Toward Railway Innovation

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Comfortable and Pleasant Railway

Mr. Ryuji Tsuchiya
Managing Editor
(General Director, International Division)

Towards More Comfortable Railways

Providing passengers with greater comfort is one of the key enablers for enhancing customer experience and making passenger railways more competitive with each other, as well as other transportation modes. It should also be pointed out that the rapidly growing wave of digitalization across almost all aspects of railway operations, including train operation, maintenance, and passenger services, has two important implications relative to passenger comfort. On the one hand, commercially available digital technologies, including the Internet and smartphones, are promoting the launch of a variety of passenger information services which accommodate the ever changing needs of passengers. On the other hand, digital technologies are a strong R&D tool to assist in making railways more comfortable. In order to build more comfortable environments for passengers, it is necessary to undergo a quantification process in which the notion of "comfort" is broken down into clearer components, the criteria for evaluating "comfort" are defined, and solutions to measure and improve the comfort level based on those criteria are devised. In other words, it is inevitable for us to use digital technologies through the process of quantifying the apparently ambiguous and broad notion of "comfort."

This issue of the Ascent magazine features current trends of railway comfort studies as well as some of the solutions that RTRI has developed for improving passenger comfort.

If the articles contained in this issue of the Ascent aid our readers who are involved in improving railway comfort around the world, I could not be happier.

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Digitalization Creating the Future of Railways

On May 1, this year, Japan celebrated the start of the new Reiwa era. Referring to the date by the specific era name, or "gengo", is a system deeply rooted in Japanese history, and the start of a new era is a refreshing change for us. Now we would like to welcome this Reiwa era with hopes for peace and prosperity.

Meanwhile, what can we expect for railways in the years within and beyond the Reiwa era? We hope that they will provide significant means of mobility with enhanced values, namely a safer and reliable, universal, and enjoyable mode of transportation.

Railways will be faced with certain challenges in the years ahead. Among them, it is particularly important to address the issue of declining numbers of working people, who today represent a large segment of our passengers, and the issue of increasingly powerful natural disasters. Furthermore, we also need to explore more ambitious measures such as further speed increases associated with Shinkansen's autonomous train operation and advancements in energy-saving technologies. To solve these issues, digital technologies are essential tools.

It is crucial for RTRI to further enhance five strengths of railways: 1.) safe and stable transportation, 2.) high-speed operations, 3.) mass transport capacity, 4.) punctuality, and 5.) energy efficiency. Accordingly, we have pursued safety enhancements through research into seismic measures for Shinkansen, earthquake-proof reinforcement of structures, and various human factor issues. Going forward, we will aim to cause a paradigm shift in railway systems through digitalizing railways through the utilization of integrated communications and controlling technologies. In targeting such digitalization, we will address the tasks of enhancing safety of train operation, automating maintenance, and developing autonomous train operation.

Dr. Norimichi Kumagai
President
Railway Technical Research Institute

In order to enhance safety of train operation, we will develop technologies to estimate the damage caused by natural disasters in real time while assisting in the early restoration of operations by estimating and monitoring precipitation amounts, wind speeds, water levels of rivers, and changes in slope conditions in order to minimize the infrastructure damage. We will also develop technology related to obstruction monitoring at stations as well as a human error prevention system that monitors drivers' physiological indices, including concentration and drowsiness.

As part of our advancements toward automated maintenance, we will address condition monitoring of facilities, automated diagnosis, failure prediction, and automated maintenance planning in order to reduce maintenance costs and labor. In order to achieve autonomous train operations, we will develop technologies for automated driving, autonomous routing by each train, and automated preparation of demand-based timetables. In addition, we will be building a shared platform to analyze the big data associated with maintenance, track conditions, and local weather.

We must create a new system by fusing new digital technologies into our knowledge, experience, and manufacturing techniques that have been developed over the years. For this purpose, it is important to provide a unique workplace to inspire creation of technology and expertise in order to attract and develop human resources for the new era.

Furthermore, we have been actively committing to the international standardization of railways in order to develop the overseas market for Japanese railways in this age of railway industry globalization. We will continue focusing on various activities to enhance the presence of Japanese railway systems through, for example, hosting the 12th World Congress on Railway Research.

Under the vision “We will develop innovative technologies to enhance the rail mode so that railways can contribute to the creation of a happier society”, RTRI will continue to address the challenges of research and development for the future of railways. In this new era of Reiwa, I wish all of you peace and prosperity, and your continued support for RTRI would be most appreciated.

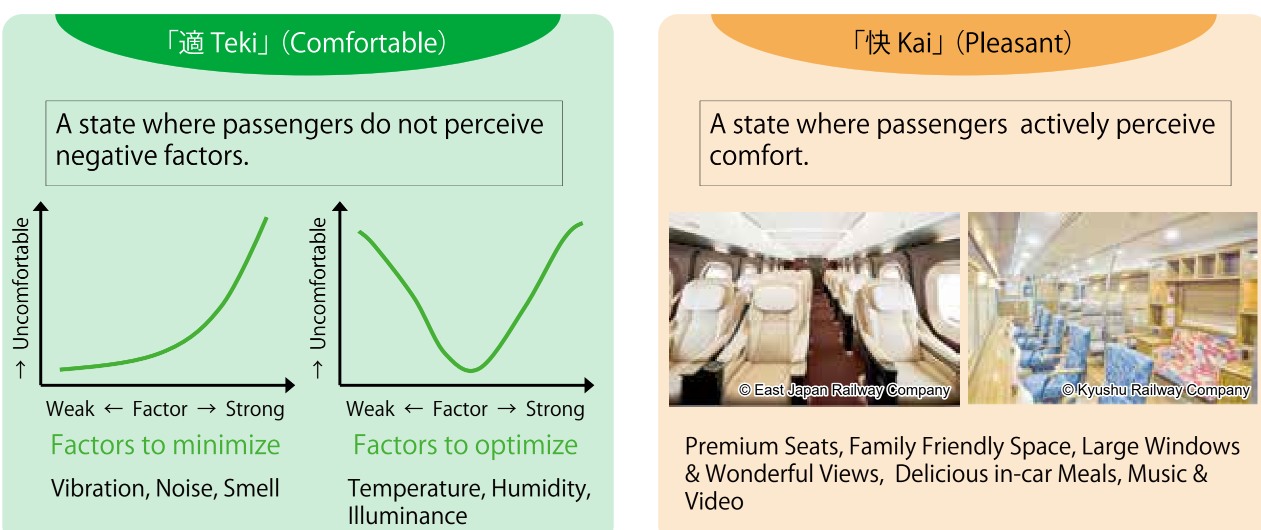
Comfort and Digitalization

Dr. Hiroaki Suzuki
Principal Researcher
Research and Development Promotion Division

