Systems Development Technology for Public Infrastructure

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OVERVIEW: To supply public infrastructure systems that keep pace with changes in society, Hitachi is promoting the symbiosis autonomous decentralized concept, a system concept for achieving the sustainability of society as a whole while treating change as the norm. To turn this concept into reality, Hitachi is developing system development technologies that satisfy the requirements at the system planning, construction, and operation/evaluation phases. These consist of: (1) Social system modeling and simulation techniques that keep these systems in an optimal and stable condition by controlling the flow of information to stakeholders, (2) System renovation techniques for rebuilding systems without interrupting services by modeling the principles of the physical structures and phenomena that support public infrastructure services, and (3) Heterogeneous system cooperation techniques for achieving optimum operation across the entire system by dynamically linking together the different systems owned by a particular organization.

INTRODUCTION

GIVEN the background of growing urban populations around the world and concern about depletion of energy and other resources, what is desirable is to use IT (information technology) to link consumer services with public infrastructure such as electric power, railways, and water to create the next generation of cities (smart cities) capable of ongoing growth and progress while also combining "conservation of the global environment" with "prosperous urban lifestyles that provide safety, security, and convenience." This is making public infrastructures increasingly important.

While existing public infrastructure has been built on the basis that it will operate in ways that have been planned in advance, there will be a strong demand in the future for systems that can continue to function autonomously and flexibly even in the event of emergencies such as natural disasters.

This article describes the system development technologies that will be required to support public infrastructure in the future.

TECHNOLOGY CONCEPTS FOR PUBLIC INFRASTRUCTURE

Aims of Technology Development

Consumers possess various ideas and motivations as they go about their lives and many cities have been established and grown quickly to satisfy these diverse needs, resulting in sudden changes in society. Smart cities require the provision of systems and solutions that can respond from a consumer's perspective, even in the face of these sudden changes in society. With the aim of achieving this, Hitachi is working on the technical development of new system concepts and architectures that extend and generalize the technologies it has built up in collaboration with advanced users of public infrastructure.

The systems with which Hitachi has been involved in the railway, electric power, and other sectors, such as those for railway traffic management or electric power system stabilization, have been designed on the basis that they will operate in pre-planned ways. Because

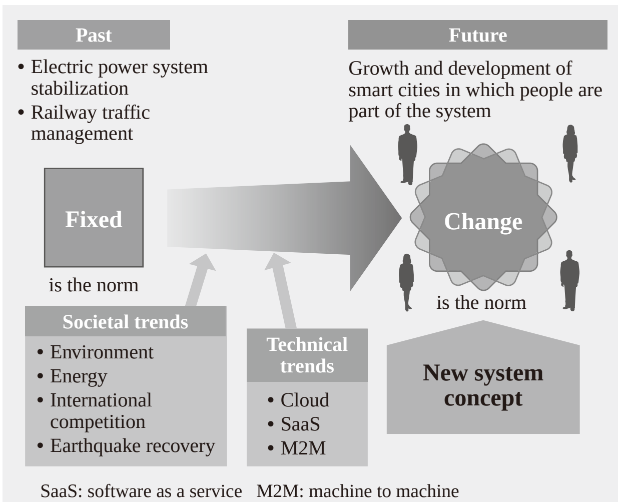

Fig. 1—Aims of Technology Development for Public Infrastructure.
A new system concept needs to be created to supply systems and solutions that can adapt to consumers' points of view amid a rapidly changing society.

