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# Autonomous Train Operation

## Introduction

The shrinking working-age population in Japan is having an increasingly serious effect across many industrial sectors. The railway industry is no exception, as securing sufficient number of train drivers and other railway personnel has become a pressing issue. Consequently, there is a growing need for labor-saving train operations.

Currently in Japan, driverless automatic train operation without personnel at the front of the train is already in service on several automated urban guided transport (AUGT) systems. If such driverless operation can be extended to standard railway lines with level crossing systems, an even greater expansion of labor-saving railway operations can be expected.

The Railway Technical Research Institute (RTRI) has been pursuing a major research theme, “Autonomous Train Operation,” aiming to achieve greater labor savings not only in driving tasks but also in the overall train operation, including train operation

management. This article introduces verification tests for autonomous train operation, conducted on the test track of RTRI using elemental technologies essential for autonomous train operation and a prototype autonomous train operation system that integrates these elemental technologies.

## Overview of Autonomous Train Operation

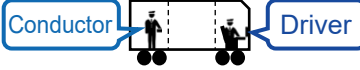



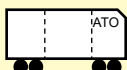
The Grades of Automation (GOAs) for railway operation are defined by the International Electrotechnical Commission (IEC) Standard IEC 62267:2009, “Automated Urban Guided Transport (AUGT)—Safety Requirements” (corresponding to JIS E 3802:2012), except for GOA 2.5<sup>\*1</sup>, and are classified according to the operation modes of onboard drivers and attendants<sup>1)</sup> (*Table 1*).

Traditionally, automatic train operation has not been implemented on conventional railway lines with level crossing systems, classified as non-automated

### \*1 GOA 2.5

GOA 1 and GOA 2 train drivers hold a driving license for operating motive power cars and are on duty in the driver’s cab in the leading car, from where they operate the train (in the case of GOA 2, driving operation between stations is, in principle, not required). GOA 2.5 included automation, in which an “attendant for automatic operation” who does not hold a driving license for operating motive power cars, is on duty in the driver’s cab in the leading car and performs actions such as an emergency stop operation. GOA 2.5 is not defined in IEC 62267 (JIS E 3802) but is defined in the report compiling the findings of “The Automatic Operation Technology Study Group on Railways” of the Ministry of Land, Infrastructure, Transport and Tourism, Japan, published on September 13, 2022.

**Table 1 Grades of automation (GOAs) of railway operation**

Grades of Automation (defined by IEC (JIS))	Visualized Operation Modes	Current Status of Implementation (Japan)
<b>GOA 0</b> On-sight train operation	Driver (and Conductor) 	Tram / Streetcar
<b>GOA 1</b> Non-automated train operation		Conventional lines with level crossing systems
<b>GOA 2</b> Semi-automated train operation	Driver [Train start, emergency stop operation, evacuation guidance, etc.] 	Some metro lines
<b>GOA 2.5</b> *Not defined in IEC or JIS Semi-automated train operation (with attendant for emergency stop, etc.)	Attendant on the leading car [responsible for emergency stop operation, evacuation guidance, etc.] 	JR Kyushu Kashii Line
<b>GOA 3</b> Driverless train operation	Attendant on board [responsible for evacuation guidance, etc.] 	Some monorail lines
<b>GOA 4</b> Unattended train operation	Unattended (No staff onboard) 	Some AUGT lines