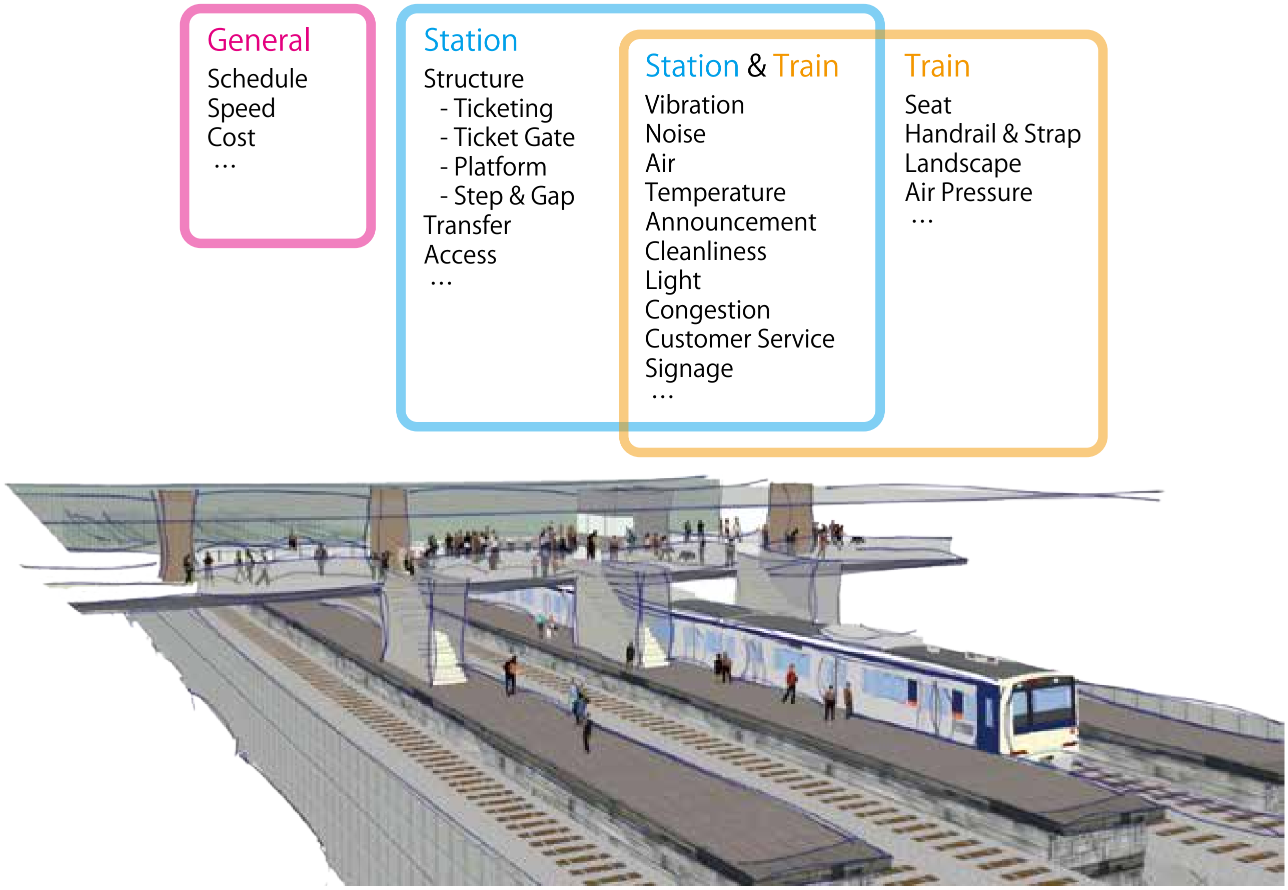
Technologies to minimize vibration and noise on trains must be developed to provide good ride comfort. It is also important to develop ways to measure the sense of comfort and discomfort of passengers because the concept of "comfort" is ambiguous. If an index of discomfort resulting from vibrations can be developed, it can be utilized to evaluate technological development aimed at minimizing that particular discomfort. To enhance the competitive edge over aircraft and expressway buses, railways have endeavored to increase speeds, improve stations, and optimize train schedules. These efforts are made through research to improve the overall comfort of passengers and to enhance customer experience at all the contact points with the railway transport service. Recently, the development of digital technologies is making it possible to further improve comfort. This article describes the basic concept of research on comfort and the direction of future efforts.

What is the Japanese word for "Comfort"?

The Japanese word for "comfort" is "Kai-Teki" (快 – 適). This word, which originally derived from a classic Chinese poem, is an important keyword in explaining the modern railway service in Japan. Let me attempt my own interpretation of this word. In English, "Pleasant" and "Comfortable" are two words with close meanings but different nuances. In Japanese, however, there are no words that can express the differences of nuances of these two English words. The word "Kai-Teki" consists of two Chinese characters with meanings close to "Comfortable." The second character "Teki" (適) also has the



Concept of "Comfort" is divided into two aspects



Factors affecting passengers' comfort/discomfort

meaning of "Proper." Here, I am venturing to define the second character "Teki" as "Comfortable" and the first character "Kai" (快) as "Pleasant." In other words, "Teki" represents a state without any uncomfortable stimulus. For example, it represents an environment on trains and at stations with reduced noise, vibration, and congestion and optimized temperature and lighting intensity; where passengers do not feel uncomfortable. These are the basic requirements to be satisfied so that efforts to increase "Teki" should form the basis of commuter transport. On the other hand, "Kai" represents a state in which pleasures are provided positively on trains and at stations, such as premium seats, family friendly space, large windows and wonderful views, delicious in-car meals, and music and video services. This state is realized by enhanced services intended to acquire new customers or enhance customer experience. As passengers' demand for services tends to get higher as time goes by, services that were "Pleasant" in the past may be recognized to be "Comfortable" at present. Some examples of such services are Wi-Fi access and power outlets for laptops and smartphones at stations and on trains.

What has been researched

Research and development to improve comfort has been conducted in the following three sectors:

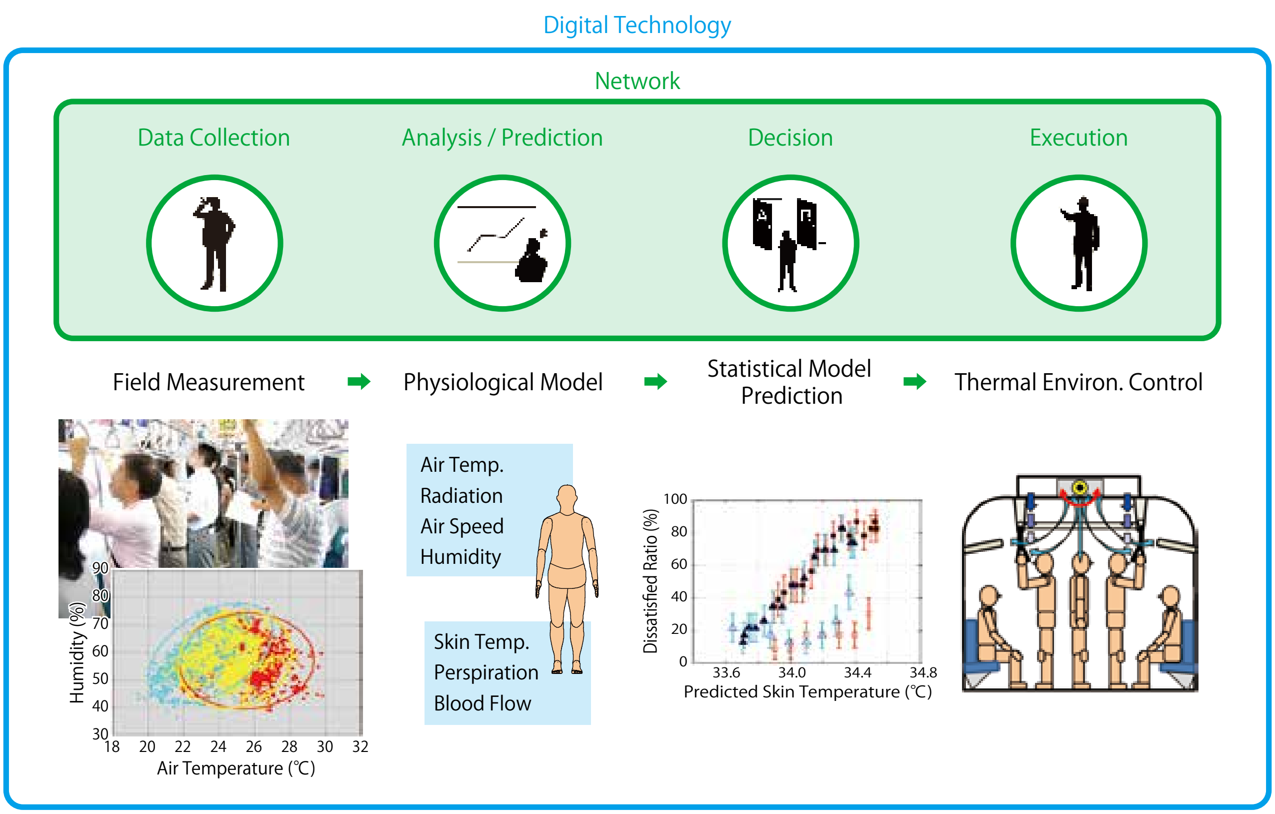
(1) On trains (vibration, noise, temperature, congestion, seats, etc.)
(2) At stations (train boarding and alighting, ease of movement, signage, announcements, etc.)
(3) In the railway usage environment (number of train services, train schedules, fare settings, access to stations, etc.)

