maintenance;
4) Low-carbon power feeding networks through coordinated power control;
5) Faster Shinkansen running speeds that take into consideration the trackside environment;
6) Improve simulation technologies.

Of these research targets, the “Autonomous train operation control” program, led by the Signalling & Transport Information Technology Division, is outlined in more detail in the following sections, highlighting the envisioned future and research and development plans. The Signalling & Transport Information Technology Division is also involved in the program of work on “Labor saving measures using digital maintenance” and the “Low-carbon power feeding networks through coordinated power control”.

4.2 “Autonomous train operation and Control”

4.2.1 What is autonomous?

Autonomous train operation and control mean that each train controls the relevant point machines and level crossings to set its course based on information on the preceding, following and other trains in the neighborhood, the conditions of the wayside and permanent way and the statuses of the point machines, crossings and other facilities, and determines the appropriate target stop point and running pattern while monitoring track safety in order to be able to run without external control. With the automatic train operation already in place, control systems on the ground control point machines based on the locations of the trains and send speed signals and other instructions to each train, allowing the trains to run according to the given patterns. Autonomous train operation and control not only has these automatic train operation attributes but also involves each train controlling the relevant points machines and level crossings, while also determining the target stop point and monitoring safety along its route.

Benefits of autonomous train operation and control include: less ground facilities, fewer cables for train control and other components leading to reduction in maintenance and running costs and the risk of failures; reduced workload on controllers and crewmembers contributing to fewer human errors; and early resumption of train operation after an abnormality contributing, which helps improve convenience and efficiency. Trains are able to quickly detect abnormalities based on detailed surrounding data and rapidly confirm a return to safe running conditions once the abnormality has been resolved, enabling the decision to resume operations in that section, to be taken swiftly. When an abnormality arises in the vicinity of multiple trains, forcing those trains to slow down or stop, other trains outside the affected section can continue to operate safely. If, for example, a train detects an obstruction on the track and stops, as soon as the obstruction is removed and it is safe to run again, the train is able to recognize this and resume its journey while continuing to monitor safety. In the event of a slope failure or other events forcing train services to be suspended for an extended period of time, the train can collate information and decide to revise the operation plans and return to the previous station accordingly while exchanging information with the following trains, allowing the passengers to quickly leave the train there for safety.

In the autonomous train operation and control system, safety-related functions are concentrated on the train. In the event that the train cannot communicate with the ground facilities, it still is capable of continuing operation as long as safety is maintained using the onboard functions such as forward monitoring.

The autonomous technology which enables flexible operation even in emergencies such as the case described above, is considered essential for railways to be able to play a key role in providing seamless mobility in the future.

4.2.2 Essential technologies for autonomous train operation and control

The research target “Autonomous train operation and
control” entails the development of related underlying technologies. That specifically means that further development of the four technologies shown in Fig. 5 will be pursued in the next master plan.

1. Detection of obstacles on and beside the track
   A technology will be developed that enables conditions on and beside the track to be continuously monitored using onboard cameras and distance sensors: captured images are analyzed to detect the presence of abnormalities on the route. The target is for the system to detect abnormalities 600 m ahead of the train. A ground-based detection system for curved and other sections will also be studied in the development program.

2. Autonomous speed profile generation algorithm integrating status information on and beside the track.
   An underlying technology will be developed that enables the train to autonomously decide to run or not while generating speed profiles to control its own operation, based on the locations of the preceding and following trains, information on obstacles on the track and onboard equipment and other data. Information from real-time hazard maps which are to be developed in the “Enhancing resilience to extreme weather disasters” program mentioned in 4.1 will be utilized in the development of the algorithm.

3. Radio-based autonomous ground facilities control
   A technology will be developed that enables the train to control points machines (route), level crossings and other ground facilities based on the information possessed by the train including the train schedule and locations of preceding and following trains.

4. Wide-area traffic control including ripple effect, prevention of and early recovery from train delays, energy saving, etc.
   An autonomous train operation and control system can be built using the technologies (1) to (3) above. However, for flexible and precise train operation geared to achieve energy savings during operation, early recovery from a disrupted schedule and other benefits, the train needs to be fed information on wide-area traffic status and passenger flows. Therefore, a technology will be developed that enables the train to gather and analyze such information from a wide area to make appropriate operating decisions. Energy saving running methods to be developed in the “Low-carbon power feeding networks through coordinated power control” program mentioned in 4.1 will be utilized in the traffic control development program.

4.2.3 Research and development schedule and road map

The Master plan commencing in FY 2020 states that underlying technologies for autonomous train operation will be developed for verification testing at the end of FY2024 using an electric test railcar on the test track at RTRI.

Development of the four technologies mentioned in 4.4.2 will begin in FY 2020. In addition, a fifth program will also start that relates to technologies to exchange control information between trains. From FY2021 onward, an additional 10 programs in total will be launched in succession for conclusion in FY2024. In pursuing these programs, related underlying technologies, including track and level crossing monitoring, train and level crossing control, integration of cloud and other technologies, will be further improved for utilization to support this work.

The results of research and development conducted in for the FY 2020-2024 Master Plan will not solely be designed to realise the goal of fully autonomous train operation. It is hoped that the technologies developed over the next five years will also contribute to improving train operation on the existing network. It is estimated that the introduction of fully autonomous commercially operating trains will require another decade or so of research and development. However, advances made in operational management and safety systems today allow RTRI to take a step-by-step approach to solving problems, and each solution paves the way to achieving the ultimate goal of fully autonomous operation (Fig. 6).

5. Conclusion

This paper outlined key results from the research and development programs relating to train operation control and demand forecasting that formed part of the Master plan which ran from FY2015 to FY2019. It also discussed plans to realize “autonomous train operation and control,” which is one of the targets set for research and development for the future of railways, set out in the subsequent
Master plan which began in FY2020.

RTRI’s goal is to realize autonomous train operation and control that is cost-efficient, safe and secure. To realize autonomous train operation and control, daunting hurdles must be overcome one by one, relating to detection of obstacles on the track, secure data transmission, methods to control ground facilities through coordination among trains based on information from more than one source, and other topics. Autonomous train operation technologies are also being developed overseas and those engaged in similar research share the recognition that it is extremely difficult to develop systems that enable trains to run autonomously without relying on control from the ground. It might therefore become necessary to launch joint programs with those overseas researchers.

As in the past, RTRI will strive to meet the challenges set out in the next Master plan to develop technologies that contribute to the maintenance and further development of railways in cooperation with railway operators and research institutes, manufacturers and universities with advanced technological expertise both in Japan and overseas.

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