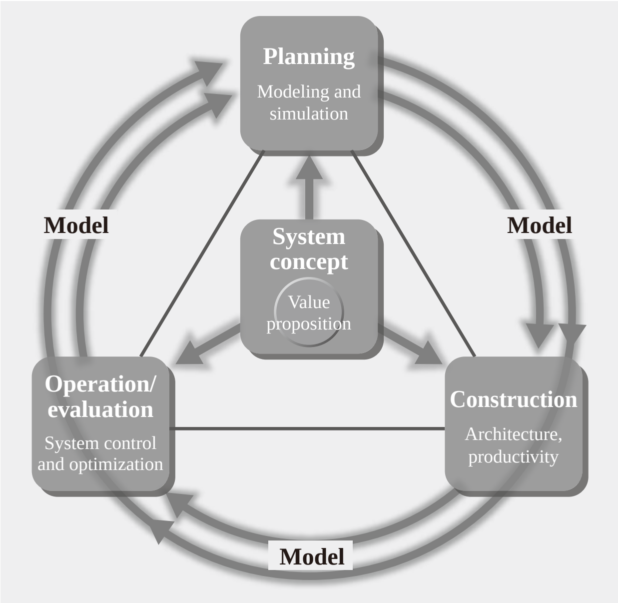

Fig. 2—Framework for System Development Technology.
The framework forms a system of technologies that support each process from planning through to construction and operation/evaluation with "value proposition" as the core system concept at the center of each technology.

people with a wide range of different objectives are part of the system, new public infrastructure systems, even while they use these existing systems as a foundation, are defined in terms of "change being the norm," with factors such as the external environment as well as the structure and component elements of the system continually changing in an evolutionary process (see Fig. 1).

Framework for System Development Technology

Fig. 2 shows the framework for system development technology used for public infrastructure systems. The framework forms a system of technologies that support each process from planning through to construction and operation/evaluation with "value proposition" as the core system concept at the center of each technology. This sequence of processes is repeated to move away from partial optimization and closer to the overall optimization of systems designed on the basis that "change is the norm," with models used as the common thread through each step from planning to operation/evaluation.

Symbiosis Autonomous Decentralized Concept

To respond to the type of changes in society referred to above, Hitachi is proposing the symbiosis autonomous decentralized concept in which the idea

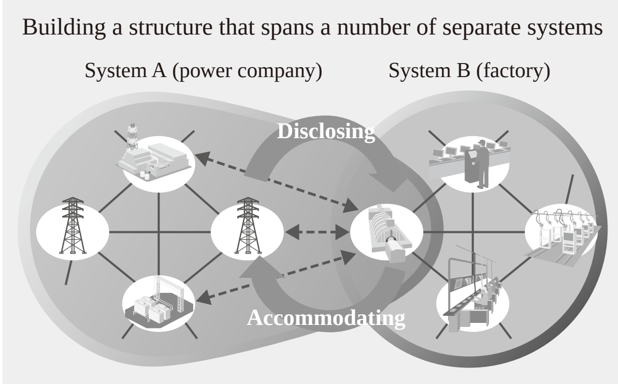

Fig. 3—Symbiosis Autonomous Decentralized Concept.
This involves making effective use of resources by building a structure that spans a number of separate systems.

of "change as the norm" is the basic system concept (see Fig. 3).

In biology, the term "symbiosis" refers to a situation in which two or more organisms coexist in the same habitat in a reciprocal relationship. Unlike the case with parasites, symbiosis means that the organisms are not detrimental to each other. Instead, living in proximity results in a relationship that is mutually beneficial.

To realize infrastructure systems in which the external environment as well as the structure and component elements are continually changing, the symbiosis autonomous decentralized concept takes inspiration from this biological way of thinking. The inclusion of symbiosis in this concept represents the synergy achieved when multiple systems intended for different purposes interoperate to the extent that their respective objectives allow.

The aim of the symbiosis autonomous decentralized concept is to extend existing autonomous decentralized systems(1) to ensure the sustainability of the overall system by accommodating finite resources across a number of autonomous systems based on their system objectives and changes in the internal and external environment. Here, resource refers to the functions belonging to each system, including the people, goods, and equipment involved in producing those functions.

