Vehicle Technology Division

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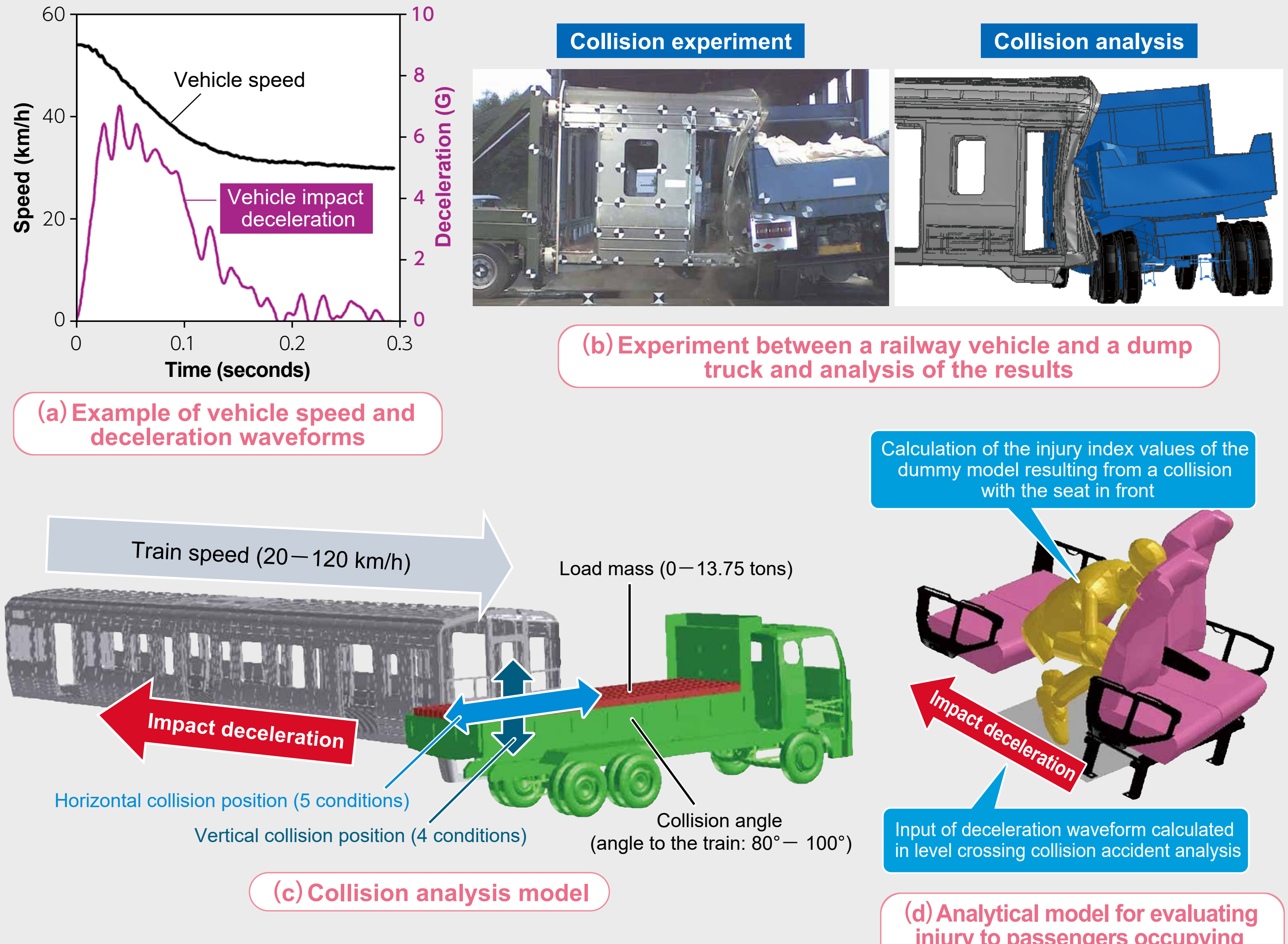
At the Vehicle Technology Division, our research and development (R&D) focuses on enhancing the safety of railway vehicles. Our work includes developing and evaluating methods to prevent derailments, mitigate collisions, and improve fire safety. We also advance R&D aimed at reducing labor requirements in vehicle maintenance by leveraging digital technologies. In parallel, we are developing energy-saving and decarbonization solutions, along with innovations to enhance passenger comfort, such as improved ride quality. This article highlights some of our recent R&D initiatives.