First, research and development on vibrational discomfort on trains is described as an example. Vibrations with the same physical intensity but different frequencies have different perceived intensities. Therefore, a filter that corrects the physical vibration intensities according to how they are felt by people was devised in an effort to develop an evaluation index of ride comfort. For example, a vibration with a frequency less than one hertz is the main cause of motion sickness. A passenger survey on trains that run in mountainous sections discovered that the number of people who get motion sickness increased in sections with frequent lateral motions of approximately 0.3 Hertz. As a result, a car that prevents motion sickness can be developed if the motion of a tilting train can be controlled to avoid this frequency band. Efforts were also made in research and development to develop a vibrational discomfort index that matches how passengers feel and helps with track management and to discover ratios of factors such as vibration, noise, seat design, and views that have impact on the overall comfort on trains.

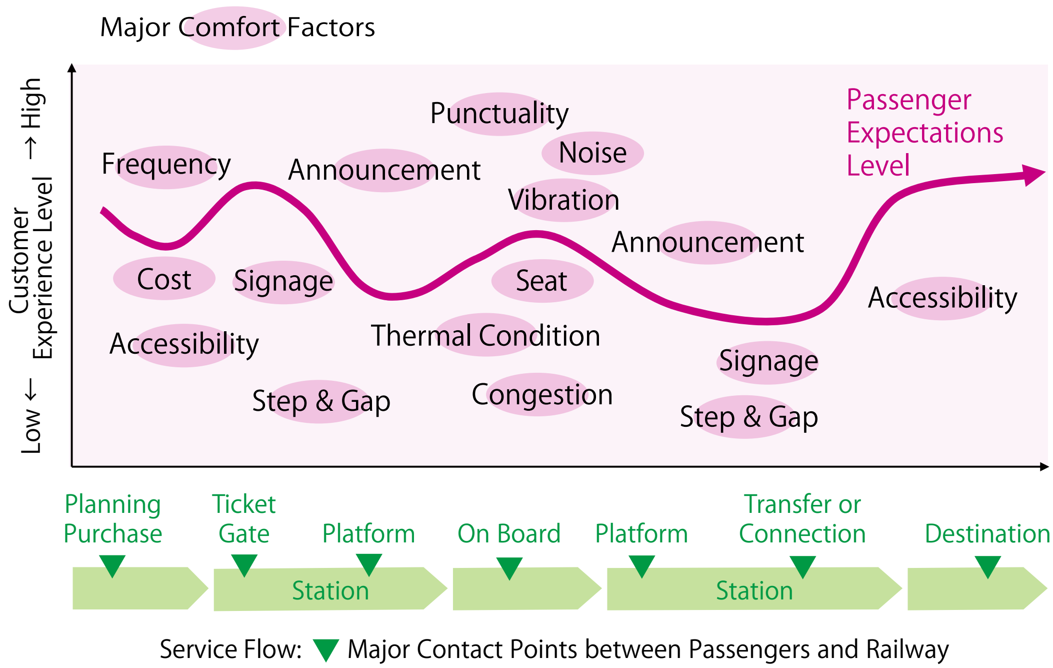
For stations, an evaluation index for difficulty of walking on the premises was developed. A simulation was also developed to visualize the flow of passengers. Efforts were also made to develop evaluation indexes of ease of listening to announcements and overall comfort of station space. Although trains operation are very frequently in Japan, congestions and delays still occur in the morning and evening. Research and development have also been conducted to quantify the degree of discomfort due to congestions and delays and optimize train schedules to adjust train intervals and level out congestion. Whereas the main approach to the study of comfort was to develop evaluation indexes and utilize them in improvement measures, the recent development of digital technologies is enabling further development.

Enhancement of customer experience by use of digital technologies

Digitalization refers to conversion of continuous analog quantities to discrete digital quantities. However, recent advancement and cost-reduction of sensors, computers, and networks have expanded the concept of digitalization. Digital data stored on computers and shared over a network is used for the sake of prompt and precise identification,



An example of utilizing digital technology for the control of thermal comfort



Examples of major comfort factors for enhancing customer experience

analysis, prediction, and judgment of system states. This process is called digitalization of operations. Whereas RTRI has already promoted digitalization efforts in the safety and maintenance sectors, digitalization can also be applied to the study of comfort.

The operational reform based on digitalization is conducted as follows: (1) Various factors that have impact on comfort at stations and on trains are converted into digital data and collected over a network (Data Collection); (2) Collected data are analyzed to reproduce the degrees of comfort in a digital model and identify and predict states (Analysis and Prediction); and (3) Methods for further enhancing degrees of comfort are formulated (Decision) to control the environments precisely (Execution).

For example, the thermal environments at stations and on trains change according to the temperature, humidity, radiation, air speed, and congestion. These are analyzed precisely to realize an optimal thermal environment. This is the digitalization of thermal comfort. Conventionally, the thermal environment on trains is controlled by conductors. However, thermal environment control by introduction of digital technologies is indispensable in the light of the future introduction of unattended- train operations. For vibration factors, the introduction of active vibration control technology by detection of vibration states of trains is under way. Moreover, the control based on digital technologies can also be applied to other factors such as ease of listening to announcements, glare of sunlight, air quality and odors.

The sense of satisfaction of passengers is influenced by the physical factors and customer services at all contact points, such as reservation and purchase of tickets, passage through ticket gates and movement on station premises, waiting time on platforms, train boarding and alighting, and environments on trains. In the future, RTRI will promote the efforts not only to improve the individual contact points but also to integrate the contact points to enhance the customer experience and thus improve the superiority of railways.

Passengers' Comfort in Railway Vehicles

Dr. Chizuru Nakagawa
Senior Chief Researcher
Head of Ergonomics Laboratory

The previous studies on passengers' comfort in railway vehicles focused on the efforts to make the vibrations, noise, and thermal environments as close to "optimal" conditions as possible. Increasingly, there have been more and more efforts in recent years dedicated to creating "comfortableness", which is discussed in this report.