Created based on the Ministry of Land, Infrastructure, Transport and Tourism's "The Automatic Operation Technology Study Group on Railways," version dated September 13, 2022  
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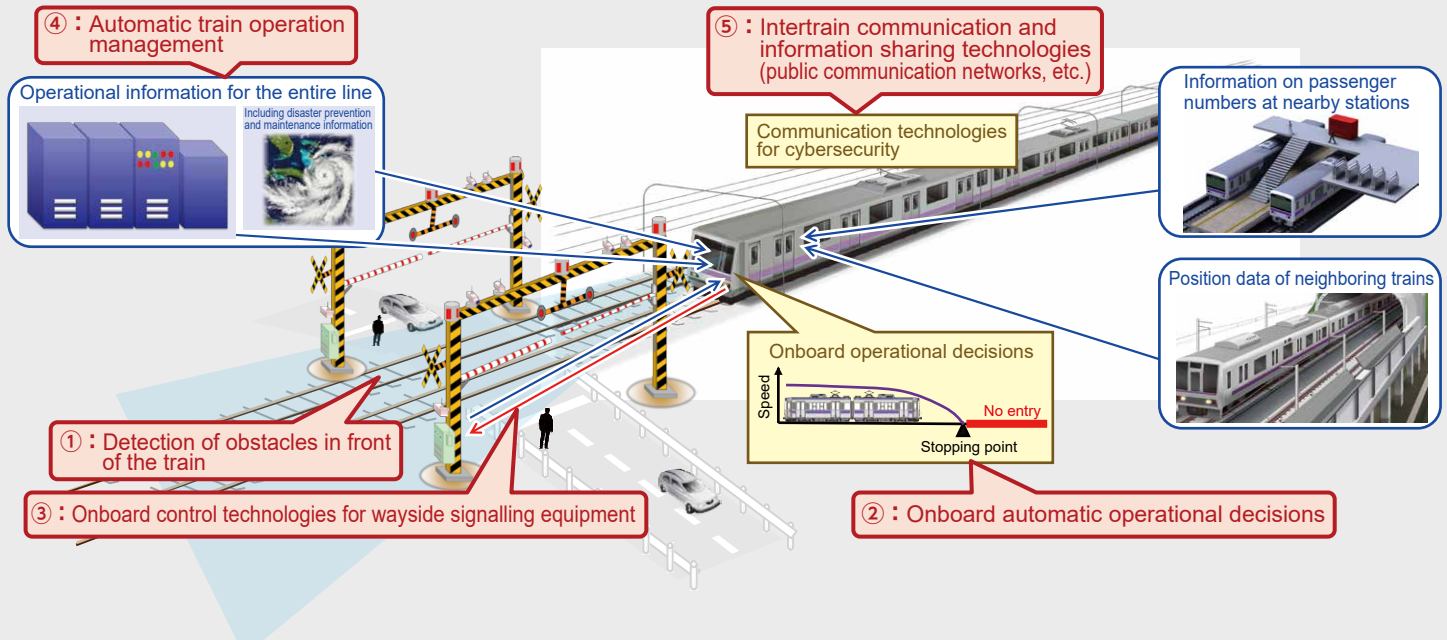
operation (GOA 1). On some lines, such as certain metros, semi-automated operation with a driver in the leading cab, classified as GOA 2, has been introduced. GOA 3 and GOA 4 correspond to driverless automatic train operation. In Japan, these two grades have been introduced only in AUGT lines without level crossing systems and equipped with structures that prevent easy access by pedestrians. Internationally as well, automatic operation of passenger trains, excluding freight trains, has thus far been introduced only in AUGT lines and metros without level crossing systems.

In automatic train operation under GOA 2 and above, the control of acceleration and deceleration from station departure to halting at the next station is automated, and the train runs between stations in accordance with an onboard operational speed profile.

This enables labor saving in the current driving operation of trains. In contrast, the concept of autonomous train operation proposed by RTRI is not limited to achieving enhanced labor saving in driving tasks that constitute the foundation of train operation through the realization of driverless automatic train operation on conventional railway lines with level crossing systems. Rather, it also aims to realize comprehensive smart train operation, including train operation management, without human intervention. This objective is based on the concept that human resources should be focused not on routine train operation tasks but on customer service tasks that only humans can perform<sup>2)</sup>. Specifically, in autonomous train operation, a driverless automatic train autonomously consolidates the information relevant to train operation onboard, such

as obstacles on and along railway tracks, operational restrictions caused by maintenance work or disasters, passenger flow, and power consumption, and independently evaluates the safety of its route (onboard operational decision-making) based on the consolidated information. During this process, the train operates safely and flexibly by controlling the signalling equipment on the ground (e.g., point machines and level crossing systems) via radio communication from the onboard. In this article, systems that enable such autonomous operation are referred to as autonomous train operation systems.

