Featured Articles

Research and Development Driving Innovations in Global Railway Systems/Services

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OVERVIEW: With rail transport receiving attention as a solution to urban air pollution and traffic congestion, Hitachi is working on innovating railway systems and services by using measurement, simulations, and the IoT as platforms for improving value for railway passengers and carriers. In addition to working on improving the basic performance of major product areas such as rolling stock, onboard components, signalling systems, and traffic management systems, Hitachi has also recently been focusing on developing solutions to increase the efficiency of large-scale, complex railway operations such as linking wayside and onboard power, linking business system operations, and identifying people flow in railway stations. In addition, it is also working on developing its methodology for collaborative creation with customers, NEXPERIENCE/Cyber-Proof of Concept, for the railway business, accelerating collaborative creation with customers.

INTRODUCTION

RAILWAY systems and services have entered the spotlight as solutions to the urban problems of air pollution and traffic congestion and, recently, also as a core for urban area creation and renovation. This article provides an overview of the research and development Hitachi is doing to attain ongoing growth toward the goal of becoming a comprehensive railway system integrator with a global presence.

OVERVIEW OF RAILWAY RESEARCH

Two organizations are leading Hitachi's railway research—the Global Center for Social Innovation (CSI), which develops services and solutions tailored to customer needs around the world, and the Center for Technology Innovation (CTI), which develops technology-driven platforms and products.

Comprising several overseas research bases, the CSI promotes collaborative creation with customers at two sites: the London-based European Rail Research Centre (ERRC) and the Global Center for Social Innovation – Tokyo (CSI-Tokyo). The ERRC works closely with the London-based headquarters of the Railway Systems Business Unit, promoting collaborative creation with customers in Europe, including homologation for rolling stock, maintenance, and traffic management systems for the UK. In addition to promoting collaborative creation with customers in the Asia-Pacific region, the CSI-Tokyo focuses on the use of experience design techniques for rolling stock and information systems design and service design R&D.

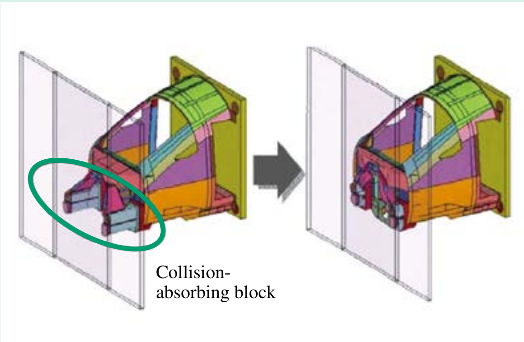
The CTI has a proprietary technology platform that systematizes various fundamental technologies. The center is a leader in technological innovation for main product areas such as rolling stock, onboard components, signalling systems, and traffic management systems. It has recently been focusing on R&D targeting optimum control in railway systems.

Measurement, simulations, and Internet of Things (IoT)-related technology platforms are particularly important in railway research. Wind tunnel measurement technology is a typical example of a measurement technology that enables accurate understanding of the complex phenomena in railway systems. This technology enables sound source distribution measurement of noise generated by moving trains and high-precision aerodynamic noise evaluation. Since inspecting railways at actual scale spends much time and investment, computer simulations are a crucial tool for validating system concepts and optimizing product designs. Identifying and controlling various system behaviors in realtime using the IoT is an important requirement for optimizing railway operations.

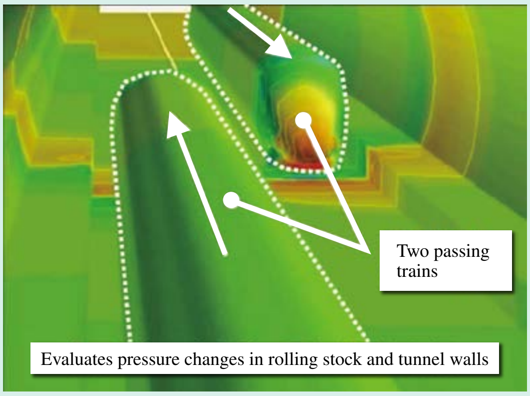
RESEARCH AND DEVELOPMENT OF MAJOR PRODUCTS

Rolling Stock Systems

Rolling stock development requires an in-depth understanding of complex interrelated phenomena such as dynamics, thermal fluids, noise, and vibrations, however reproducing these phenomena at actual scale requires major time and cost investments. So, starting with the early phases of rolling stock development, Hitachi has been using large-scale numerical simulations (hereafter, 'analysis') to reduce the development time and cost through analysis-led design (see Fig. 1).



