Outlines and Future Outlook of Research and Development Activities relating to Utilization of Information and Communication Technology for Signalling and Telecommunication Systems

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With the recent developments in information and communication technology (ICT), various research and development projects are ongoing in the world to propose new train control technology for safer and more stable transportation services. These technologies are expected to reduce costs and the number of equipment used for safe train operation.

RTRI has been challenging to develop new technology to realize digitalization of railway systems, and RTRI sets up a new project to accelerate R & D on utilization of ICT from FY2020. This paper introduces the plan for the R & D on the new autonomous train operation control system using ICT in the new master plan of RTRI started from FY 2020, after surveying the R & D that has been undertaken in the previous master plan of RTRI from FY2015 to FY2019.

Keywords: signal security, ICT, automatic operation, autonomous train operation, Master Plan

1. Introduction

Conventional signal communication systems were until now built using railway-specific technology. However, using recently developed digital technologies, it is be possible to design and build safer, less labor-intensive protection systems which can be operated with fewer facilities.

This paper overviews progress in research and development (R&D) relating to the use of ICT from the last five years, based on signal-communication-related feature papers published in RTRI Reports during the period of RESEARCH 2020 (RTRI Master Plan [FY2015-19]). It then describes remaining issues that need to be solved and directions being taken to find relevant solutions, with a special focus on safety and R&D projects relating to autonomous train operation and control systems, that will be tackled in RESEARCH 2025 Master Plan (FY2020-24), which began this fiscal year.

2. RESEARCH 2020 results and feature papers

2.1 Background and system of emphasizing ICT utilization research

In January 2015, RTRI published its RTRI Vision statement, "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” and laid out three missions and strategies to accomplish this vision. The three missions are: to intensify R&D activities to improve railway safety, technology and operation, responding to customers’ 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, to pioneer cutting-edge technologies for Japanese railways and become a world leader in railway technology. In FY2015, the Master Plan "RESEARCH 2020" was formulated as the five-year concrete activity plan to implement this vision. The Master Plan established four R&D goals: “Improvement of safety,” “Cost reduction,” “Harmony with the environment” and “Improvement of convenience.” In addition, three pillars were defined, aimed at supporting and framing the efficient progress of R&D on the subjects: “R&D toward the future of railways,” “R&D of technology for practical use” and “Basic research for railways.”

In RESEARCH 2020, the six laboratories belonging to the Signalling & Transport Information Technology Division (hereinafter “the Division”) carried out R&D on a total of 97 subjects, including 69 subjects related to signalling and communications, and topics primarily managed by related research divisions. Figure 1 shows the breakdown of the number of subjects in each R&D pillar.

A landmark advance in the Division during the five-year FY2015-19 plan, was the establishment of the Image Analysis and IT Laboratory in December 2017. This laboratory was established to speed up ICT utilization research by unifying that research on the utilization of images and IT that had been conducted individually in each research division and concentrating the technical capabilities and knowledge in RTRI [1].

FY2017 was when RTRI as a whole began in earnest to conduct R&D related to ICT utilization; the ICT Promotion Team, which started its activities in June 2017, organized the direction and specific issues of ICT utilization research in December of the same year [2]. In the next fiscal year, FY2018, the ICT Innovation Project was established to formulate an execution plan for cross-disciplinary ICT utilization research and promote related R&D activities quickly and smoothly [3].

The Division reflected the policy and execution plan discussed and formulated in the ICT Innovation Project in its con-
concrete R&D work programs, placing emphasis on ICT utilization research. In addition, it proposed an R&D plan to develop an ideal form of train operation control system for the future.

The policy and plan presented by the ICT Innovation Project were reflected in the new Master Plan, which ended at the same time as the RESEARCH 2020 plan. This work has now been taken over by the Digital Technology Innovation Project, which was established in April this year [4].

2.2 Background and system of emphasizing ICT utilization research

This section overviews ICT utilization research in the Division during the RESEARCH 2020 implementation period based on signal-communication-related feature papers reported in this journal over the last five years. Table 1 is a complete list of the feature papers published in the signal-communication-related special issues from Vol. 30 No. 1 of RTRI Report (in Japanese), published in FY2015, to the present issue, excluding general articles, survey reports, and commentaries. The table lists the titles of the papers, the laboratories in charge of each research item, and the goals and pillars they related to, with ICT utilization research papers indicated by a checkmark (√).

Papers to be published in the RTRI Report are often written when the outcome of the subject is organized, and there is a time lag of about half a year to one year from the completion of a subject to publication. For this reason, out of the issues in Table 1, those before Vol. 31 No. 3 issued in FY2017 primarily reported on outcomes of subjects started during the previous second Master Plan, and those in and after Vol. 32 No. 5 issued in FY2018 primarily addressed outcomes of research started under the RESEARCH 2020 plan. For reference, the Division was also in charge of R&D follow the previous Master Plan.