To ensure that the accommodation of resources across multiple systems can be maintained in a stable manner, instead of allowing a system that requires resources to acquire those resources from other systems unilaterally, it is desirable that a system that is being requested to supply resources comes to its own autonomous decision on whether to accommodate the request, based on whether it can do so without significantly impacting its ability to achieve its own objectives. This concept is represented by "disclosing" and "accommodating" relationships whereby each system discloses information about what resources it possesses. Systems that receive this information decide to what extent to accept ("accommodate") requests from systems that lack resources based on whether their resources are excess to requirements or their use can be restricted. This can be thought of as a distinctively Japanese concept in which, instead of treating each system as having a fixed role, the systems have flexible roles and collaborative and relative self-configurations while remaining autonomous.

This resource accommodation across multiple systems makes it possible to achieve benefits, such as improving the efficiency of resource use and reducing waste, and to ensure the sustainability of society as a whole.

Necessary System Requirements and Development Technologies

The lifecycle of public infrastructure systems consists of three repeated phases, namely "planning," "construction," and "operation/evaluation." Turning the symbiosis autonomous decentralized concept into reality requires systems development technologies that deal with a variety of different social systems as a single entity in accordance with requirements in each phase along with the IT that supports these technologies (see Fig. 4).

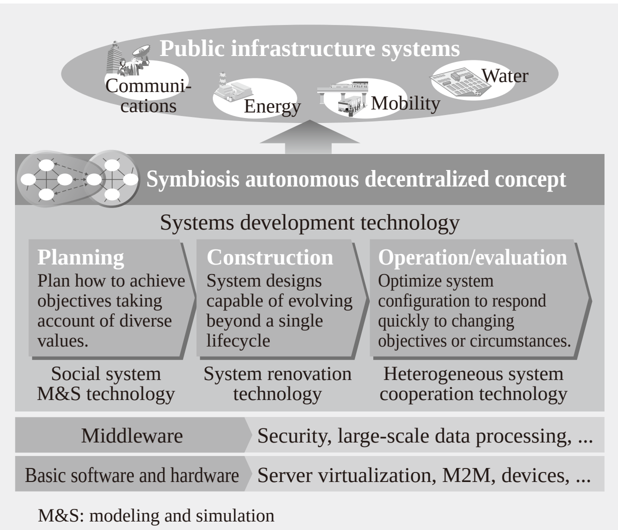

Fig. 4—Systems Development Technologies Supporting Symbiosis Autonomous Decentralization.
Hitachi has developed systems development technologies to satisfy the requirements of the planning, construction, and operation/evaluation phases.

The planning phase involves predicting the actions and needs of a range of different stakeholders with various diverse values (including consumers and urban service operators) when planning aspects of the city such as its structure and functions so that they can be optimized for solving the various issues the stakeholders face. The construction phase involves anticipating changes in society such as urban growth and changes in lifestyles, as well as other changes such as modifications to the functions that systems need to perform, and designing systems that can evolve in ways that transcend lifecycles and generations. The operation phase involves adjusting things like a system's configuration and functional priorities to optimize it quickly in response to changes in objectives and circumstances so that it can make a smooth transition from normal circumstances to an emergency situation and can adapt quickly to a different environment when it is redeployed elsewhere, such as in an emerging economy or a different industry.

Hitachi is developing systems development technologies to meet the requirements of each phase. These consist of social system M&S (modeling and simulation) technologies, system renovation technologies, and heterogeneous system cooperation technologies. These are part of a new trend in systems development technology, corresponding respectively to micro-level simulation techniques such as agent-based simulation, system development methodologies such as SysML (systems modeling language) (a language designed for use in system engineering), and SoS (system-of-systems) and other system configuration techniques[2].

The following sections describe these systems development technologies in detail.

SYSTEMS DEVELOPMENT TECHNOLOGIES SUPPORTING SYMBIOSIS AUTONOMOUS DECENTRALIZATION

Social System M&S Technologies

Simulation is performed in the system planning phase based on models of social systems that express the mutual interactions between stakeholders, defined as the consumers and urban service operators as well as the equipment and facilities they use (such as electric vehicles shared between a number of consumers). The simulation is used to predict the actions and needs of these stakeholders with their diverse values when planning aspects of the city, such as its structure and function, so that they can be optimized for solving the various issues the stakeholders face.