(a) Collision analysis case study of lead railcar colliding with collision-absorbing block



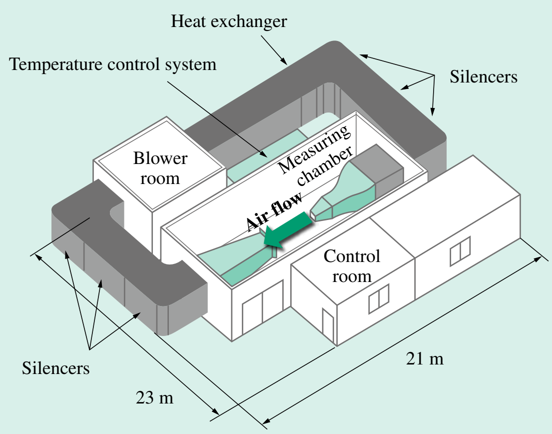
(b) Surface pressure change analysis case study of rolling stock passing in tunnel

Fig. 1—Application of Analysis-led Design.
Analysis-led design enables large-scale testing to be replaced with precise evaluations of rolling stock characteristics, reducing rolling stock development time and cost.

Hitachi has also developed a high-speed, low-noise wind tunnel specialized for railway research. It is designed to be used for noise evaluation, for which it is difficult to isolate phenomena using simulations. The wind tunnel has an environment that enables high-precision measurement of noise generated from model rolling stock in a 420 kph air flow. Utilizing this wind tunnel enables pre-evaluation of exterior noise and aerodynamic characteristics, a crucial requirement for developing high-speed rolling stock (see Fig. 2).

Traction Systems/Driving Support Systems

Targeting improvements such as energy savings, Hitachi draws on the benefits of components such as silicon carbide-based low-loss power modules, high-efficiency electric motors, and lithium-ion batteries in the traction systems and the control technology for those systems. For example, it uses detailed magnetic field simulations to identify harmonic magnetic flux distributions of traction motors, and uses them to develop controls designed to reduce harmonic loss.



(a) Overall structure of facility

(b) Overall view of measuring chamber

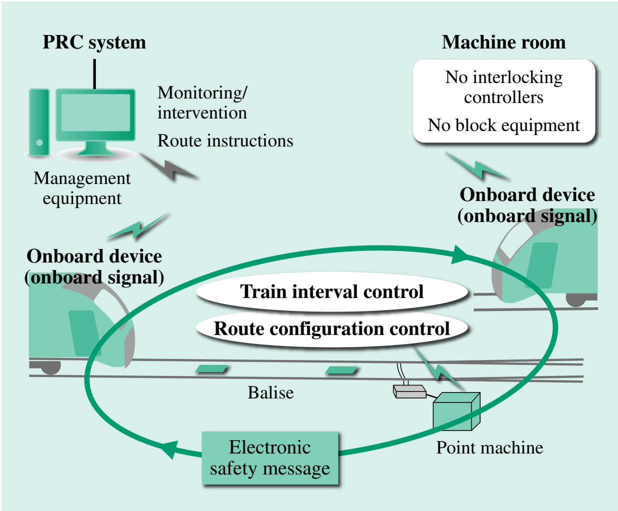
Fig. 2—High-speed, Low-noise Wind Tunnel.
The wind tunnel can generate air flow of 420 kph in an environment of low background noise.

One example of an R&D project for driving support systems is an automatic parameter adjustment function for a train automatic-stop control system. The function continually applies statistical processing to the train's past travel data to identify changes in rolling stock characteristics. The results are applied to travel control commands to ensure constant output of the proper brake commands. The function can reduce the amount of labor needed for initial adjustments when rolling stock is delivered and can maintain stopping accuracy during commercial train operation.

Signalling Systems

The ultimate form of signalling system is thought to be one in which only the equipment that is essentially required for train operations exchanges information to ensure safety. Creating this type of system can minimize the amount of equipment and reduce system life cycle costs.