Introduction

Improving operational safety—particularly by preventing derailments, collisions, and fires—remains the highest priority in the R&D of railway vehicles. In addition, lessons from the COVID-19 pandemic have heightened the demand to reduce operating costs by improving labor efficiency in vehicle maintenance. Furthermore, achieving carbon neutrality by 2050 requires continued efforts in energy conservation and decarbonization for railway vehicles. To ensure that railways remain a preferred mode of transportation, continuously enhancing passenger convenience and comfort is also essential. This article presents representative examples of R&D initiatives at the Vehicle Technology Division that address these vehicle-related challenges.

Crashworthiness Analysis[1)]

One of the key challenges in improving safety is developing collision analysis models and evaluation methods that account for collisions between trains and road vehicles at level crossings. Because preventing road vehicles—including automated ones—from entering level crossings is practically impossible, evaluating passenger safety in such scenarios is crucial. To assess safety, clarifying the relationship between the impact deceleration experienced by the railway car body during a collision (*Crashworthiness Analysis (a)*) and the severity of injuries sustained by passengers is necessary. Based on past level-crossing collision accidents, we developed a collision analysis model simulating a dump truck–train collision and conducted physical collision experiments between a leading railway vehicle and a dump truck for comparative verification (*Crashworthiness Analysis (b)*). These experiments significantly improved the accuracy of the model. Using the validated model, we carried out collision analyses under various conditions, including different collision speeds, dump truck masses, impact positions, and collision angles. The results allowed us to calculate the resulting deceleration of the railway car body and better understand its effect on passenger safety (*Crashworthiness Analysis (c)*). Furthermore, by using the obtained impact deceleration, we analyzed the impact on a passenger seated on a cross seat that was thrown from the seat and collided with the seat in front, and calculated the severity of passenger injuries (specifically, the force applied to the femur)

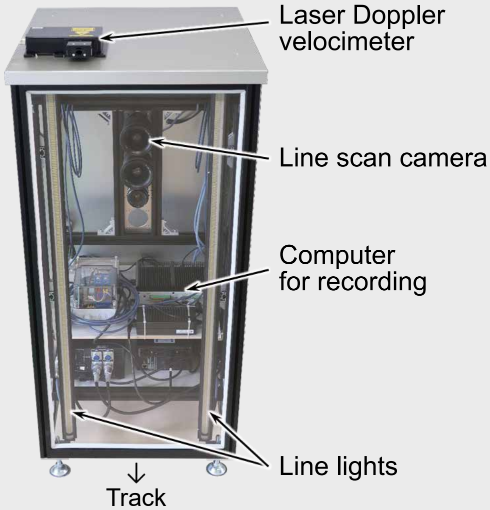


Crashworthiness Analysis

(*Crashworthiness Analysis (d)*). From these analysis results, we proposed that the integrated value of the impact deceleration—roughly corresponding to the velocity at which a passenger collides with the seat in front—is an appropriate evaluation index for passenger safety. Moving forward, we plan to analyze the entire train set, including coupling sections, to further refine the evaluation.

