The railway sector is facing major changes due to declining birthrates, an aging society, the intensification of meteorological disasters, and the need to further reduce CO₂ emissions. The spread of COVID-19 since 2020, has had a major impact on the railway business, leading to an urgent need to respond to the drastic changes in demand for mobility in society. Until now, the Signal and Transport Information Technology Division has focused on research and development to further improve the safety and convenience of train operations and reduce the cost and burden of operations related to train operation management. Now, it is necessary to extend research and development to take into account the consequences of COVID-19 by, for example, speeding up our R&D. This paper introduces the purpose and goals of R & D undertaken by the Transport Operation Systems Lab and the Transport Planning and Marketing Lab in FY2020. This paper also describes the R&D concepts and policies for responding to a post-COVID-19 environment.

Key words: train operation control, demand forecasting, digital technology, COVID-19

1. Introduction

The railway sector in Japan is facing major challenges and changes, because of declining birthrates, and aging population, damage from increasingly intense meteorological disasters, and a need to reduce CO₂ emissions and save energy. Furthermore, the Covid-19 pandemic (hereinafter COVID-19), which began in 2020, has also had a major impact on railway business, and we are urgently required to respond to the drastic changes which will affect passenger transport in a post-COVID-19 world.

Until now, RTRI has worked on various R&D topics to contribute to further improving the safety and convenience of train operations, reducing operational burdens related to train operation, and reducing costs. Now however, it is necessary to accelerate and concentrate on R&D in anticipation of post-Covid-19 needs.

This paper overviews the R&D outcomes obtained by the Transport Operation Systems Lab, and the Transport Planning and Marketing Lab in FY2020, and also explains the R&D concepts and policies put in place to take into account the needs of a post-COVID-19 society.

2. Research and development undertaken in FY2020

The Quarterly Report of RTRI Vol. 61 No.4 contains an overview of some of the major R&D outcomes obtained prior to and in FY2019 and outlines RTRI’s Master Plan “RESEARCH 2025,” which started in FY2020, and its key R&D projects [1]. This issue is organized as a special feature issue that reports in detail the outcomes of R&D completed in FY2019, while this paper overviews the outcomes of R&D undertaken in FY2020.

The “RESEARCH 2025” Master Plan lists three basic R&D guiding policies: (1) the improvement of railway safety, especially resilience to natural disasters, (2) the innovation of railway systems by digital technologies, and (3) the creation of high-quality outcomes that demonstrate comprehensive strengths. Following these basic policies, in FY2020 the Signalling & Transport Information Technology Division planned and conducted a total of 35 R&D projects, including five R&D projects for the future of railways, nine practical R&D projects, and 21 basic railway studies.

Cost reduction goals accounted for the majority of projects, 14 in number, whilst there were 10 studies on improving safety and 11 studies to increase convenience. Approximately half of these R&D activities aimed to solve problems by utilizing digital technologies such as machine learning, image processing, data analysis, and wireless networks.

R&D for saving energy, which is one of the major R&D issues for the future of railways, is under the remit of the Transport Operation Systems Lab. which is working on the project on energy-saving driving in “Low-carbon power feeding networks by coordinated power control”, supervised by the Power Supply Technology Division.

The next chapter outlines work done in FY2020 on the main subjects of study within the Transport Operation Systems Lab. and the Transport Planning and Marketing Lab.

3. Initiates related to topics implemented in FY2020

3.1 Transport Operation Systems Lab.

3.1.1 Timetable punctuality evaluation method

Train timetable revisions should ideally be analyzed and evaluated in detail from various perspectives such as user arrival time, train operation frequency, number of transfers, train delays, and operating costs. The revised plans should then be compared with other timetables before a decision is made. However, preparing and evaluating timetable revisions is currently a very time-consuming procedure, which makes it difficult to perform detailed analyses or quantitative comparative evaluations of multiple proposed plans. This R&D project therefore first aimed to establish an evaluation method for timetables, keeping in mind that in the future, automatic proposals and evaluations of multiple schedules should improve the quality and efficiency of operations. Focusing on train delays in particular, a method was constructed to quantitatively evaluate timetables from the perspective of delays [2].