Hitachi is working toward this vision by developing ring topology communications-based train control (CBTC) systems in which safety functions are implemented by only onboard devices and point machines (machines that operate the railway switches on the track). The train interval control and route setting control functions that are the core safety functions have previously been handled by wayside-based equipment such as interlocking controllers and block equipment. The proposed signalling system can replace this wayside-based control equipment with information-sharing between onboard devices and point machines. In other words, safety functions are achieved autonomously by routing electronic messages containing safety information. The electronic messages are routed using a highly reliable communication protocol that ensures message uniqueness (see Fig. 3).



CBTC: communications-based train control
PRC: programmed route control

Fig. 3—Ring Topology CBTC System.
The ring topology CBTC system can provide the train interval control and route configuration control functions conventionally handled by equipment such as interlocking controllers and block equipment with circulation of electronic safety messages, enabling train control from simple wayside-based equipment.

Traffic Management Systems

While mutual direct operation for rail transport improves convenience, recovering service after disruptions is time-consuming, and there are concerns

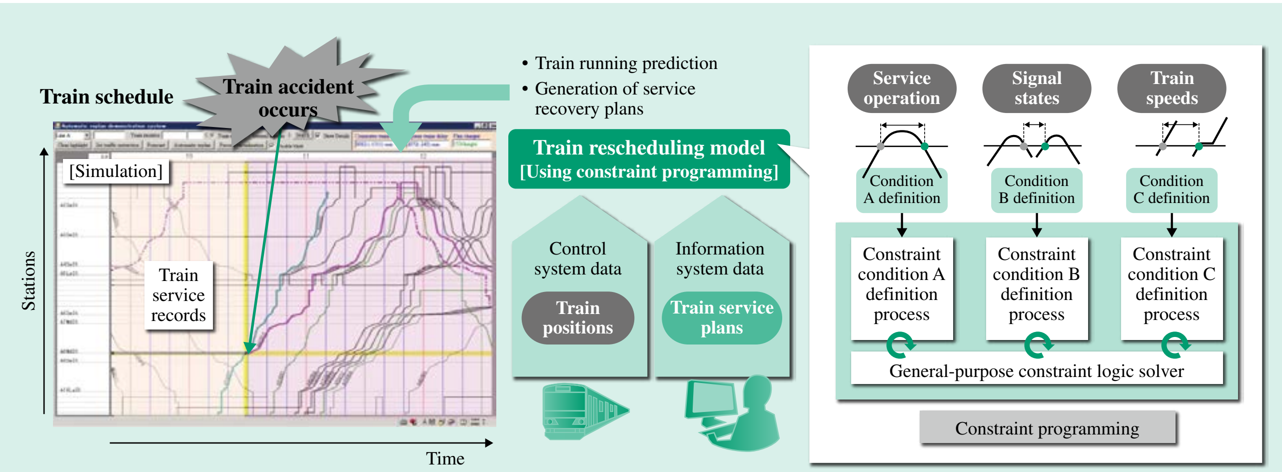


Fig. 4—Train Running Prediction Technology Using Constraint Programming.
This technology models railway service conditions such as service operation, signal states, and travel speeds in the form of constraint equations, enabling rapid calculation of predicted train times.

over deteriorating passenger service quality. Hitachi has responded by developing a train rescheduling assistance technology driven by mathematical programming.

Train running prediction is one of the technologies used for train rescheduling assistance. It determines the times of trains up to several hours in advance of the current time. Operators can use train running prediction results to anticipate service impediments before they occur and take precautions. Hitachi has developed a train running prediction technology that uses constraint programming (a type of mathematical programming) to achieve the high-speed responsiveness and running prediction accuracy needed for train rescheduling work (see Fig. 4). The technology models railway service conditions such as service operation, signal states, and train running speed in the form of constraint equations, enabling rapid calculation of solutions (predicted train times) using a constraint programming technique called constraint propagation.

The technology has been applied to actual railway routes, and is helping to ensure daily safety and accurate train service.

RESEARCH AND DEVELOPMENT FOR GREATER RAILWAY OPERATION EFFICIENCY

Energy Management Technology Linking Wayside and Onboard Systems

Efforts to reduce rolling stock operation energy consumption (which accounts for about 70% of all railway system energy consumption) have previously focused on reducing rolling stock weight and increasing traction system efficiency. Hitachi is looking into building on these energy-reduction efforts by linking onboard traction systems with wayside-based traffic management, substation, and power management information to provide detailed instructions for operations such as departure deferral or coasting, based on real-time travel conditions.