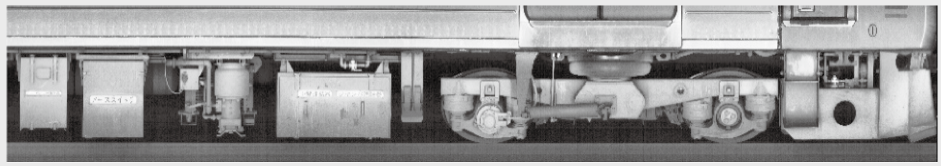
Visual Inspection System for Vehicle Underbody[2)]

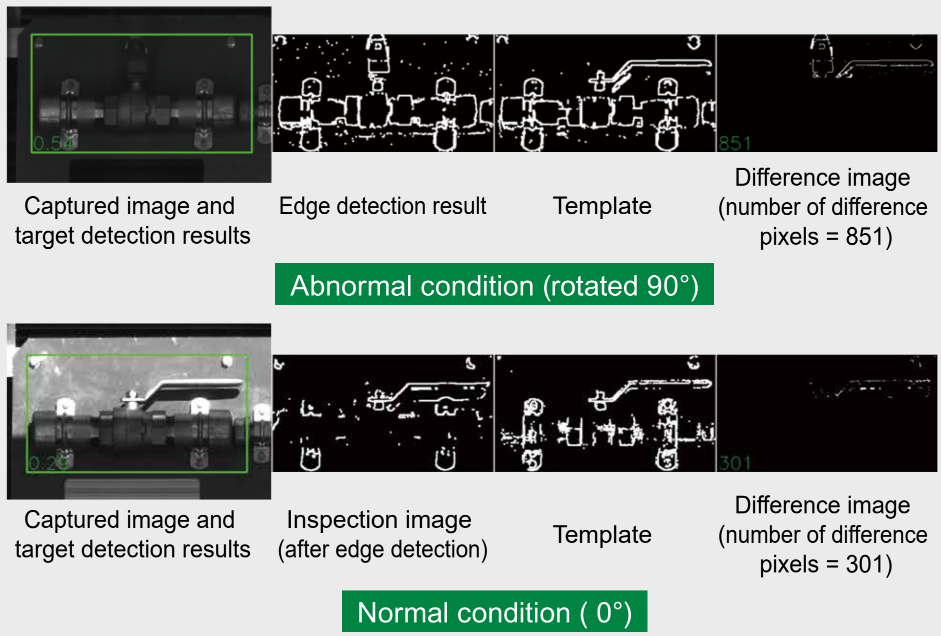
Periodic inspections are essential to ensure the safe operation of railway vehicles. To reduce the labor required for these routine inspections while maintaining inspection quality, RTRI has developed a visual inspection system for vehicle underbodies. Conventionally, inspection conducted on the entire vehicle without removing parts involves inspectors approaching the vehicle to visually check the mounting conditions and any damage to the onboard equipment. To automate this inspection process, we first developed a device capable of capturing side images of the vehicle's underbody while the vehicle is in motion (*Visual Inspection System for Vehicle Underbody (a)*). A laser Doppler velo-