Specifically, the constructed method first identifies the areas affected by the spread of delays at each location, from daily delay record data, and quantitatively evaluates the number of trains and stations in these areas to express the impact of the delay. Then, a method was devised to extract locations which had higher average impact values for a certain period (e.g. 1 month) which would be locations where delay measures should be considered with priority. Finally, a system loaded with this information was developed, to support delay countermeasures (Fig. 1). This has enabled the quan-
tification of the effect of delay countermeasures by applying the proposed evaluation method to the revised data and old data for the timetable.

This system enables us to quantitatively evaluate the validity of delay countermeasures more quickly. This has made it possible to cut the time needed to plan measures to improve punctuality to about one-fifth of the time required until now, which should improve operational efficiency.

3.1.2 Constructing a passenger train selection preference model

A method using data obtained from automatic ticket gates has been developed as one method for estimating the number of passengers on a train. However, conventional methods make estimates of which trains passengers will board along their route on the assumption that there is a certain percentage of passengers who will behave differently. Given that each user’s preferences for selecting which trains they will board along their route depends on the route taken and its situation, improving the accuracy of estimations requires us to know the factors that influence the passenger’s preferences for selecting a train.

Thus, in this R&D, passenger train selection preferences were analyzed using data obtained from automatic ticket gates, train operation record data, open data, and the like; in addition, a method for estimating the number of train passengers based on the analysis results was constructed.

Specifically, using passenger usage record data available from automatic ticket gates, the proposed method extracted the factors that influence passengers’ train selection preferences through decision-tree machine learning and estimated the boarding behavior of passengers from this extraction result. In addition, a decision tree was constructed to determine passengers’ train selection preferences using actual data, and by trying route estimation, it was verified that a generally valid model was obtained (Fig. 2) [3].

With this method, even timetable creators unfamiliar with the mathematical estimation model can intuitively grasp which factors influence train selection preferences.

By the end of this fiscal year (FY2021), the Lab. will build a method for estimating the number of passengers on trains which reflects passenger train selection preferences and verifies estimation results. Once this R&D is complete, the Lab will aim to increase the periods, line sections, and station-to-station sections that can be estimated and also construct a more accurate model by making improvements such as adding a process to exclude data generated in timetable disturbance.

Fig. 1 Example of a method for applying the delay impact evaluation [2]

Fig. 2 Part of an example of a constructed decision tree [3]

3.2 Transport Planning and Marketing Lab.

3.2.1 Study of the effect of railway transport services on the degree of attachment to routes

Looking ahead 10 to 20 years, railway operators are implementing a wide range of measures, including capital investment (e.g. installation of new stations and introduction of new rolling stock) and the revision of train settings (e.g. train timetable revision). In Japan, where the population is declining, for railways to maintain stable demand for their services, it may be effective to increase the attachment of wayside residents to railway routes through these medium- to long-term measures.

Railways are therefore studying a method to quantitatively analyze the relationship between railway transportation services, attachment to railway routes, and future intentions of residents about using urban railways. A preliminary study was conducted by the Lab. using academic findings in the data analysis and marketing fields. It then conducted a survey to gain insight into actual user values and satisfaction with railway transport services and their attachment to routes, and extracted and systematized the railway transport service factors which could influence these values and satisfaction (Table 1) [4].

The results of this preliminary exploration helped clarify the factors which affect the degree of attachment to routes. For example, regarding the degree of attachment to railway routes, the degree of attachment to railway lines did not increase even if they have been using the railway for a longer time. In another example, in addition to convenience including punctuality, express routes, and the number of in-service trains, the results showed that the degree of
attachment was relatively highly related with the newness and design of rolling stock and station facilities [4].