Hitachi's railway total simulator is the technology that assists the core of this energy management technology (see Fig. 5). The simulator links major subsystems such as rolling stock, signalling, traffic management, and feeding systems in a common framework to enable evaluation of indicators of energy consumption and other parameters from individual subsystems up to the entire system.

Railway Station People Flow Analysis Technology

Hitachi is researching and developing a people flow simulator that uses railway station user number fluctuations and train service conditions to predict railway station congestion and enable evaluations and proposals for improvement (see Fig. 6).

Using the interior design of stations and models of passenger behaviors such as embarking and disembarking in accordance with train movements, the simulator can evaluate cases such as how adding extra trains would alleviate congestion if a special event caused a spike in passenger numbers.

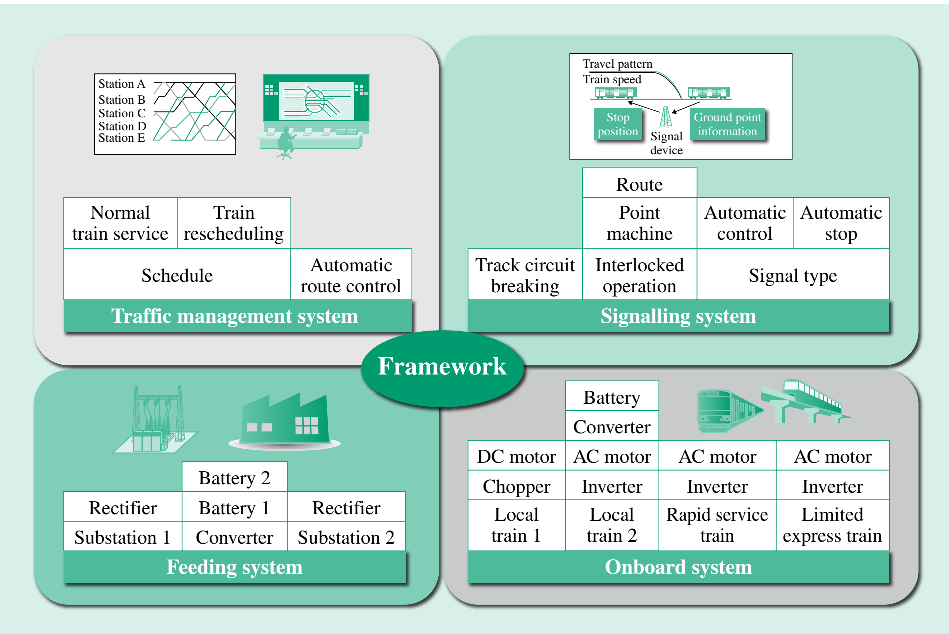
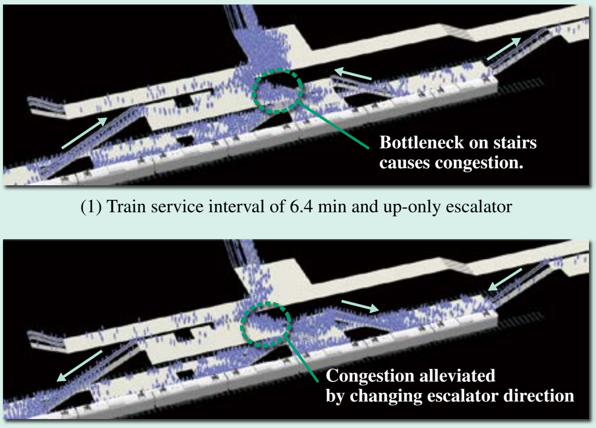


Fig. 5—Features of Railway Total Simulator.
The user can select the required subsystems and equipment to include to study any configuration from individual devices up to the entire system.



(1) Train service interval of 6.4 min and up-only escalator

(2) Train service interval of 6.4 min and down-only escalator

Fig. 6—One Example of Prediction Results of Railway Station People Flow Simulator.
The simulator enables prior studies of changes in people flows caused by renewal of existing stations or construction of new lines or stations.