### Elemental Technologies Constituting Autonomous Train Operation System



**Figure 1 Five elemental technologies constituting the autonomous train operation system**

The establishment of an autonomous train operation system requires five elemental technologies. RTRI has been conducting research and development to establish these elemental technologies<sup>3),4)</sup> (Figure 1).

Technology (1): Detection of obstacles in front of the train and on and along the railway tracks by using cameras and LiDAR (Light Detection and Ranging) sensors

Technology (2): Railway Dynamic Map, an information platform that consolidates the conditions on and along the railway tracks and the train condition, and onboard automatic operational

decisions based on the information obtained from the Railway Dynamic Map  
Technology (3): Onboard control technologies for wayside signalling equipment (point machines and level crossing systems) utilizing radio communication

Technology (4): Automatic train operation management, including train traffic rescheduling techniques, across wide areas to prevent the cascading of delays, enable early recovery from train delays after disruptions, and ensure energy-efficient operation.

Technology (5): Intertrain communication

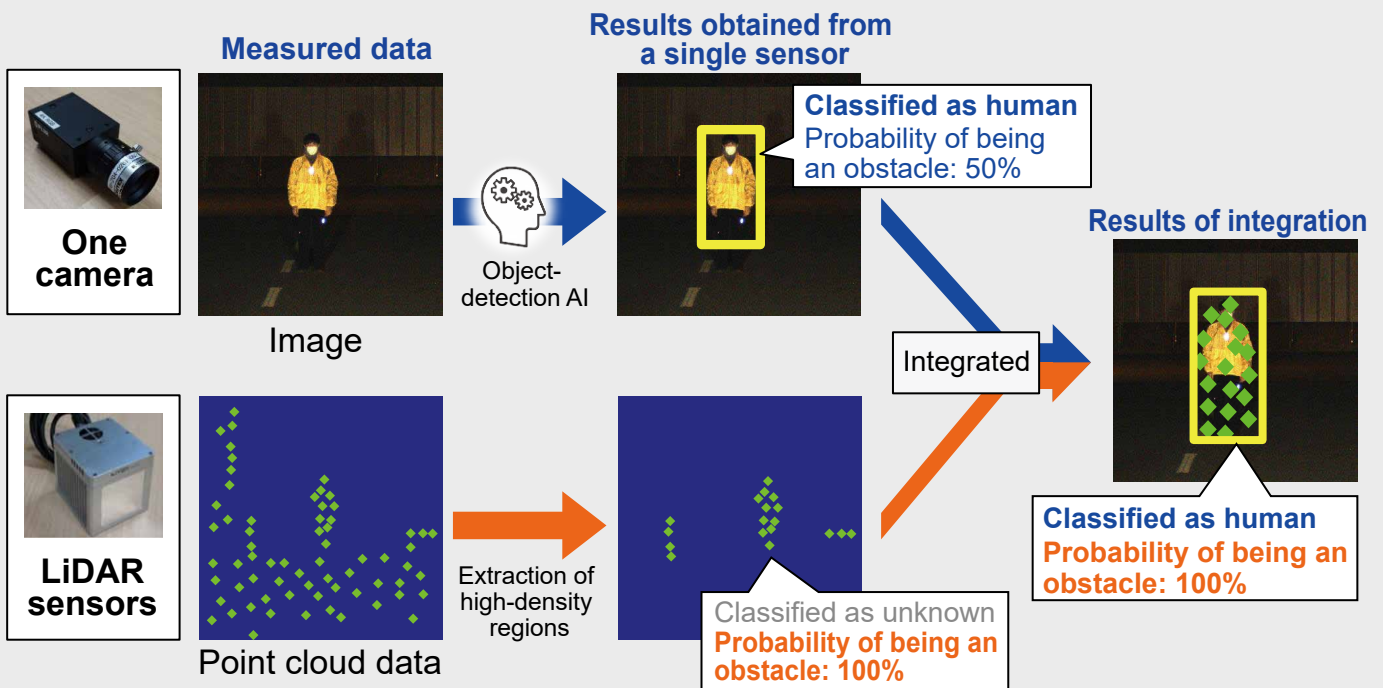
and information sharing technologies utilizing public communication networks with appropriate cybersecurity measures

This article introduces Technologies (1) and (2) described above.