Past studies examined means of producing an "optimal" environment

Vibrations environment (motion sickness and riding comfort)

When it comes to vibrations, the corresponding perceptual organs of humans differ according to frequencies and directions. For instance, "shaking" , which is vibration with low frequency (under 1 Hz}, becomes the main cause of motion sickness. The results of the research involving passengers on a train running over a mountainous route have revealed that, of those experiencing motion sickness, the majority became ill in a section with frequent lateral motions of approximately 0.3 Hz. Even if the intensity of vibrations is the same, the perceived intensity will differ at the different frequencies. Therefore, in order to assess the vibrations, a weighting filter needs to be applied based on frequencies to conform to how humans feel. For measuring motion sickness, studies on seasickness aboard ships are ongoing where the indicator Motion Sickness Dose Value (MSDV) is defined in international standards. To apply this measurement system to trains, we have developed the indicator MSDV-y in which the lateral (y) vibration is added. Some trains running at high speeds in curved sections are equipped with car body tilting systems. This indicator is used to explore means of controlling car body tilting in a manner that reduces passengers' exposure to feelings of motion sickness.

In the 0.5-60 Hz bandwidth, vibrations are highly impactive relative to "riding comfort". We have used this bandwidth to reflect the human perception sensitivity to vibrations and proposed a method of estimating the sensory ride comfort using the measured vibration acceleration data obtained by synthesizing the vertical, lateral, and longitudinal vibrations. We have also developed the "Integrated Display System for Riding Comfort Information" that enables the integrated display and understanding of these estimated values with vehicle, track, and other interdisciplinary information. Since use of this system allows us to intuitively determine what vibrations affect the riding comfort, the system is used to identify the factors deteriorating the riding comfort and take measures to improve them while validating the effects of the measures.

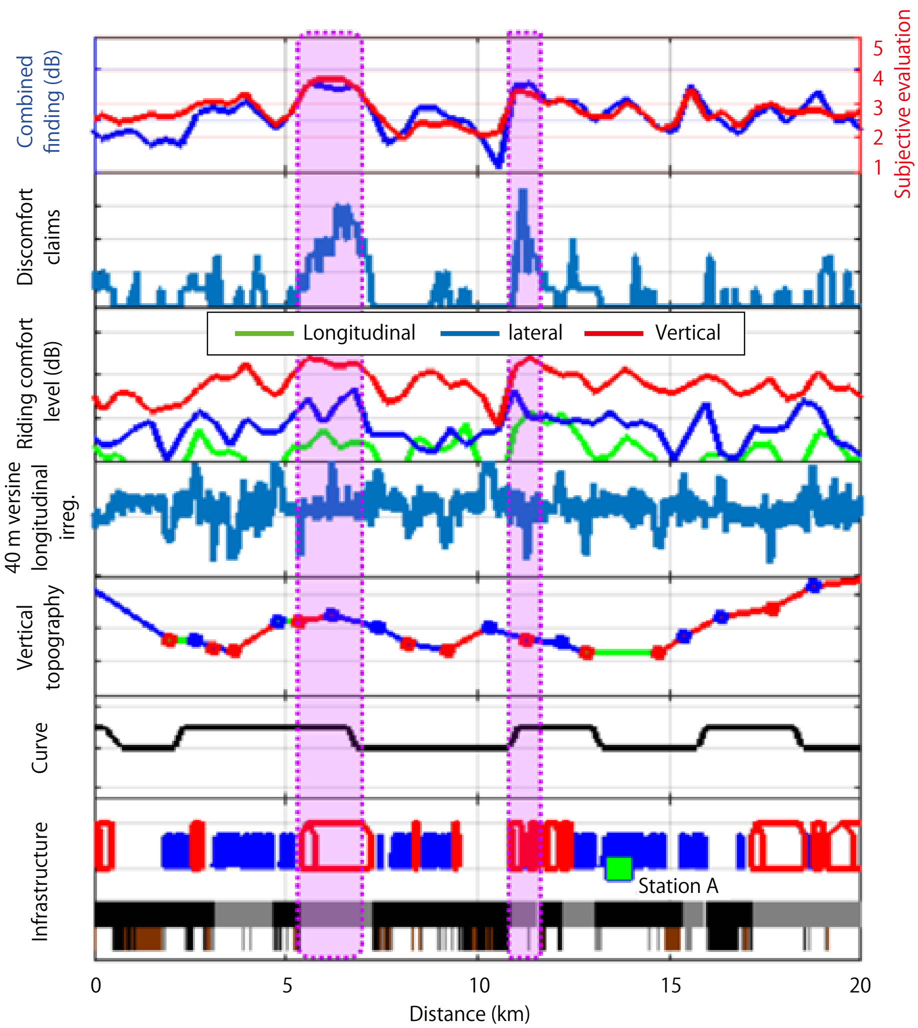
Noise environment

The vibration at 20 Hz or more is also perceived as noise. Again, the level of the sound loudness experienced is not proportional to how discomfort is felt. This is especially true when considering voices intended to provide important information during a conversation. It is difficult to decide whether they contribute comfort or discomfort by simply judging from their sound pressure or auditory perceptive characteristics. In our study, we have found that the chatter of the passengers sitting next to the study's subjects and the ringtones of mobile phones are felt more uncomfortable than the vehicle running noise at the same sound pressure. The reason is thought to be because the running noise is derived from the vibration associated with traveling, which is deemed to be advantageous, and therefore tolerated considering that it cannot be avoided. Conversely, the neighboring chatter and mobile phone ringtones are nuisances without any associated benefit, which causes passengers to feel uncomfortable.

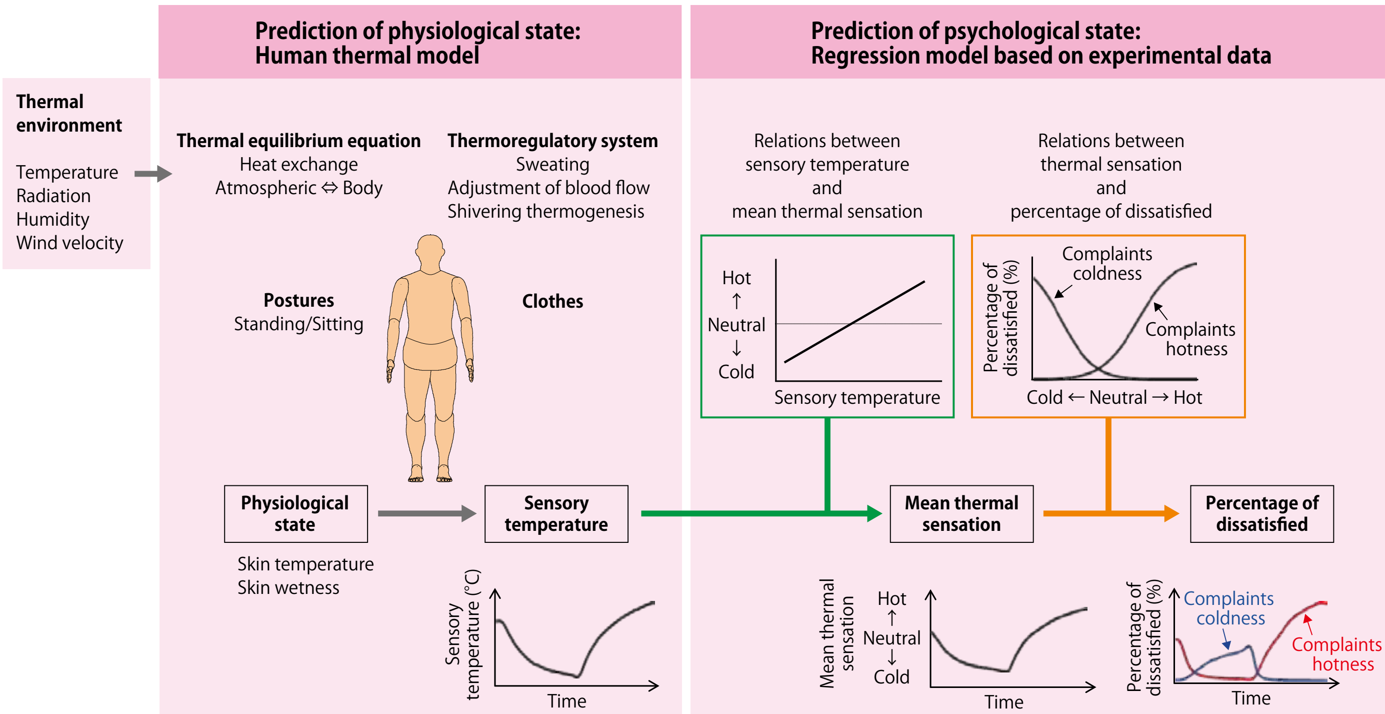
The mutual effects between the vehicle running noise and vibration were examined through an experiment using an in-car comfort simulator. It was concluded that the vehicle running noise creates the illusion that, as the sound volume decreases, the vibration also decreases. However, it has been verified that the opposite to those findings does not occur. If the running vibration decreases, we do not feel that the noise is reduced. Instead, if the noise is heard at a lower level, we feel the vibration has increased rather than the noise has decreased.