As for signal-communication-related subjects, the Division published 34 papers, ranging from subjects that aimed to elucidate hardware-oriented phenomena such as examining the status of signal facilities, life prediction, and lightning damage / inductive obstruction, to subjects proposing systems using wireless transmission or new devices. As can be seen from the “R&D goal” and “R&D pillar” columns in Table 1, there were almost the same number of papers relating to the goals for improvement of safety and cost reduction, while the sum of these two goals accounted for 90% of the total, and basic research occupied half of the subjects under the three pillars. In addition, the effect of emphasizing ICT utilization research as described in Section 2.1 is reflected in the increase in ICT-utilization-related papers since Vol. 32 No. 5 (2018).

3. Research and Development in RESEARCH 2025

3.1 Outline of the new Master Plan

In April 2020, the new Master Plan, RESEARCH 2025, started. RESEARCH 2025 set out five basic policies: (1) Enhancing safety with an emphasis on improving resilience to natural disasters; (2) Innovating railway systems based on digital technologies; (3) Creating high-quality results by taking advantage of our collective strength; (4) Enhancing international presence of the Japanese railway technologies; and (5) Creating a motivating workplace where staff can demonstrate their abilities. Among these, R&D is concentrated on policies (1), (2), and (3) [5].

In relation to basic policy (2), a particular focus is being attached to digital technologies to ensure they are exploited transversally across all R&D fields to yield results that contribute to the realization of railway systems meeting the latest trends, needs and environmental requirements. In order to foster an environment conducive to the uptake of digital technologies across the board, RTRI is also encouraging innovation in the field of railway business application of digital technology, R&D that is able to respond to emerging technological issues, conducting integrated research through interdisciplinary collaboration, and carrying out activities such as utilization and development of R&D know-how and resources in the Digital Technology Innovation Project, mentioned in Section 2.1.

The categories of the goals in the subjects (improvement of safety, cost reduction, harmony with the environment, and improvement of convenience) and pillars (future research, practical research, and basic research) in advancing R&D follow the previous Master Plan.

This section outlines the R&D for the future of railways included in the current Master Plan, “RESEARCH 2025”, and introduces the R&D plans for the realization of autonomous train operation. In April 2020, the new Master Plan, RESEARCH 2025, started. RESEARCH 2025 set out five basic policies: (1) Enhancing safety with an emphasis on improving resilience to natural disasters; (2) Innovating railway systems based on digital technologies; (3) Creating high-quality results by taking advantage of our collective strength; (4) Enhancing international presence of the Japanese railway technologies; and (5) Creating a motivating workplace where staff can demonstrate their abilities. Among these, R&D is concentrated on policies (1), (2), and (3) [5].

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| Vol. No. (Month/year of Issuance) | Feature paper title | Laboratory in charge | R&D Objectives | Pillars of R&D | ICT utilization |
|-----------------------------------|---------------------|----------------------|----------------|----------------|----------------|
| Vol. 30 No. 1 (Jan. 2018)        | A Train Position Detection System Using Inertial Sensors Together with Tachometer Generators | Train Control Systems | Cost reduction | Basic research for railways | ✓ |
|                                  | Safety improvements |                      |                |                |                |
|                                  |                     |                      |                |                |                |
| Vol. 31 No. 3 (Mar. 2017)        | Method of Variable Route Control by the Networking of the Interlocking Devices | Train Control Systems | Improved conveniences | Basic research for railways | ✓ |
|                                  |                     |                      |                |                |                |
| Vol. 32 No. 5 (Aug. 2018)        | Tunnel Lining Crack Detection Method by Means of Deep Learning | Image Analysis & IT | Cost reduction | Development of practical technologies | ✓ |
|                                  |                     |                      |                |                |                |
|                                  | Network Formation Method and Transmission System among Vehicles for Condition Monitoring | Telecommunications & Networking | Safety improvements | Basic research for railways | ✓ |
|                                  |                     |                      |                |                |                |
| Vol. 33 No. 7 (Jul. 2019)        | Method for Estimating States of Electric Pole Machines and Track Circuits Using Remote Monitoring Data | Signaling Systems | Cost reduction | Basic research for railways | ✓ |
|                                  |                     |                      |                |                |                |
|                                  | On-board Train Positioning System Combining Tachometer Generators with Inertial Sensors and GNSS | Train Control Systems | Cost reduction | Basic research for railways | ✓ |
|                                  |                     |                      |                |                |                |
|                                  | Safety improvements |                      |                |                |                |
| Vol. 34 No. 7 (Jul. 2020)        | Rail Deterioration Detection Method of Image Spectral Analysis | Image Analysis & IT, Track Maintenance, Rail Maintenance and Welding | Cost reduction | Basic research for railways | ✓ |
|                                  |                     |                      |                |                |                |
|                                  | On-board Train Positioning System Combining Tachometer Generators with Inertial Sensors and GNSS | Train Control Systems | Cost reduction | Basic research for railways | ✓ |
|                                  |                     |                      |                |                |                |

Table 1: Signal-communication-related feature papers of RTRI Report published in the last five years, excluding general articles, survey reports, and commentaries.
3.2 Research and development toward the future of railways

With regards to R&D for the future of railways, the aim is to anticipate needs with a view to being able to implement outcomes in practice in about twelve years. To this end, RTRI has established six research targets to meet railway operator needs and accommodate changing social trends (Fig. 2).