Two points in particular are important considerations when planning the optimum city structure and functions. The first is to consider multi-agent, multi-purpose systems because of the existence of multiple stakeholders. It is likely that many stakeholders will hold one or more different criteria for assessing services based on a diverse range of values. The important factor in this situation is to consider what is meant by “optimum.” The second consideration is to achieve stability of the systems themselves. What we are dealing with is the society in which people reside and go about their lives. This requires not only the optimization of systems, but also that their stability is assured in both social and economic terms. Modeling the behavior of stakeholders such as consumers and urban service operators is important because, unlike that of machines, it appears at first glance to be very indeterminate and complex.

Hitachi has identified the idea of “harnessing” as a technical concept for modeling smart cities of this kind[3].

Deriving from the harnesses (bridles and so on) used on horses, the concept of “harnessing” refers to controlling the flow of information to city stakeholders who act in an autonomous and decentralized manner so that systems are kept in an optimum and stable condition.

The following approaches are adopted to harness smart cities in this way. First, the values of the city’s stakeholders are analyzed to identify KPIs (key performance indicators), and then the ideas of “stability” and “optimization” are formalized in the form of an evaluation function (KPI analysis and identification). Either actual data on stakeholders is analyzed or, if no such data is available, the behaviors of urban service operators, consumers, and others are quantified in the form of expected values and spreads based on hypotheses (stakeholder modeling). Finally, the relationships between stakeholders are analyzed (stakeholder interaction). Based on this modeling, simulations are performed to assess how to implement harnessing in the city (in other words, determining whether systems function effectively when information on “who,” “when,” and “what” is circulated) in terms of stability, optimality, and fairness (see Fig. 5).

Fig. 6 shows an example of social system M&S technologies applied to mobility infrastructure planning. Modeling uses the system dynamics method. Factors like the level of traffic congestion and consumer comfort and safety are used as the KPIs. The stakeholder models include consumer and transportation operator models. The interaction model consists of a model of the exchange of services between stakeholders.

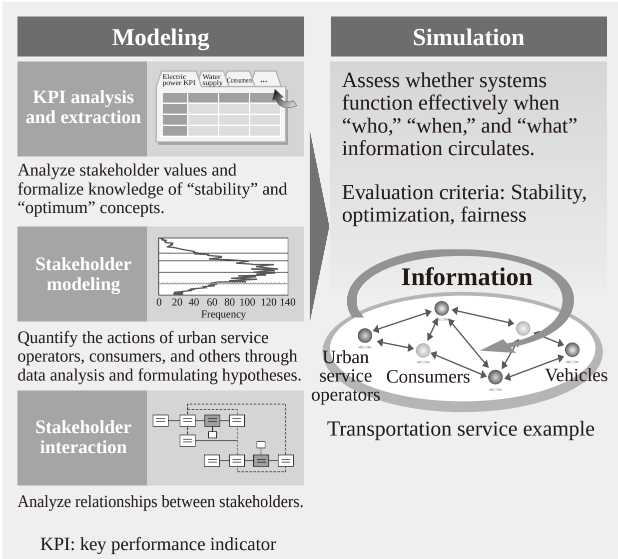

Fig. 5—Social System M&S Technologies.
These technologies are used for modeling and simulation of KPIs, stakeholders, and relationships between stakeholders.

These techniques are an effective way to identify structures that are in conflict with each other in ways that cause activities that would be expected to be beneficial to turn out to be counterproductive.

Simulation highlights trade-offs and can identify factors such as the quantity and timing of guidance information provided to users by quantitatively assessing future changes under different anticipated conditions. It can also be enhanced to better match actual results based on actual measurements from the mobility infrastructure.