Thermal environment

Many of the complaints from passengers are related to the thermal environment. Such complaints have the common characteristic that it should be neither too warm nor too cool. The thermal environment is also greatly affected by such factors as the clothes, gender, and physiques of individuals. In addition, it is easy to produce temperature changes on trains by the opening/closing of doors and the loading/unloading of passengers. Particularly in commuter service, the temperature in railway vehicles is hard to control since they can fluctuate greatly depending on the number of passengers, frequent door openings, and the size of opening areas. Under the circumstances, we propose a method of predicting the thermal sensations experienced by passengers, which are difficult to quantify, through the use of the bodily sensation experiment data for the thermal environment in a railway vehicle. We are proceeding with the research to contribute to the realization of an in-vehicle thermal environment which is comfortable throughout the year.



Displaying along distance structure of track, infrastructure and vehicle vibration data reflecting the human perception sensitivity to vibration, the causes for the vibrations can be multilaterally identified and analyzed. The combined findings estimating the sensory ride comfort, obtained by synthesizing the measured vertical, lateral, and longitudinal accelerations are in good agreement with the bodily sensation assessment in an experiment.



RTRI propose a method of predicting the thermal sensations experienced by passengers, which is composed of two sections: physiological state prediction section and psychological state prediction section.

Recent efforts towards establishing "comfortableness"

In recent years, the railway passenger companies have been marketing campaigns advertising the enjoyment of "rail travel", such as on cruise trains. The in-vehicle information accessibility and information service are enhanced by installing monitors and providing power points and a WiFi environment. As such, there are only a few elements to be studied for "comfortableness". However, RTRI has studied the effect of odor (scent) and obtained the result that the sensory temperature varies according to the effect of scent.

Progressing towards future enhancement of passengers' comfort in railway vehicles

Considering the future enhancement of passengers' comfort in railway vehicles, one of its critical features will be the public nature of railways, that is, sharing the "place" and "time" with others in the age of the driving of autonomous cars. Since human beings are social animals, a place to share "comfortableness" with others while moving will bring about new value. Amid the population decline, it is more critical to promote the repeated use of railways. To achieve this target, it is possible to estimate the psychosomatic states of passengers from the image, audio, physiological, and other data and encourage them to act for the better and make a psychological change.

Approach to Make Stations More Comfortable

A full-scale simulated model of an over-track station (a Station Simulator)

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Assistant Senior Researcher
Architecture Laboratory

Current State and Change of Train Station Environment

Recently, some of the concourses at terminal stations in Japan are beginning to have shopping and dining facilities. This gives them the characteristics of a space for staying instead of a space for passing through, as in the past. In addition, railway operators are trying to expand businesses at stations to increase the number of visitors. This is needed because, in this age of declining population, the number of passengers is expected to decrease in the long-term.

The introduction of escalators and elevators has made it easier for visitors to move around concourses and other

Walking experiments and complicated passenger flow experiments are conducted on the Station Simulator to accumulate and update the database on passenger behaviors. It allows to develop evaluation methods on public announcement and thermal environments, which are both important to the comfort of a station space.

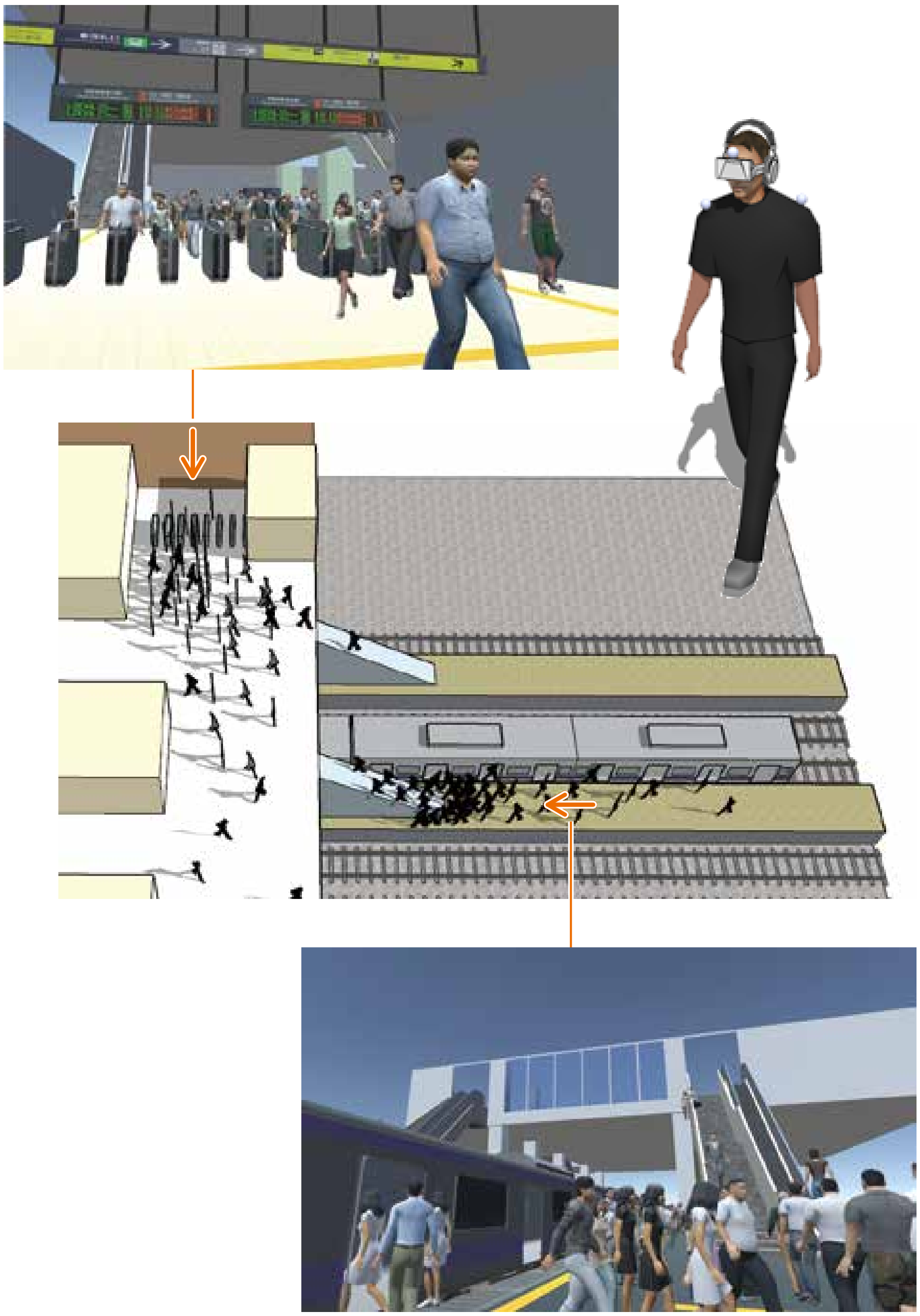
station spaces. However, they have not yet necessarily formed a comfortable environment for staying.