### Obstacle Detection Technology

RTRI has developed an obstacle detection algorithm combined with integrated camera-LiDAR sensing to detect obstacles on and along the railway tracks<sup>5)</sup> (Figure 2).

A conventional visible-light camera captures light reflected from an object and focuses it onto its image sensor, making it possible to not only detect the presence of an object but also identify the



**Figure 2** Visualized detection of obstacles using integrated camera-LiDAR sensing

type of object by processing the camera images. However, while the detection performance of the camera is not affected in the daytime, its detection performance is degraded at night owing to the low-light conditions. Meanwhile, the LiDAR sensor irradiates target objects with near-infrared (IR) laser light with a wavelength of approximately 900–1,500 nm and measures the distance by capturing the reflected waves from the objects. As a result, objects can be recognized during both daytime and nighttime as point-cloud data consisting of laser reflection points. Thus, it is possible to prevent the degradation in the detection performance at night by integrating the image processing results obtained from a camera with the point-cloud data acquired from the LiDAR sensors.

An evaluation test was conducted to as-

sess the human-detection performance at night by integrating the data from the camera and LiDAR sensors. In this test, instead of mounting the equipment on a train, we installed one camera, nine LiDAR sensors, and two LED headlights on a truck bed at a height of approximately 1.5 m above the ground to simulate the installation conditions on an actual train, and obtained images and point-cloud data at 50 m intervals from a stationary target object. Under clear nighttime conditions, we confirmed that humans 400 m away could be detected with a probability of 90% or higher by the combined use of one camera and nine LiDAR sensors (Figure 3). In addition, we estimated that the detection rate increases with increasing laser point-cloud density\*2 from the LiDAR sensors (the results for 12 LiDAR sensors shown in Figure 3 are desk

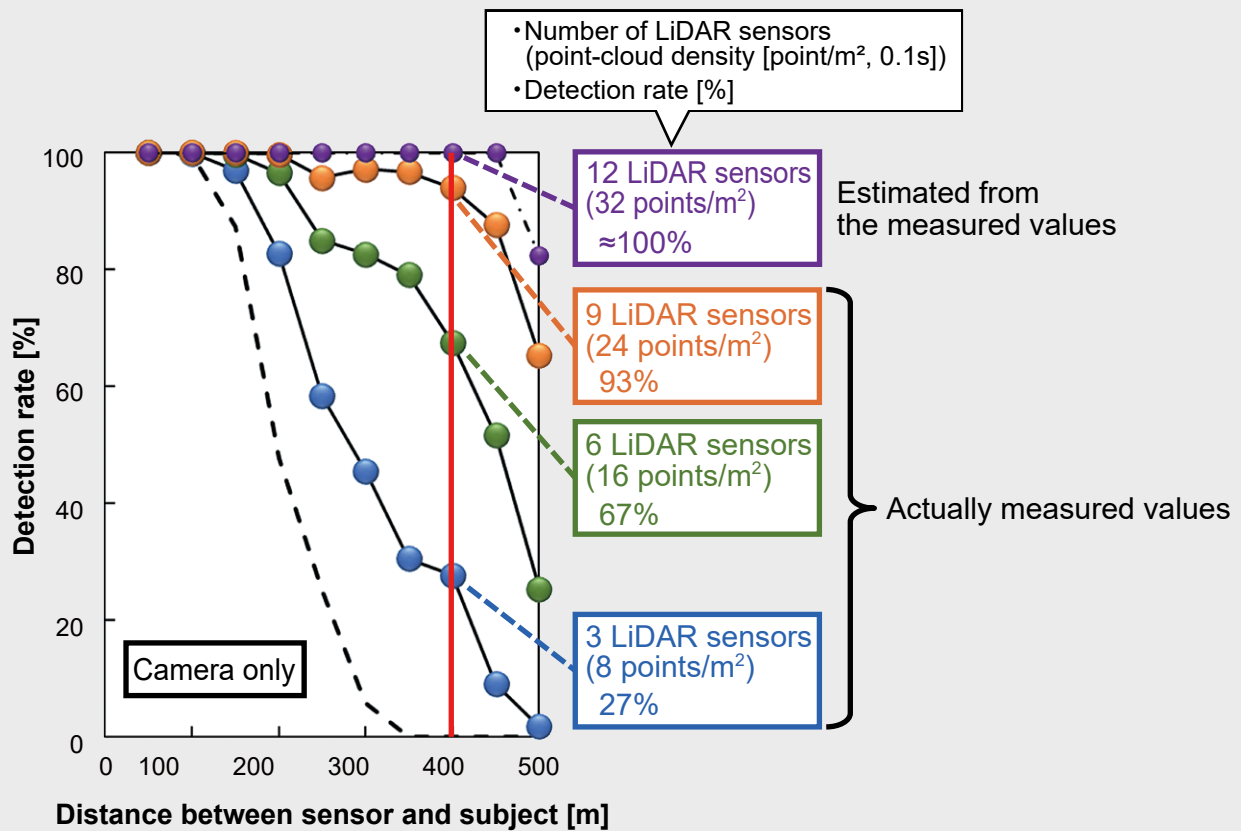
calculations of the detection rate based on the point-cloud density).