(a) Imaging equipment


(b) Imaging equipment capturing a passing vehicle

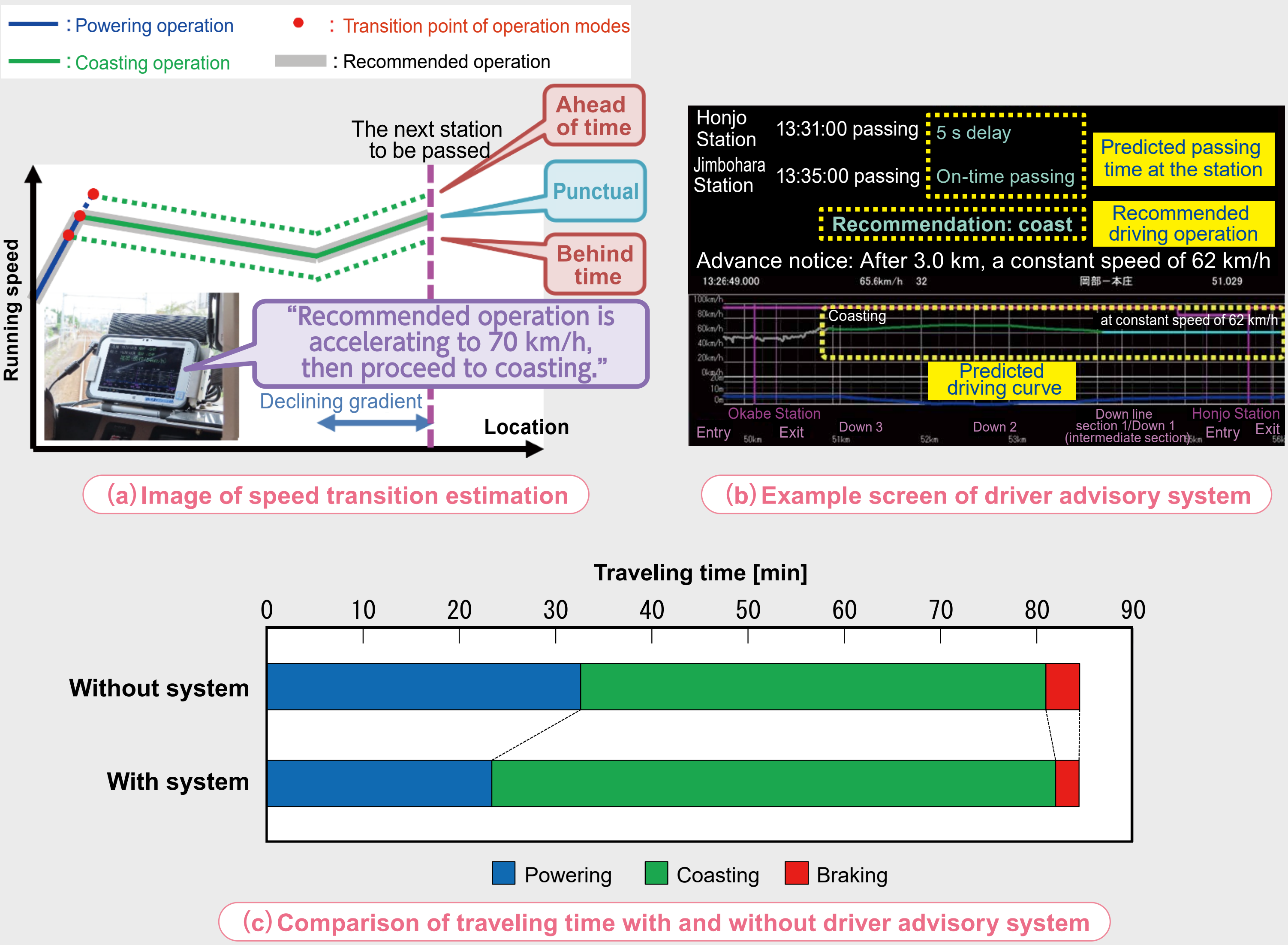

(c) Example of a captured image



(d) Example of diagnostic processing results (cock)

Visual Inspection System for Vehicle Underbody

cimeter was used to measure the vehicle's passing speed, allowing the scan sensor camera to capture images in synchronization (*Visual Inspection System for Vehicle Underbody (b)*). This approach enabled us to obtain high-resolution, continuous images (*Visual Inspection System for Vehicle Underbody (c)*) that are unaffected by variations in vehicle speed. In addition, the system can automatically recognize vehicle identification numbers from the captured images. As an application example, we demonstrated the automated diagnosis of the cock handle angle under the test vehicle (*Visual Inspection System for Vehicle Underbody (d)*). The target inspection area was extracted from the images, and edge (contour) detection was performed to assess the handle's position. The luminance difference between the extracted image and a prepared normal image (template) was calculated, with areas differing from the normal highlighted in white. The number of white pixels was then counted. If this count was below a specified threshold, the condition was judged as normal; if it exceeded the threshold, it was judged as abnormal. In addition to diagnosing the cock handle angle, we have confirmed that this system can accurately detect missing bolts,