1) Enhancing resilience to extreme weather disasters
2) Autonomous train operation
3) Labor saving by digital maintenance
4) Low-carbon power feeding networks by coordinated power control
5) Speed increase on Shinkansen considering track-side environment
6) Improving simulation technologies

Of these research targets, "Autonomous train operation", led by the Signalling & Transport Information Technology Division, is outlined in the following sections, highlighting the envisioned future and R&D plans. The Signalling & Transport Information Technology Division is also involved in the "Labor saving by digital maintenance" and "Low-carbon power feeding networks by coordinated power control" programs.

3.3 Aim and R&D plans of autonomous train operation

R&D plans concerning autonomous train operation were introduced at the Annual RTRI Meeting held in February 2020. In this section, we present its aim and plans for the specific subjects.

The purpose of this branch of research is to develop underlying technologies for a train operation control system that allows trains to operate autonomously, safely, and flexibly while controlling wayside facilities, based on digital information on the in-track and wayside conditions, passenger flow, disaster prevention, maintenance, and electricity. It aims to develop a technology that can implement advanced automatic operation with fewer ground facilities so that the automatic operation system, currently installed only in railway sections meeting various conditions, can be deployed in general railway sections at low cost (Fig. 3).

In FY2020, we start a total of five subjects, including four subjects that address the following four technological tasks and a subject related to communication technology for train-to-train control information transmission.

1) Detecting in-track and wayside anomalies with screen images and radar
2) Algorithm that integrates information on the in-track/wayside and vehicle conditions to determine whether train operation is ready
3) Controlling ground facilities autonomously by radio from a train
4) Wide-area train operation control algorithm for delay ripple effect prevention and early recovery from delays, energy saving, etc.

Tasks (1) and (2) of the above four include technologies that are indispensable for the sophistication of the current automatic operation systems and their application to general railway sections, and task (3) includes the core technologies for autonomous train operation. These three are all important tasks in ensuring the safety of the system.

RTRI plans to launch subsequent subjects in sequence during and after FY2021 and implement a total of 10 subjects, while also conducting a demonstration experiment using a test train on the RTRI test line at the end of the final fiscal year, i.e. FY2024. In pursuing these programs,

![Fig. 2 Research and development toward the future of railways](image1)

![Fig. 3 Aim of autonomous train operation](image2)
related underlying technologies, track and level crossing monitoring, train and level crossing control, integration of cloud and other technologies, will be further improved to adapt them for practical use and support RTRI’s final aims. Whilst it is important to draw on past experience and technologies that are unique to the railway signalling communication field, we believe it is necessary to fundamentally review the question, “What should be done and what is required to operate trains safely in the first place?”

The results of the five-year programs of the next Master Plan are designed not only to achieve the ultimate goal of autonomous train operation, but also to form a basis for proposals to enhance and expand existing automatic train operation system to general and other sections. It is expected that it will take just over a decade for autonomous train operation to be introduced in commercial sections including for the completion of migration from the current train operation control and protection systems. Realization of this work will be a gradual process, requiring each hurdle to be cleared one at a time (Fig. 4).

4. Conclusion

This paper overviewed the flow of R&D on ICT utilization in RESEARCH 2020 based on the signal-communication-related feature papers published in this journal in the last five years and detailed the R&D plan for autonomous train operation, which is one of the R&D tasks toward the future of railways under RESEARCH 2025.

Our aim is to realize autonomous train operation that is cost-efficient, safe and secure. To realize autonomous train operation, daunting hurdles must be overcome one by one relating to permanent way monitoring, secure data transmission, methods to control ground facilities through coordination among trains based on information from more than one source, and other areas. Autonomous train operation technologies are also being developed overseas and those involved there 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 continue to work hard on R&D to meet the challenges set out in this paper, 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.

References

[1] RTRI News Release “RTRI Launched Image Analysis and IT Laboratory” : https://www.rtri.or.jp/eng/press/2017/nr20171201_01_detail.html, December 2017.
[2] Kunihiro KAWASAKI, “Trends and Topics in Research and Development Related to the Improvement of Signalling and Telecommunication Systems Using Information and Communication Technology,” Quarterly Report of RTRI, Vol.60, No.1, pp.6-9, 2019.
[3] RTRI News Release “ICT Innovation Project Launched” : https://www.rtri.or.jp/eng/press/2018/nr201805_01_detail.html, May 2018.
[4] RTRI News Release “Digitalization Technology Innovation Project Started” : https://www.rtri.or.jp/eng/press/2020/nr202003_detail.html, April 2020.
[5] RTRI Master Plan “RESEARCH 2025” : https://www.rtri.or.jp/assets/edga9q0000003x7-att/RESEARCH2025RTRI_E.pdf, April 2020.

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