They continue to study the relationship between user values for various services in railway use and intentions to continue living in the area.

### 3.2.2 Evaluating the convenience of pattern diagrams on regional railways

Having features such as “Trains depart at regular intervals” and “One-hour cycle timetables,” pattern diagrams (Fig. 3) are considered to be one of the means to provide easy-to-understand transport services to passengers and regions. The effects of patterned timetables on passenger evaluation of and demand for transport services are, however, not clear, and it has not yet been possible to take them fully into consideration to inform transport measures.

Thus, the Lab. conducted a basic analysis of how passengers evaluated timetable convenience, in order to understand the effect that introducing pattern diagrams on regional railways would have on passenger perceptions of convenience. First, in order to understand differences in user evaluations of timetable patterning, they conducted a web questionnaire survey to collect data about how passengers evaluated the convenience of various timetables with different characteristics, including pattern diagrams, among residents along regional railway routes throughout Japan. Based on the data collected, a regression analysis was conducted to express the evaluation of convenience of timetables by passengers, by using the characteristics of timetables (e.g. number of trains in operation and trains departing at equal intervals) as explanatory variables, and the effects of those characteristics of timetables on passenger evaluations were quantified. The results showed that (I) pattern diagrams which included the characteristics of trains departing at regular intervals and train times shown as a one-hour cycle, increased convenience from the passengers’ point of view, and (ii) the strength of the effect differed depending on the number of trains in operation [5].

This suggests that the introduction of pattern diagrams on regional railway routes could improve convenience. The Lab. then applied the constructed model to an actual timetable revision and carried out the convenience evaluation calculation of the revised and old timetables. Future work will focus on deepening this research and analysis, in particular, taking into account ‘ease of remembering timetables’, ‘user habits in using the railways’, and how people imagine timetables should be organized.

### 4. Research and development for a post-COVID-19 society facing a ‘new normal’

As mentioned in the introduction, the Signalling & Transport Information Technology Division has to date been engaged in R&D that contributes to the achievement of three goals in order to respond to major changes in the social environment, such as declining birthrates, an aging population, intensified meteorological disasters, and the need to reduce CO₂ emissions. These can be expressed as:

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| Table 1 Example of awareness survey results for transport services [4] |
|---------------------------------------------------------------|
| **Classification** | **Sub-classification** | **Importance**<sup>1</sup> | **Satisfaction Level**<sup>2</sup> |
|-------------------|------------------------|--------------------------|-----------------------------|
| Fare              | -                      | 0.135                    | 3.15                        |
| Time required     | -                      | 0.069                    | 3.01                        |
| Number of trains  | -                      | 0.155                    | 3.38                        |
| Number in operation | -                      | 0.044                    | 3.55                        |
| Timetable         | -                      | 0.102                    | 3.57                        |
| Access            | -                      | 0.039                    | 3.31                        |
| Vehicle side      | -                      | 0.027                    | 3.09                        |
| Station facilities| -                      | 0.046                    | 3.47                        |

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<sup>1</sup> Relative evaluation with the total assumed as 1.<br>
<sup>2</sup> Average in 5-grade evaluation from 1 to 5. The higher the value, the higher the satisfaction level.

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**Outbound trains for XX station**<br>**Inbound trains for YY station**

| Hours | Minutes | Hours | Minutes |
|-------|---------|-------|---------|
| 10    | 07 22 37 52 | 10    | 03 18 33 48 |
| 11    | 07 22 37 52 | 11    | 03 18 33 48 |
| 12    | 07 22 37 52 | 12    | 03 18 33 48 |
| 13    | 07 22 37 52 | 13    | 03 18 33 48 |
| 14    | 07 22 37 52 | 14    | 03 18 33 48 |

**Fig. 3 Example of pattern diagram**

This suggests that the introduction of pattern diagrams on regional railway routes could improve convenience. The Lab. then applied the constructed model to an actual timetable revision and carried out the convenience evaluation calculation of the revised and old timetables. Future work will focus on deepening this research and analysis, in particular, taking into account ‘ease of remembering timetables’, ‘user habits in using the railways’, and how people imagine timetables should be organized.