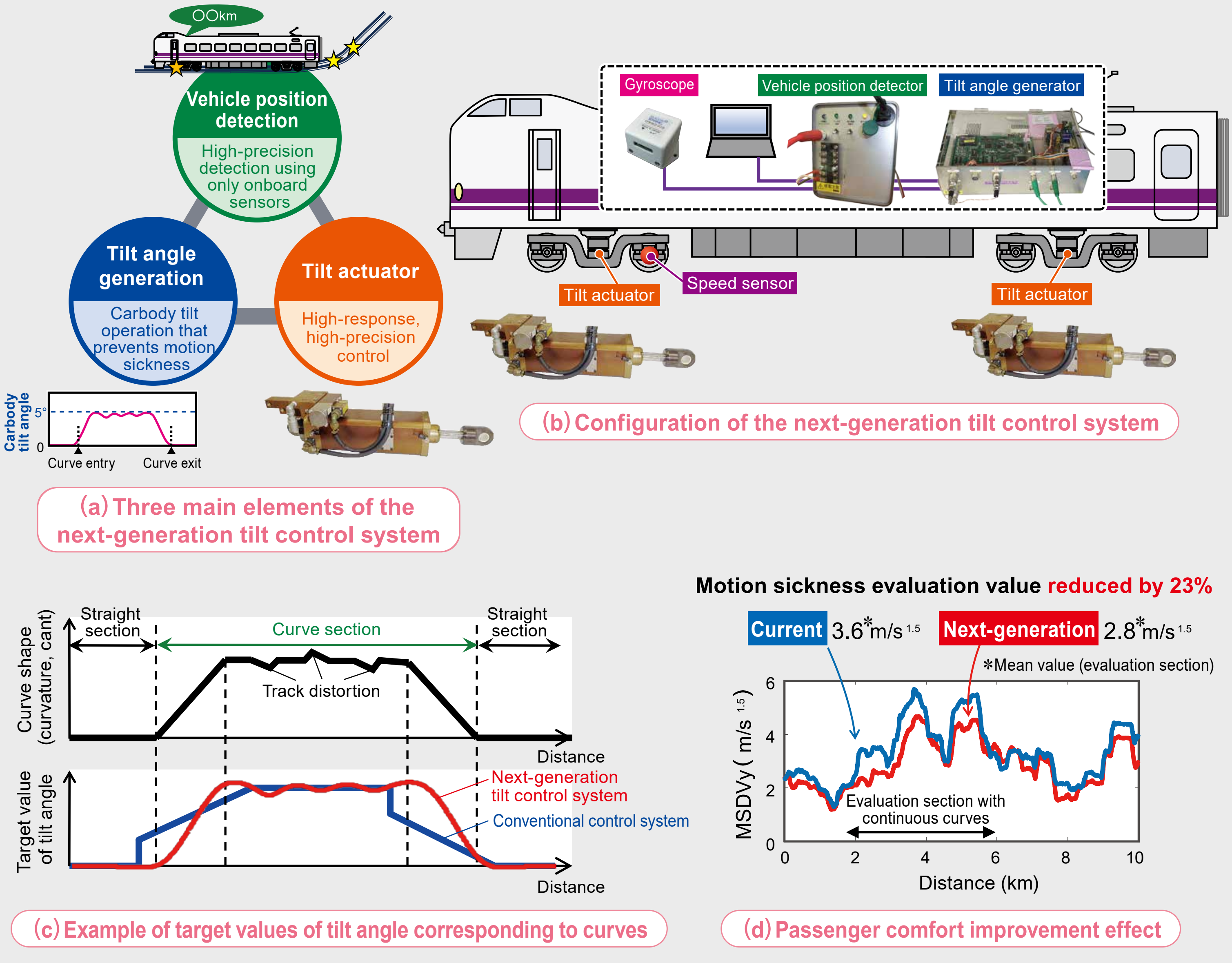


Energy-Saving Driver Advisory System

bent adjustment rods, and pipe deformations. By using this system, inspectors can assess vehicle conditions indoors by reviewing the captured images, eliminating the need to approach the vehicle closely. Furthermore, the system's automatic image diagnosis reduces reliance on manual labor, improving both the efficiency and reliability of underbody inspections.