Approach to Building a Comfortable Train Station

"Comfort" is becoming an essential element in enhancing the appeal of a train station. However, no sufficient discussion or study has been conducted yet on how to realize comfort in designing a station because of the difficulty in quantitative measurement of human senses in an indoor or semi-outdoor station space.

To solve this problem, RTRI has built a full-scale simulated model of an over-track station (a Station Simulator) and is using it to conduct experiments for evaluation of a station space.

One example is the evaluation of train overcrowding. To reduce train overcrowding during morning rush hour, which is recognized as a problem in Japan, we are developing a simulation that visually reproduces passenger flows on station premises. Regarding passenger behaviors, data such as walking speeds vary according to changes in the social environment such as the age of the population and widespread use of smartphones when walking. Therefore, we are conducting walking experiments and complicated passenger flow experiments on the Station Simulator to accumulate and update the database on passenger behaviors. Furthermore, we are conducting Station-Simulator experiments and developing evaluation methods on public announcement (difficulty in understanding public address) and thermal environments, which are both important to the comfort of a station space.



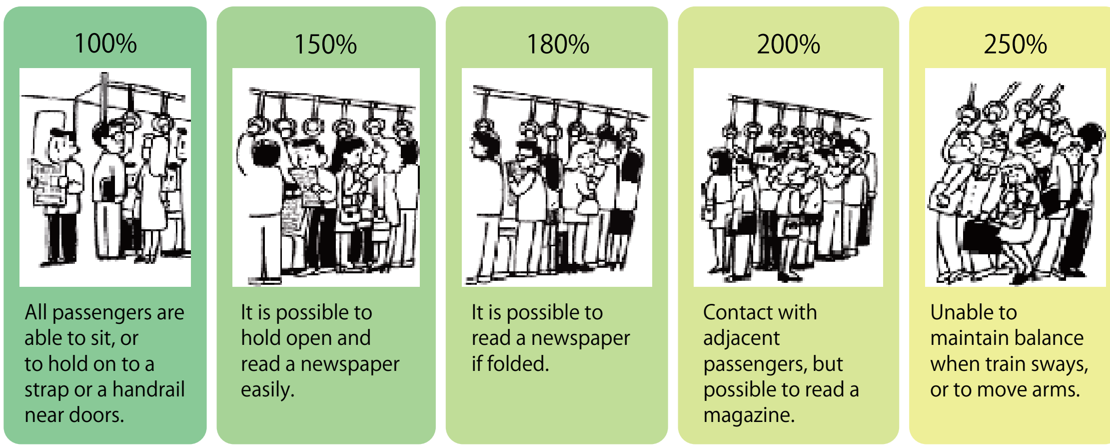
VR(Virtual Reality) simulation of walk-through in a station wearing a head mount display

Future Prospects

We are in an age when a station environment can be easily digitalized by construction of a station space using virtual reality (VR) technologies and used to forecast passenger flows and thermal environments through IT-based information collection. The Station Simulator has an advantage of allowing us to conduct experiments that are hard to conduct in an actual station space (due to difficulties in reproducing the same conditions and making long-term measurements). There are also restrictions in using a real space due to its fixed size and difficulties in changing the environmental conditions.

In the future, we intend to develop experimental methods that integrate factors that can only be reproduced in a real space (such as overcrowding and oppressive feelings) and those which can be digitalized by VR technologies. Finally, we will pursue development of a system that allows us to evaluate a station environment by implementing various evaluation methods such as thermal environment, overcrowding, and ease of understanding of public address as digital inputs to simulated passengers.

Mitigation of Overcrowding Train



Passenger congestion levels (PCLs)

Overview

Overcrowding on trains is a source of discomfort for passengers. Overcrowding on trains on metropolitan railway lines in Japan during morning and evening rush hours is recognized as a social problem. Overcrowding also causes train delays so that various efforts are made by railway operators to reduce it.

The use of ICT has recently made it possible to acquire data on daily train delays as well as passenger congestion levels (hereinafter referred to as PCLs). The large amount of past data has allowed RTRI to formulate a method of analyzing and forecasting daily train delays and PCLs At present, we are studying a traffic control system that may be capable of reducing train overcrowding and improving passenger comfort in the future.

Passenger congestion levels of urban railways in Japan and reduction measures

In metropolitan areas in Japan, overcrowding on trains during morning and evening rush hours is recognized as a problem. Whereas the Japanese Ministry of Land, Infrastructure, Transport and Tourism has set a goal of attaining a PCL of 150% or less, many of the train lines in the Tokyo

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Mr. Daisuke Tatsui
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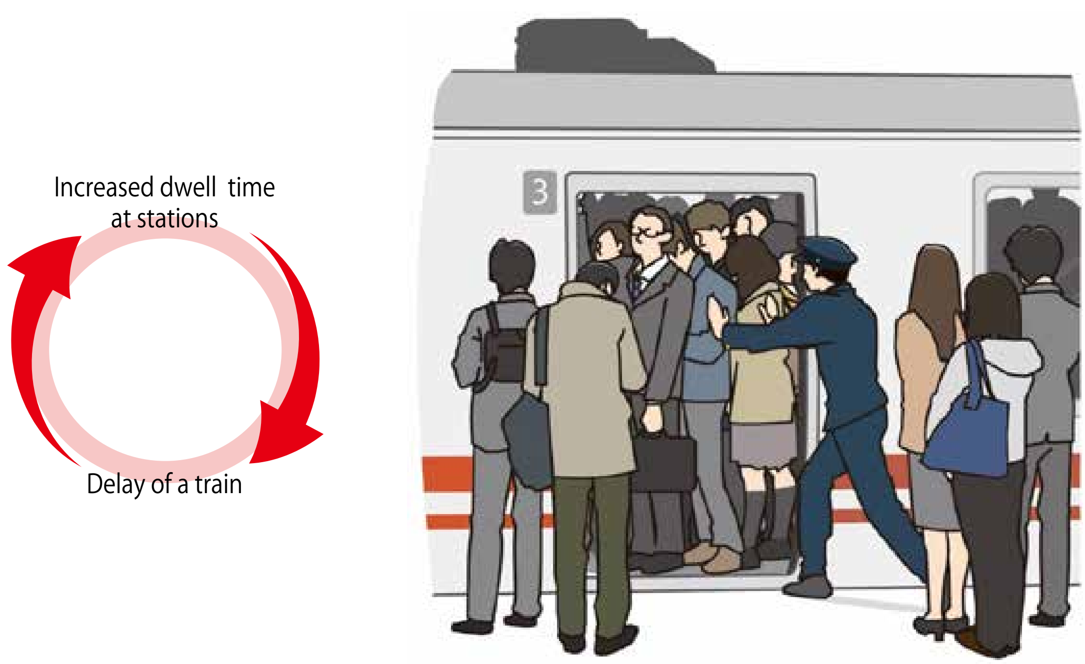
metropolitan area have a PCL of 180% or more. The reduction of such high PCLs is required.