### Onboard Automatic Operational Decisions Based on Railway Dynamic Map

In the current railway operations, dispatchers at operation control centers determine whether train operations can be resumed in a wide-area operation involving numerous trains, whereas train crews are

#### \*2 Laser point-cloud density

Laser point-cloud density is a value that indicates the number of laser points that hit a given target object and is expressed as the number of points per m<sup>2</sup>



**Figure 3 Human-detection performance of integrated camera-LiDAR sensing at night**

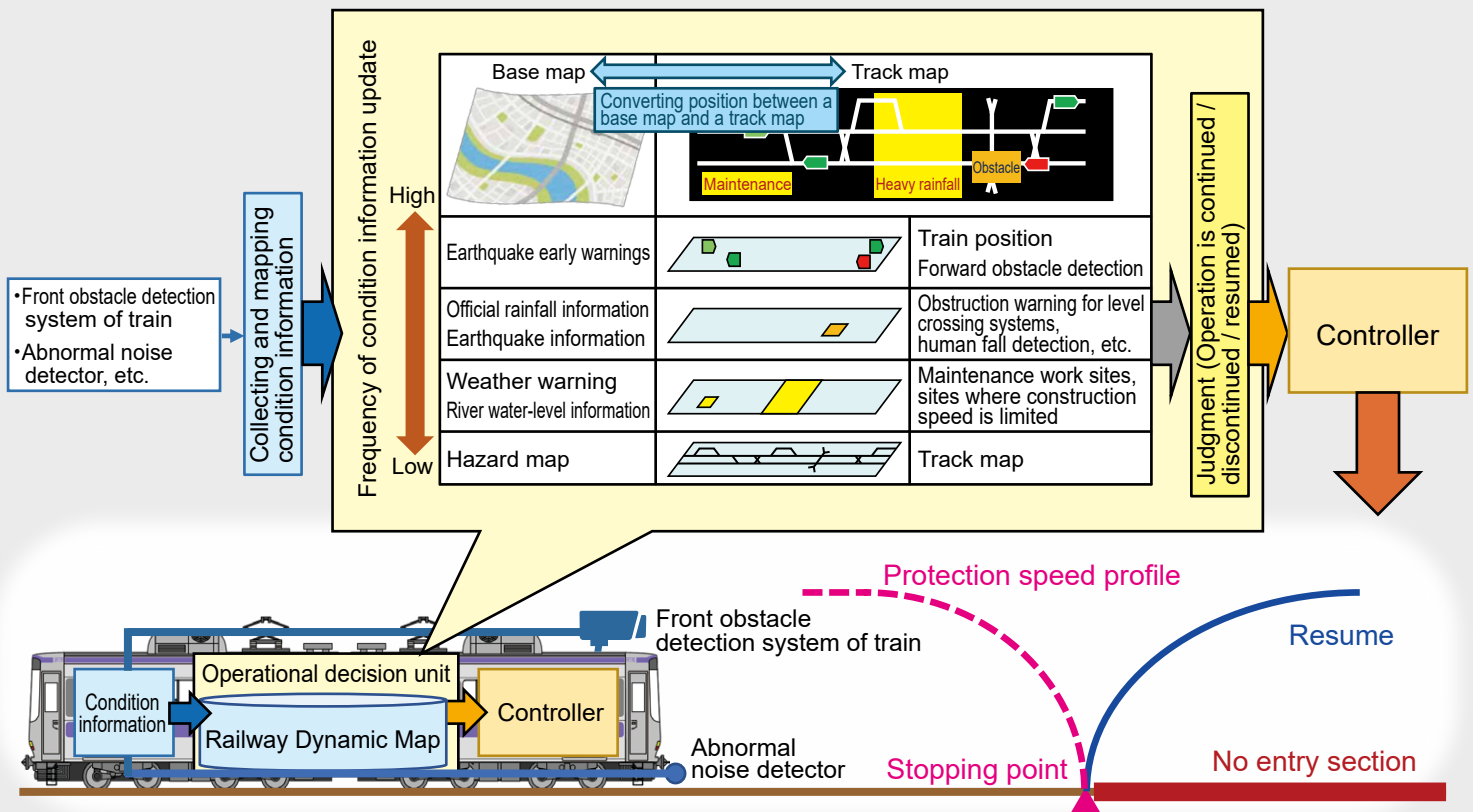
responsible for onsite operational decision-making. In contrast, in autonomous train operation, each train consolidates various types of condition information required for operational decision-making and automatically performs onboard control according to the consolidated condition information (e.g., stopping within a certain point, running at a reduced speed in a specific section, and avoiding no-stop areas) and decision-making for resuming the railway operation. We have developed the Railway Dynamic Map as an information platform that consolidates the condition information and performs onboard automatic op-