System Renovation Technologies

A consequence of including operations such as stakeholder analysis or social system simulation in the system planning phase is that the results lead to changes in the functions required of the system. What will be required of public infrastructure systems in the future is that they keep up with changes in the required functions and continue to provide reliable services that keep pace with the growth of the city and other lifestyle changes in a way that extends beyond a single lifecycle. Accordingly, Hitachi is developing system renovation technologies in the belief that it is important to pay meticulous attention from the system construction phase to production methodologies that can rebuild systems without interrupting services.

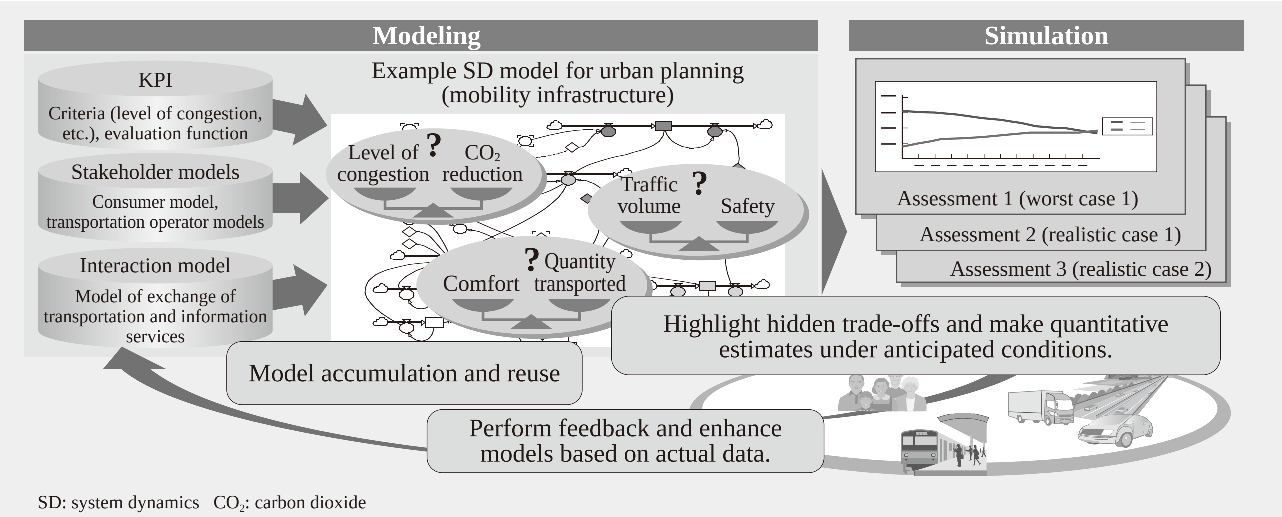

Fig. 6—Example Application in Mobility Infrastructure Planning.
Using outcomes such as the level of congestion as criteria, mobility infrastructure plans are formulated using models of consumers, transportation operators, and the exchange of services between them (representing their interaction).

Public infrastructure systems include services that must remain available in the future as they have been in the past. For example, while the concept of value in railway transportation services has shifted toward things like greater safety and convenience, the physical requirement of using a train running on rails to carry people and freight remains the same as it was in the analog era. In other words, the value that public infrastructure services provide to users has expanded to their physical structures and other physical circumstances through the application of control, information, and other technologies (see Fig. 7).

Hitachi has directed its attention at the physical structures and other physical circumstances that underpin public infrastructure services and believes that it is possible to upgrade these systems without interrupting services by modeling them in terms of the