Overcrowding on trains also causes train delays. The more crowded a train, the longer it takes for passengers to get on and off at stations. This means the train stands for a longer time at the stations, causing it to get behind schedule. Delaying a train expands the interval between it and the preceding train causing a higher concentration of passengers at a station at which it is going to stop. As a result, the standing time at subsequent stations increases further and the delay expands further.

Railway operators are taking measures to reduce train overcrowding. Even though an increase in the number of trains is difficult due to limitation by track capacity, operators are attempting to level out PCLs between trains by adjusting train intervals using revised train schedules and traffic control. Recently, they are also beginning to introduce or upgrade a "reserved-seat service with additional fare" for some trains in appropriate time slots in order to ensure passengers can have a seat during transportation.



Congestion results in the vicious circle of train delays and increase dwell times

Use of digital data for measures against overcrowding

Recently, progress in ICT has enabled the acquisition of data on PCLs on trains in each track section and train delays at each station in daily operation. A massive amount of this data has been accumulated. Furthermore, passenger flow data has been acquired from automatic ticket gates using information on passengers' tickets. This has enabled RTRI to formulate a method of analyzing and forecasting daily train delays and PCLs. Such analysis and forecasting are realized using neural networks and deep learning, which are techniques of machine learning. We expect that, if train delays and PCLs at some future time can be forecast, it is possible to devise appropriate train schedules and adjust train intervals to level out PCLs on trains and thus reduce the discomfort felt by passengers on trains.

Future prospects

In the future, we are going to study a system that enables real-time adjustment of train schedules and control of trains utilizing the results of forecasting train delays and PCLs to further reduce the discomfort of overcrowding felt by passengers.

Current Status of WCRR2019

As previously reported in ASCENT No. 4 and No. 5, RTRI will host the 12th World Congress on Railway Research (WCRR 2019) that will take place in Tokyo, Japan, from October 28 to November 1, 2019, and will be held at the congress venue called the "Tokyo International Forum," a multi-purpose exhibition center. This is the world's largest international congress on railway research, proudly unprecedented in the sense that railway researchers and engineers gather together with managers and executives of railway operators in one congress.

At the executive committee meeting held in Nagahama, Japan in January 2019, 352 abstracts were selected for presentation at the congress out of 637 submissions and authors were requested to submit full papers by the end of May. Submitted full papers are currently under the review of session Chairpersons in order to secure the quality of the papers.

In this congress we are going to have 3 Plenary Sessions to which executives of major rail-related organizations in the world are invited as panelists. Plenary Session 1 moderated by Prof. Anson Jack of the University of Birmingham will focus on the role of railway operators in enhancing the customer experience. Plenary Session 2 moderated by Mr. Nick Kingsley of Railway Gazette International will feature the contribution of railway suppliers in elevating the value of railways. Plenary Session 3 moderated by Prof. Roderick Smith of Imperial College London will be held on the theme of the research and development for the future of railways.

What makes this congress unique is that unlike previous WCRRs we are going to have what we call "Organized Sessions" as part of the parallel sessions. Organized Sessions are specially prepared sessions in which leading experts from respective fields are invited to be Chairpersons with the aim of promoting active and in-depth discussions on research topics attracting high interest in many countries around the world. Organized Sessions consist of invited papers as well as papers submitted from the public, and these sessions are characterized by a high sense of unity of contents and freedom of presentation format.

We are also preparing social events including a Welcome Reception on the evening of October 28, a Tokyo Bay reception on the evening of the 29th, a Gala Dinner on the evening of the 30th, eleven courses of technical visits, and three cultural visit courses during WCRR 2019.

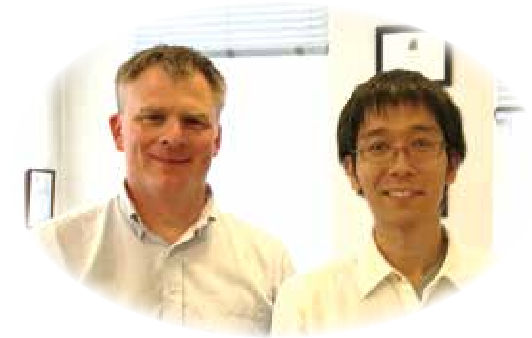
We sincerely hope that this congress will be a great opportunity for railway professionals from around the world to share their ideas, expertise and experiences to enhance the customer experience and to make the railways a safer, more efficient and greener mode of transport.

http://wcrr2019.org
For questions about WCRR, please contact: wcrr2019@issjp.com

(**Tetsuo Uzuka,** General Manager, WCRR 2019 Headquarters)

Collaborative Research with Sheffield University

RTRI has researched the in-situ measurement of the wheel/rail contact condition with Professor Roger Lewis at The University of Sheffield from April 2017. Sheffield is famous for pioneering novel steel-making processes, metals and metal products, and The University of Sheffield has developed to teach applied science with the foundation from the steel industry. Professor Roger Lewis teaches tribology in the university and the world-leading researcher in the area of wheel/rail contacts issues.



Prof. Roger Lewis and Mr. Shinya Fukagai

Since the friction condition between the wheel and rail plays a vital role in the transmission of driving and braking forces, it should be kept at an optimum level to secure the proper acceleration performance and braking distance. On the other hand, it is known that high traction coefficient and slip at curves could lead to severe wear and deformation of wheel and rail, energy consumption, squealing noise and wheel-climb derailment. It is important to understand what is happening at the interface between the wheel and rail to understand the mechanisms of these phenomena. However, the difficulty in obtaining accurate non-destructive interfacial measurements has hindered systematic experimental investigations. Professor Roger Lewis has conducted in-situ measurement of the wheel/rail contact using ultrasound waves. This technique enables us to obtain information on the contact conditions, such as the contact shape and the distribution of contact stiffness with consideration for surface topography.