erational decision-making<sup>9)</sup> (Figure 4).

The Railway Dynamic Map consists of a base map and track map and a hierarchical structure that is divided according to the update frequency of various types of condition information. For example, information on the detection of obstacles in front of the train, where sudden changes in condition may occur, has a high update frequency of the condition information, whereas information on large-scale planned construction work lasting for a long period has a low update frequency of the condition information. The Railway Dynamic Map, can be converted between positions on a

base map and track map, integrate railway-specific kilometrage-based condition information and official condition information (e.g., weather information) based on the position on the map, and chronologically manage the integrated information.

When abnormalities occur in the condition information affecting the train operation (e.g., conditions on and along the railway tracks) or in the weather-related condition information (e.g., rainfall amount and wind speed), the detected information is mapped on the Railway Dynamic Map. Each train can search for and identify abnormalities on its running route on the



**Figure 4 Railway dynamic map**

map based on its current position and automatically stop or resume its operation.

### Verification of Autonomous Train Operation

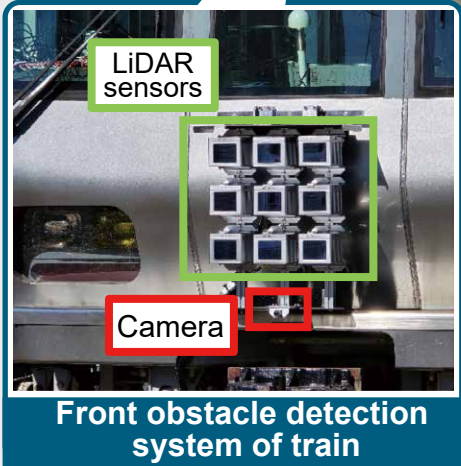
The autonomous train operation was verified on the test track of RTRI using a prototype autonomous train operation system, which implements the five elemental technologies, including the detection of obstacles in front of the train and onboard automatic operational decisions.