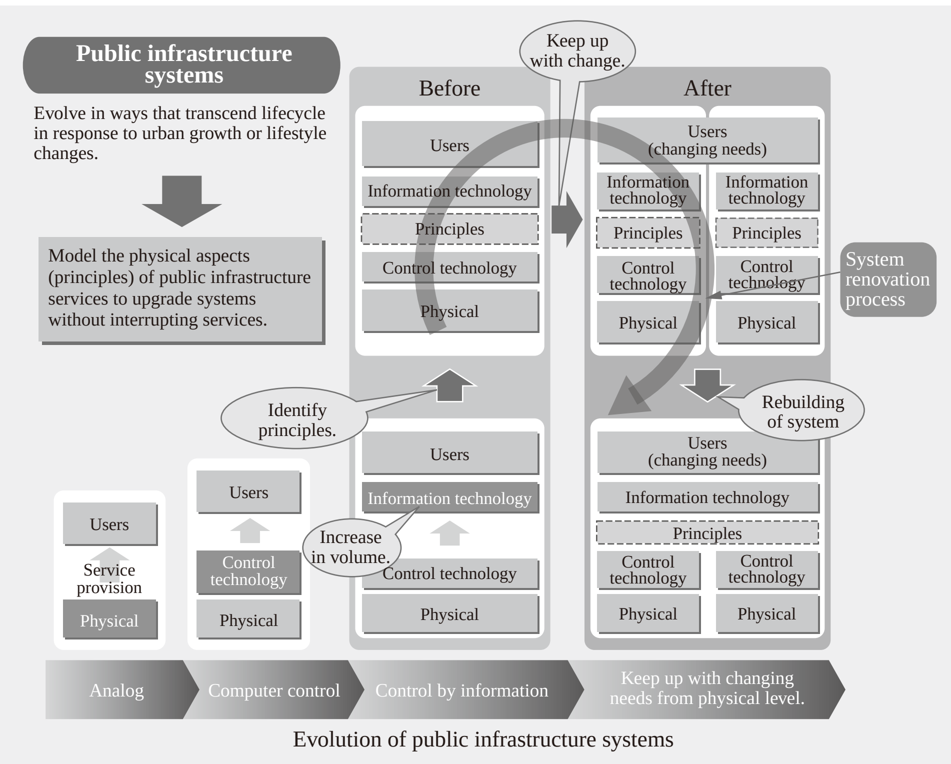

Fig. 7—System Renovation Technologies.
Systems can be upgraded without interrupting services by modeling the principles of public infrastructure services.

principles of their system configurations. Hitachi also believes it is possible to cope with dynamic changes in system configuration that occur in response to stakeholder decisions or circumstances by coordinating the principles of different systems in the case of heterogeneous system cooperation described below.

The system renovation process is called the R3 process as it consists of three steps: "reform (repair)," "refine (rebuild)," and "renovation (upgrading)" (see Fig. 8). The reform step does not extend as far as identifying the system's principles, and instead involves "visualizing" (making visible) a system so that it can be repaired. The refine step involves identifying the principles of the system (the nature of which has been "made visible" by the reform step) so that it can be rebuilt. The renovation step considers what form the system should take given the principles identified in the refine step and upgrades the system accordingly.

In this way, by basing its control systems, monitoring systems, and planning systems on common principles, a railway traffic management system, for example, could be upgraded to a highly flexible system that can handle things such as autonomous routing during emergencies, support for the prompt issuing of instructions based on the actual situation on the ground, and changes to timetables based on feedback from users.

Heterogeneous System Cooperation Technologies

Heterogeneous system cooperation technologies seek to satisfy the requirements for the construction and operation/evaluation phases in particular, with the aim of achieving optimum operation across the entire system by having systems that have their own independent evaluation criteria coordinate the operation of systems dynamically in response to change.

Heterogeneous systems are systems that have different evaluation criteria and judgment autonomy, with systems determining how to operate based on each of these evaluation criteria, and with cooperation between systems being built dynamically based on those decisions.

To implement these functions, systems are made up of the following elements in a heterogeneous system cooperation architecture.

(1) Service layer: Formulates and executes operation plans for the overall system, including the control layer and the various systems.
(2) Control layer: Performs monitoring and control of equipment such as production or transportation machinery.
(3) Control-service cooperation bus: Links the control and service layers and provides a pathway for field data such as sensor measurements from equipment or control targets derived from the operation plans.
(4) Heterogeneous system cooperation bus: Links different types of system and discloses resource information for each system.