Passenger Flow Analysis Technology

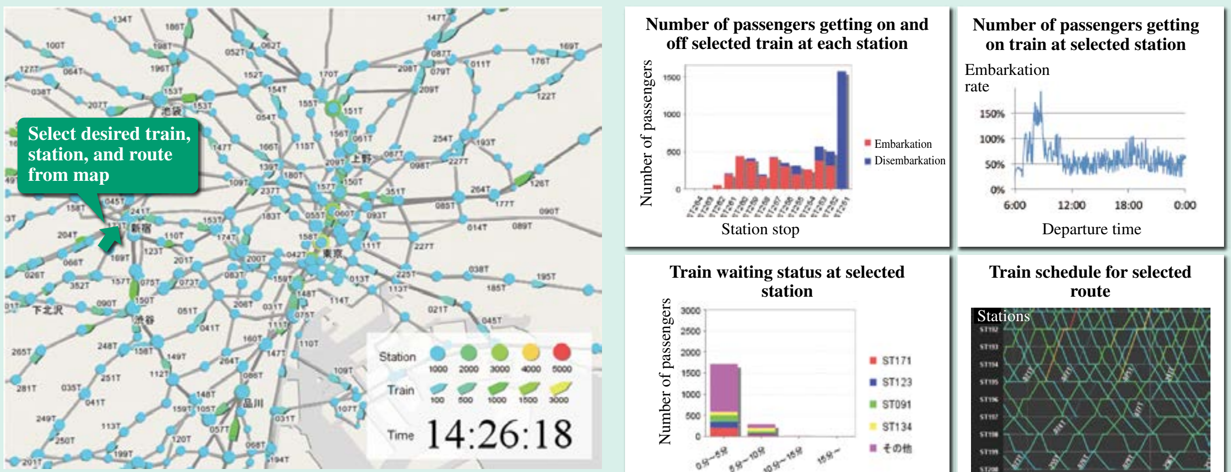
Hitachi is researching and developing a passenger flow simulator that models trains traveling according to schedules and passengers behaving autonomously to estimate flows of passengers moving in accordance with train service (see Fig. 7).

Drawing on the route-finding technology expertise Hitachi has acquired in the field of road traffic, the simulator successively calculates the interrelated effects of trains and passenger movements. Trains are assumed to travel according to schedules, and passengers are assumed to behave autonomously by rationally choosing travel routes in light of conditions such as travel time and number of transfers. The simulator can reproduce train services on tens of thousands of routes, and estimate the movements of tens of millions of passengers in accordance with these train services in 1-s increments.

Collaborative Operation Technology for Railway Resource Management

Hitachi is developing a collaborative operation technology that enables highly efficient operation by using the traffic management system as a hub to connect the other systems. For example, collaborating railway timetables, train allocation, and crew allocation together around the traffic management system as the central core will enable efficient use of vehicles, crew, and other resources when service is disrupted (see Fig. 8).

This technology will also be able to increase business efficiency and improve railway service quality by collaborating with passenger information systems, train driving support systems, maintenance systems, and various other business systems through the traffic management system.



The data used (numbers of people moving between stations during each time slot) are from the rail origin-destination survey in the 2005 Metropolitan Transportation Census.

Fig. 7—Passenger Flow Simulator Functions.
The simulator can reproduce train services on tens of thousands of routes, and estimate the movements of tens of millions of passengers in accordance with these train services in 1-s increments.

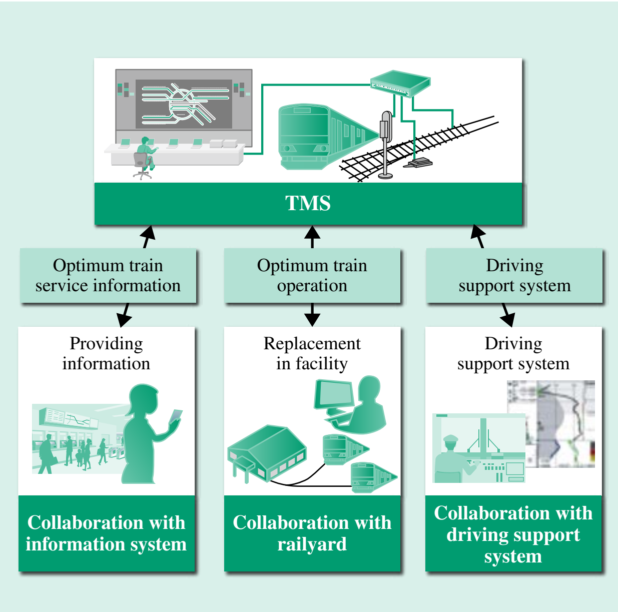


Fig. 8—Overview of Technology Collaborating Business Resources and Operation.
Railway resources such as crew can operate efficiently by linking them around the traffic management system as a central core.