Through the verification, the following functions of the system were confirmed:

- The test vehicle can be automatically operated according to the operational speed profiles while controlling wayside signalling equipment (e.g., point machines and level crossing systems) via radio communication from the onboard system.
- Information about obstacles on the track, detected by the front obstacle detection system (*Figure 5*, top) of the train, is mapped onto the onboard Railway Dynamic Map (*Figure 5*, middle).
- Based on the information mapped on the Railway Dynamic Map, the

onboard system determines whether the train needs to stop, and if necessary, the train can be stopped before reaching the obstacle. After the removal of obstacles from the track, the onboard system automatically decides whether it is possible to resume the train operation, and if so, automatic train operation can be restarted (*Figure 5*, bottom).

The results of the aforementioned function verification under both normal and abnormal conditions confirmed the feasibility of autonomous train operation.

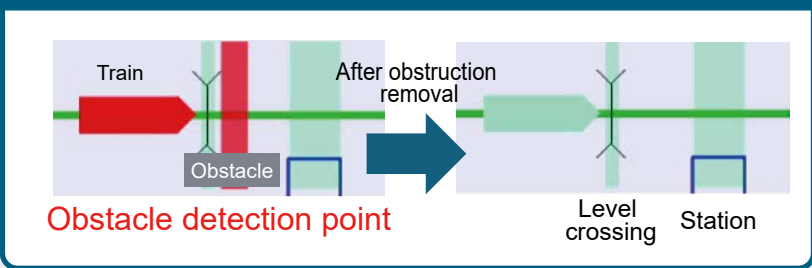


## Effects Achieved by Applying Autonomous Train Operation System

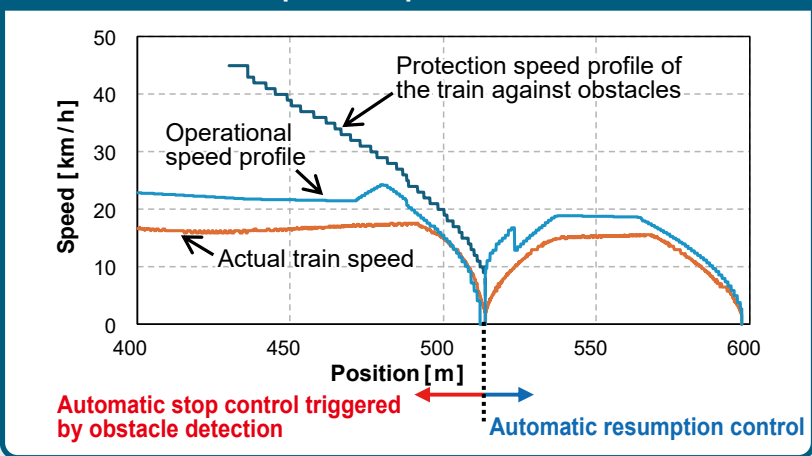
The autonomous train operation system allows for onboard automatic operational decision-making and automatic operation management. Consequently, it becomes possible to reduce the personnel required not only for driving operation but also for operation management tasks such as issuing dispatch instructions. The flexible operation provided by the autonomous train operation system makes it possible to improve customer service, secure sufficient maintenance work intervals, and perform energy-saving driving operation by considering the running conditions of multiple trains. In addition, by directly controlling the point machines via radio communication from the onboard system<sup>7)</sup>, it is possible to reduce the number of signal houses, especially on regional railways with fewer trains and small-scale station premises (Figure 6).

Furthermore, the forward obstacle detection technology, which is one of the elemental technologies, can be utilized not only for autonomous operation but also for advancing driverless automatic train operation on conventional lines with level crossing systems. In addition, information sharing technologies and automation technologies for operational decision-making using the Railway Dynamic Map, as well as automation technologies for operation management, can be applied to reduce the burden on current train operation management tasks.