To allow different types of system in this arrangement to come to accommodations over use of resources, each system operates in accordance with the following principles.

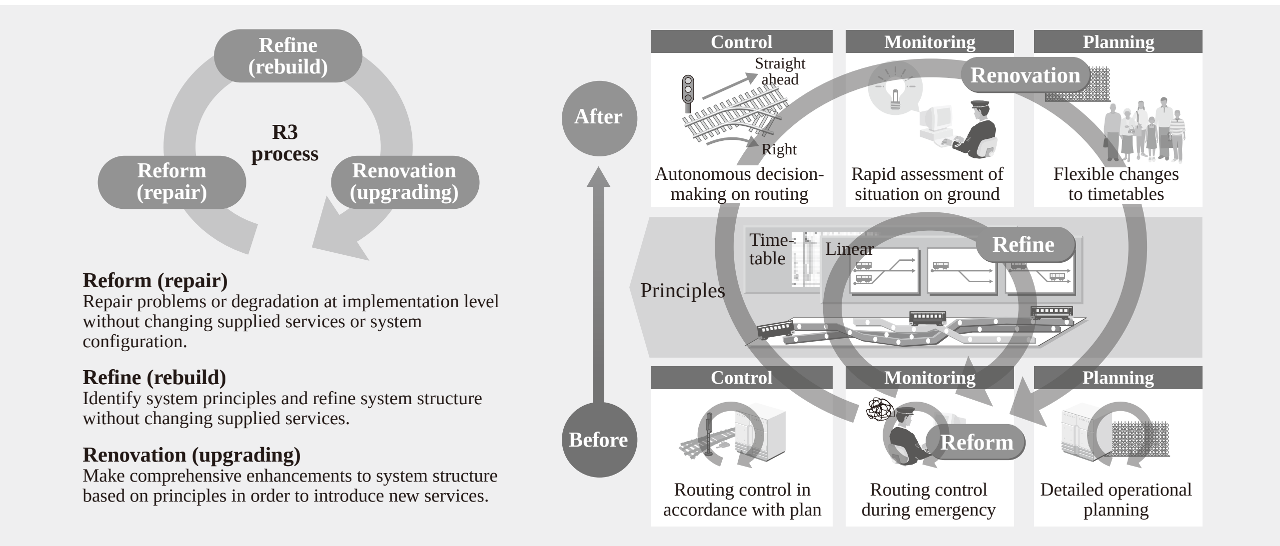

Fig. 8—R3 Process and Example Application to Railway Traffic Management System.
The R3 process uses three steps, "reform (repair)," "refine (rebuild)," and "renovation (upgrading)," to identify the form a system should take (its principles) and upgrades it to be highly flexible.

A system that wants to come to an accommodation over receiving a resource maintains and analyzes a heterogeneous system control model to predict whether each different type of system has an excess or deficit of that resource. Based on this, it discloses the resource that is in short supply and the period of time it is needed to those systems that it predicts will be able to come to an accommodation over the resource.

A system that receives a disclosure uses the received resource information to determine what effect providing the resource will have on its own operation, then decides on whether and how much resource to provide accordingly. To provide the level of resource it decides upon, the system passes control targets to the control layer (taking account of control limitations), and the equipment in the control layer operates autonomously based on these control targets to supply the resources (see Fig. 9).