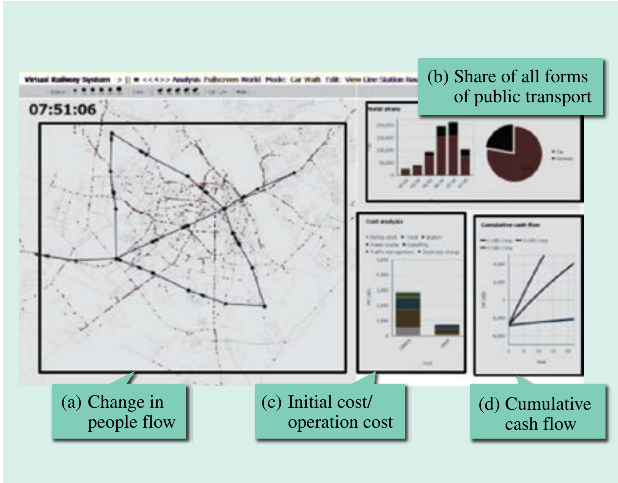


Fig. 9—NEXPERIENCE/Cyber-Proof of Concept Screenshot.
This tool accelerates collaborative creation activities with customers by presenting the congestion alleviation benefits and profitability of laying new railway lines into large cities.

ACCELERATING COLLABORATIVE CREATION WITH CUSTOMERS: NEXPERIENCE/CYBER-PROOF OF CONCEPT

Hitachi has developed a tool called NEXPERIENCE/Cyber-Proof of Concept that assists collaborative creation activities. The tool is used during the initial phase of system investigation to share the project overview with the customer, along with the value the project provides. For the railway industry, Hitachi has developed a tool that combines the simulator described in the previous section with a business operation simulator. In a single snapshot, it provides an overview of the congestion alleviation benefits achieved by adding new line in a chronically-congested large city, along with the project's profit comparison. The tool is being used to accelerate activities involving collaborative creation with customers (see Fig. 9).

CONCLUSIONS

This article has presented the research and development Hitachi has been doing that drives its innovation of railway systems.

With the addition of AnsaldoBreda S.p.A. (now Hitachi Rail Italy S.p.A.) and Ansaldo STS S.p.A. to the Hitachi Group in FY2015, the Group is looking to expand its work in the grobal railway industry. The R&D Group is also strengthening its collaborative creation with customers and its technological innovation, and drives railway system innovation.

REFERENCES

(1) S. Hirose et al., "Hitachi Experience Design in Railway System," JREA **56** No. 11 (Nov. 2013) in Japanese.
(2) H. Nakamura, "The Innovation of Railway Signaling Systems," IPSJ Magazine **55** No. 3, pp. 268–276 (Mar. 2014) in Japanese.
(3) K. Katsuta et al., "Feasibility Study of Ring Topology CBTC System with Information Sharing among Onboard and Switch Controllers," Proceedings of the 6th International Conference on Railway Operations Modelling and Analysis (Rail Tokyo 2015) (Mar. 2015).
(4) S. Sakikawa et al., "A Method of Train Regulation Planning by the Constraint Programming Using Train Regulation Knowledge," IEEJ Transactions on Electronics, Information and Systems **130** (2010) No. 2, pp. 332–342 (Feb. 2010).
(5) M. Suzuki et al., "Development of Railway Integration Evaluation System," Proceedings of 48th Symposium of the Congress of Japan Railway Cybernetics **103** (Nov. 2011) in Japanese.
(6) M. Fujiwara et al., "Estimating Changing Congestion Using Simulator that Considers Train Services and Passenger Flow throughout Entire Railway Station," Proceedings of J-RAIL2014 (Dec. 2014) in Japanese.
(7) M. Fujiwara et al., "Development of a Passenger Flow Simulator for Railways," Proceedings of 2013 IEEJ Annual Meeting (Mar. 2013) in Japanese.
(8) M. Kato et al., "Development of Business Valuation Tool for Collaborative Creation with Customers and Its Application to Assessing New Railway Construction," Cybernetics (Jan. 2016) in Japanese.

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