Energy-Saving Driver Advisory System[3)]

We have developed a driver advisory system aimed at reducing the energy consumption during train driving operations while maintaining punctuality. Conventionally, train operation consists of three modes: powering (where the motor generates tractive force to accelerate), braking, and coasting (running by inertia without powering or braking). Train drivers manually select the appropriate mode based on factors such as timetables, speed limits,



Next-Generation Tilt Control System

and track gradients. The newly developed driver advisory system enhances this process by performing real-time simulations during travel. It estimates speed transitions at various points along the route under different driving patterns and then recommends the pattern that optimizes both energy efficiency and punctuality. Specifically, the system defines several candidate driving patterns from the train's current position to the next station. Using information such as train mass, running resistance, track gradients, current position, and current speed, it predicts the speed profile for each candidate pattern (*Energy-Saving Driver Advisory System (a)*). For each candidate driving pattern, the system selects the one that most closely matches the scheduled passing time at the next station while minimizing energy consumption. The recommended pattern is then presented to the driver in real time through a tablet display (*Energy-Saving Driver Advisory System (b)*) and voice guidance. Effectiveness verification tests were conducted by comparing actual running data with and without the use of the driver advisory system. The results confirmed an energy-saving effect ranging approximately from 4% to 14%, depending on the route. In the case studied, the reduction in energy consumption was attributed to decreased powering and increased coasting (*Energy-Saving Driver Advisory System (c)*). Ongoing efforts focus on expanding the system to additional lines and vehicle types to develop it into a practical tool for widespread deployment.

Next-Generation Tilt Control System[4)]

When trains travel at high speeds through sections with numerous curves, passengers experience centrifugal force due to the lateral acceleration of the carbody. To mitigate this effect and improve ride comfort, tilting vehicles are commonly used. The basic tilting mechanism, known as "natural tilting", relies solely on centrifugal force. However, the mainstream approach is "controlled natural tilting", which adds pneumatic actuators to suppress the phase lag of the tilting motion. Aiming to suppress the characteristic slow, low-frequency oscillations of tilting vehicles and provide a smoother, more comfortable ride, we have developed a next-generation tilt control system. This system integrates three key technological elements, as illustrated in *Next-Generation Tilt Control System (a)*.

First, to ensure that the train body tilts at precisely the right time on curves, continuously and accurately determining the train's running position is essential.

For this purpose, we devised a self-position detection technique using a gyro sensor and a speed sensor installed on the vehicle (*Next-Generation Tilt Control System (b)*). These sensors measure the curvature of the track during travel, and by comparing the measurements with pre-recorded data, the system accurately determines the train's position. Based on the detected position, the system calculates the ideal tilt angle (target tilt value) by accounting for the curvature, cant of the upcoming curve, and the train's running speed (*Next-Generation Tilt Control System (c)*). This target value closely follows the actual track geometry, including any irregularities. In addition, the system cancels low-frequency oscillations caused by centrifugal force and track irregularities, thereby reducing motion sickness—a common drawback of tilting vehicles. To realize such precise control, we developed a high-response pneumatic actuator capable of achieving the ideal tilt angle in real time. The performance of the next-generation tilt control system, which integrates these technologies, was successfully verified through running tests. The maximum error in vehicle position detection was ±2 meters, ensuring sufficient accuracy for tilt control. Furthermore, the Motion Sickness Dose Value along the y-axis (MSDVy)—an index reflecting the degree of motion sickness—was reduced by approximately 23% compared with the conventional control system (*Next-Generation Tilt Control System (d)*). The next-generation tilt control system has been installed on JR West's 273 series Yakumo Limited Express and is now in operation on commercial lines.

Conclusions

In this article, we introduced recent initiatives undertaken by the Vehicle Technology Division, including crashworthiness analysis, visual inspection systems for vehicle bodies and underbodies, energy-saving driver advisory systems, and next-generation tilt control systems. To ensure the long-term sustainability of railways, we remain committed to advancing vehicle technologies through R&D that enhances safety, reduces maintenance costs, promotes energy efficiency and decarbonization, and improves passenger comfort.

References

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