### Mapping of obstacle information on the Railway Dynamic Map



### Control of automatic stopping before reaching the obstacle and automatic resumption of operation after obstacle removal



## Conclusions

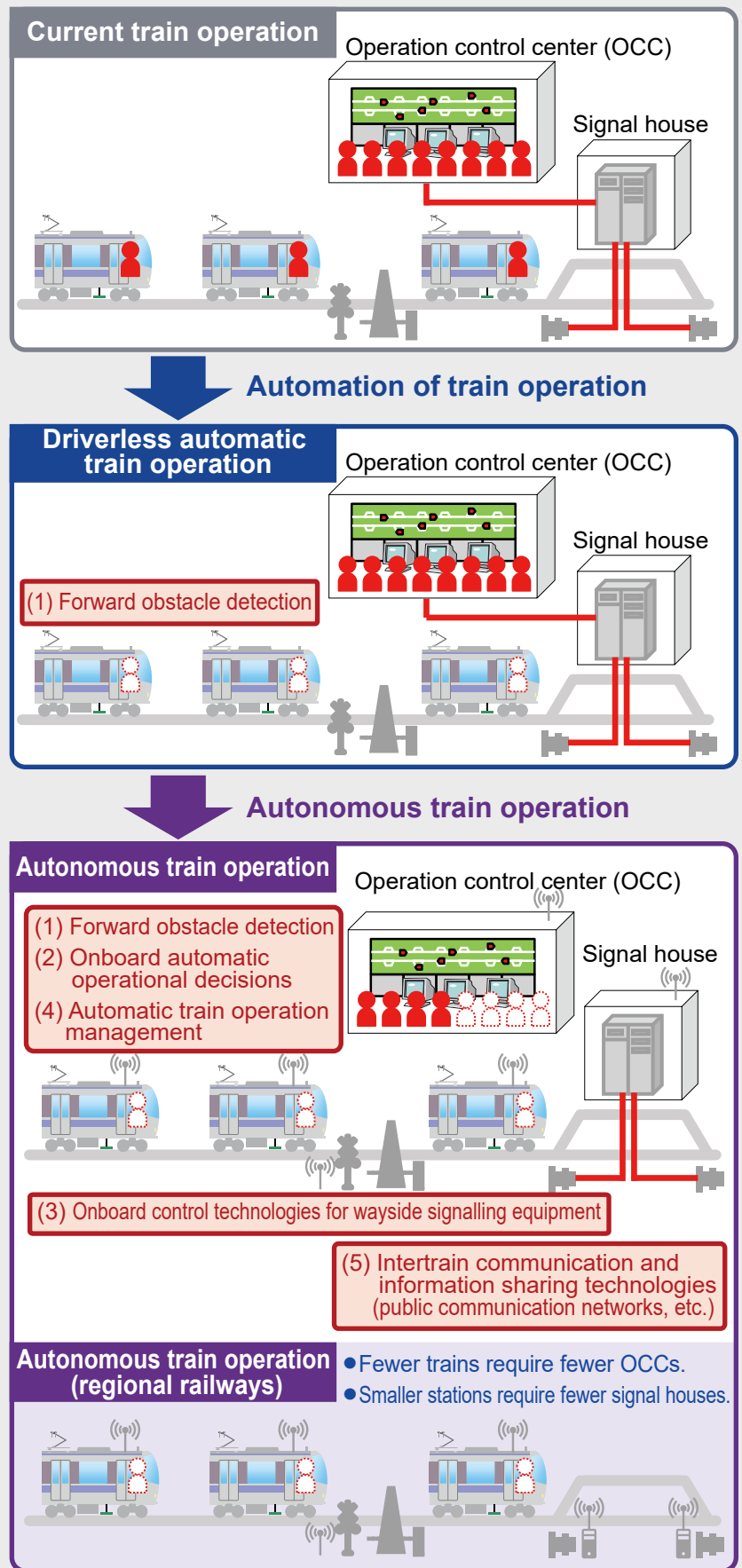
This article introduced the autonomous train operation system. However, challenges, such as improving the environmental robustness in forward obstacle detection (including the evaluation of detection performance under rainy and snowy conditions) and enhancing the scenarios for onboard automatic operational decisions us-

Figure 5 Example of verification tests of autonomous train operation on the test track of RTRI

ing the Railway Dynamic Map, persist. RTRI will steadily resolve these issues and realize labor-saving train operation through the autonomous train operation system, which is a highly advanced form of automatic operation, thereby contributing to the sustainable development of railways.

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**Figure 6 Labor saving through autonomous train operation**  
(comparison between current train operation and driverless automatic train operation)