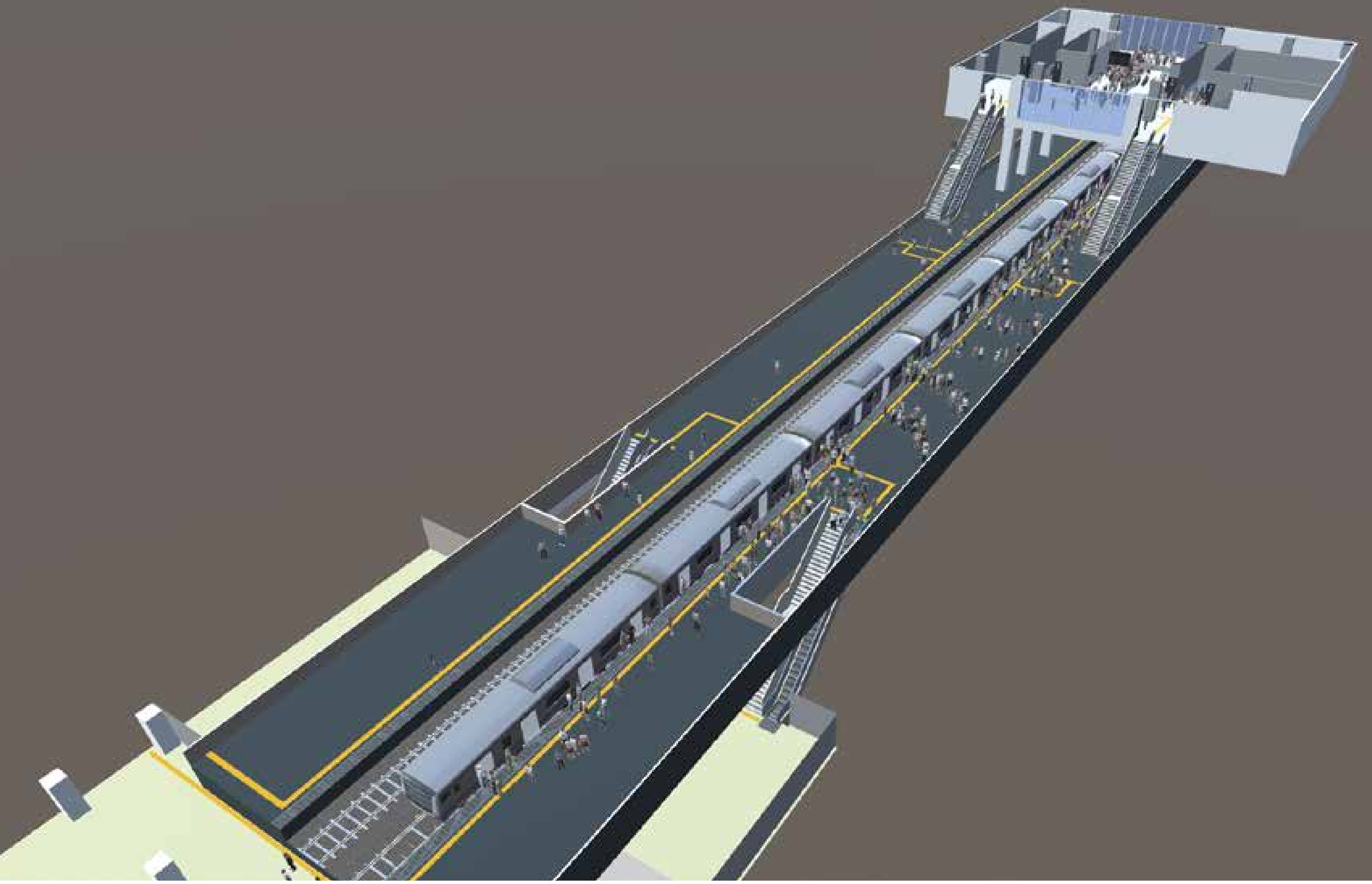
The University of Sheffield

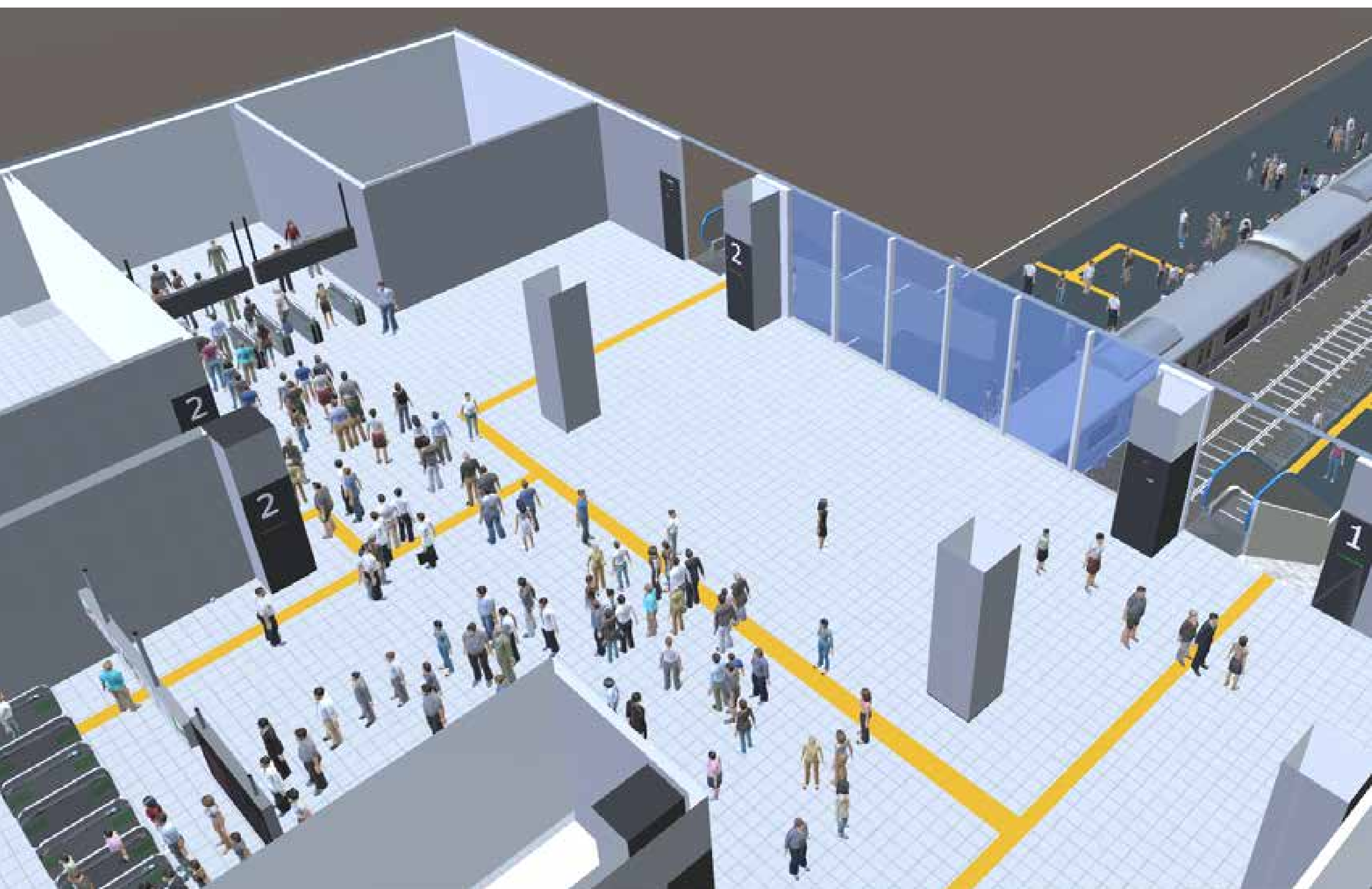
Full-scale wheel/rail test facility

RTRI has applied this technique to the rolling-sliding contact between full-scale wheel and rail and clarified the relationship between contact stiffness and friction force. The work will allow recommendations on how to treat the surface topography of the wheel and rail to control the friction force.

Our future work will aim to apply this technique more widely to the wheel/rail contact issues, such as wear, damage, traction, noise and derailment.

(**Shinya Fukagai,** Frictional Materials)

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