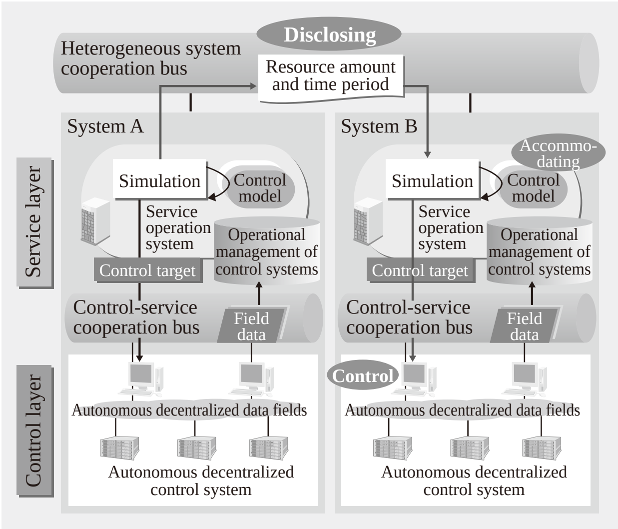

Fig. 9—Heterogeneous System Cooperation Architecture.
Coordinate the overall system by maintaining models of the control layer and various different systems in the service layer.

The heterogeneous system cooperation architecture can be used to balance power supply and demand within a region suffering from a power shortage. This involves the buildings, factories, and consumers in the region working together to make up the power shortage through in-house power generation or power savings (see Fig. 10).

The power company or other organization responsible for regional power supply uses a control model of the buildings, factories, and other consumers of power in the region to analyze regional supply and demand and discloses power information to the region's consumers.

In the event of a power shortage, factories make autonomous decisions on whether to reduce power consumption by adjusting production plans, taking account of the characteristics of the production machinery and the impact that the accommodation would have on things like production and income, and then control their production lines and other equipment accordingly.

CONCLUSIONS

This article has proposed the symbiosis autonomous decentralized concept as a way to cope with changes in society and described the system development technologies required to achieve it. The concept represents a new initiative in the field of system development technologies for supporting public

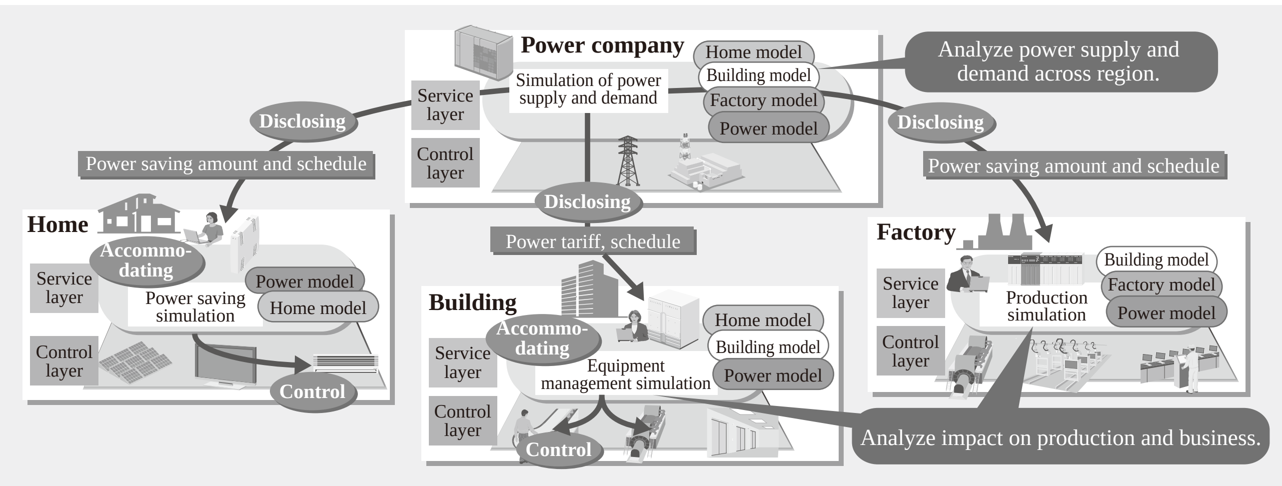

Fig. 10—Application to Regional Power Supply.
In response to the disclosure of electric power information, the region's stakeholders use their control layers autonomously to adjust power supply and demand within the region.

infrastructure and is based on an assumption that change is the norm.

In the future, Hitachi intends to help create flexible and sustainable social systems while also enhancing systems development technology through smart city demonstration projects in Japan and different parts of the world.

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