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reduction of personnel and costs involved with train operation and facility maintenance, (ii) implementation of a train operation control system that can quickly recover and continue train operation while ensuring safety even in the event of an abnormality such as a disaster, and (iii) further energy saving by energy-saving driving, power storage technology, etc.

The COVID-19 pandemic which began to rage in 2020, has brought fresh challenges, which are also affecting the railways. There is therefore an urgent need to respond to the dramatic changes in the transport needs of society, as it enters a new normal in a post-COVID-19 era. The work mentioned so far in this paper will contribute to the establishment of technologies required to reduce fixed costs and flexibly respond to changing needs in maintaining railways in the society with COVID-19. The speed of R&D should be further accelerated especially for the labor-saving and automation technology for facility maintenance and the technology for supporting or automating train operation control to maintain safe and stable operations not only in the event of disasters but also in abnormal situations such as the spread of infectious diseases.

One of our first aims is to reduce the workload and time needed to make decisions and predictions, and increase automation by developing methods which exploit a variety of different types of data, the latest data processing, and AI. We will aim to achieve low cost and high reliability of systems and equipment simultaneously by constructing (i) reliability/valilation evaluation methods with high-speed processors, such as general-purpose CPUs and GPUs used in applying AI, and wireless communication network technologies, such as the 5G Mobile Communication Systems to safety-related work and (ii) methods to detect abnormalities in decision-making and processing results.

We will also work on the R&D for the future to change to a system that can achieve both of the following: (i) autonomous train operation and (ii) equipment and energy saving, by constructing a cross-sectoral data-sharing infrastructure or migrating to automatic train operation.

In addition, our aim is to speed up the provision and roll-out of research outcomes. To date, findings have only been released when the degree of perfection had been fine-tuned to a high degree and practicality and reliability were ensured. However, now, even if research outcomes can only be used within certain constraints or have limited performance, it is important to release or provide these outcomes as soon as possible to satisfy the needs of railway operators albeit only partially. In terms of outcomes using digital technology in particular, since the development and obsolescence of base digital technology is itself a rapid cycle, we should deliver solutions to railway operators as soon as possible so that they can be updated in service. Of course, the performance and effect should be verified carefully regarding the issues directly related to safety and passenger satisfaction, while other R&D outcomes will still have to be developed to a refined level before they can be released to be used in service. As such, R&D outcomes will be handled on a case by case basis, and railway operators will be consulted, before they can be released to be placed into service.

5. Conclusion

This paper outlined and described the status of R&D activities relating to transportation and transport planning that were implemented in FY2020. It also described R&D policies aimed at facilitating railway maintenance and development in a post-COVID-19 society.

COVID-19 is not expected to disappear completely, and also spread rapidly across in Japan from December 2020. As such, it is necessary to prepare long-term and continuous infection prevention measures. Even as the pandemic slows COVID-19, passenger demand and use of transport is not to expected to return to pre-COVID-19 levels. Nevertheless, railways are an important social infrastructure that supports activity in society. Therefore, if trains can operate safely and stably, they can contribute a sense of security in people’s lives and, by extension, support social stability. Currently, vaccination is widely progressing, and the development of therapeutic agents is also progressing, and it is expected that the number of railway passengers will increase after the end of COVID-19 pandemic. So, it is also important to consider what technologies are required to adapt to the shifts in the way people use transport and its distribution patterns in a post-COVID-19 society, and ensure these considerations are reflected in future R&D. Our R&D work will also strive to foster cooperation with Japanese domestic and overseas railway operators and research institutes, manufacturers, and universities with advanced technologies so that we can do everything we can to contribute not only to the maintenance of railways as social infrastructure, but also to promote its development into the future.

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