# CEMS Development and Demonstration in Toyota City Verification Project

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**Toyota City Low-carbon Society Verification Project was a large-scale social system demonstration project that was held between 2010 and 2014 at Toyota City, Aichi, Japan. The goal of the project was to verify that the realization of a low-carbon society can be facilitated by introducing leading-edge devices and technologies such as smartphones, tablets, big data, cloud computing, machine-to-machine (M2M), and the Internet of Things (IoT). These devices and technologies made it possible to collect information on electricity usage and electrical device status from society as frequently as every minute. The collected data was stored for analysis and then the results were fed back to society in the form of behavior support information, or as control signals to control electrical devices remotely. This paper presents Fujitsu's approaches towards the development and demonstration of a community energy management system (CEMS) that utilizes the IoT, a system which is critical for the realization of sustainable low-carbon societies.**

## 1. Introduction

The "Roadmap for the Next-Generation Energy and Social Systems"[1)] created by the New Energy and Industrial Technology Development Organization (NEDO) in Japan describes visions for 2020 to 2030 including:

- With prices of solar panels steadily decreasing, the cost of photovoltaic energy generation will be reduced and it will become even more widespread among ordinary households.
- Alongside with heat pump water heaters, prices of rechargeable batteries will also decrease, leading these devices to become widespread among ordinary households.

Realizing these visions will allow customers (energy consumers), who have been just consuming energy, to generate and store electrical energy. The roadmap mentioned above estimates that, with the shift of the role of customers, an energy management system for each area would become increasingly necessary for the efficient use of energy.

Recognizing these issues, the Ministry of Economy, Trade and Industry (METI) conducted the Next-Generation Energy and Social Systems Demonstration Project from 2010 to 2014 for the purpose of realizing efficient energy use and a low-carbon society that staves off global warming. For this demonstration, four areas [Yokohama City, Toyota City, Kansai Science City (Keihanna), and Kitakyushu City] were selected to verify the effectiveness of technologies, services, and business models for realizing smart communities.

This paper presents an overall outline of the Toyota City Low-carbon Society Verification Project[2)] hereafter, Toyota City Verification and Fujitsu's approaches towards the demonstration of the EDMS,[note)] a system that manages energy data of the entire living sphere. This paper also describes the knowledge acquired from the demonstration and the results produced.

## 2. Outline of Toyota City Verification

Toyota City Verification was a social system demonstration project led by Toyota Motor Corporation, which was the administrative agent, with the eventual

note) EDMS stands for energy data management system and is the name of the community energy management system (CEMS) in Toyota City Verification.

participation of 50 companies, and residents. The demonstration focused on the home sector (homes and traffic) and verified the validity of a system that realizes efficient energy use and a low-carbon society. The demonstration was conducted and evaluated respectively for the following five modules which were chosen based on the behavior flow lines of consumers such as homes, transportation (commuting to work, school, and going out), and destinations, and then the overall evaluation of the home sector was performed (**Figure 1**).

1) Home: optimization of energy use usage at home
- Automated control of various energy-saving, -generating, and -storing devices
- Energy supply from plug-in hybrid vehicles and electrical vehicles (PHVs/EVs) to homes (V2H)

2) Transportation: development of low-carbon traffic systems
- Introduction of next-generation vehicles (ultra-compact EVs)
- Coexistence of public transportation systems

3) Destination: optimization of energy usage in commercial and public facilities
- Introduction of rechargeable batteries to commercial facilities
- Utilization of PHVs and EVs in disaster situations

4) Living sphere: optimization of energy usage within communities
- Encouragement of action by using incentives
- Control coordination between each local energy management system (EMS) based on the energy usage of the entire community

5) Internationalization: study for global expansion
- Study of specifications of each EMS-linked operation interface
- Introduction of standardized interfaces

Toyota City Verification was aimed at realizing a next-generation regional low-carbon society that achieved not only optimization of energy use for each of the respective modules but also their integration, to achieve overall optimization of energy use in the entire living sphere. Specifically, the energy data for 1) to 3) were gathered and accumulated to be used to generate information for visualization, behavior support, and control. The generated information was then provided to consumers and devices as a service. The results were fed back, to be examined so as to determine the possibility of optimization.

The EDMS was a part of the module "4) Living sphere." The EDMS was intended for optimizing the energy demand and supply balance within the entire community, in addition to each home and consumer. To achieve such an optimization, various sensors including electrical energy sensors were installed to gather and utilize data, so that the use of elemental technologies of the Internet of Things (IoT) such as advice to customers and automatic control of devices

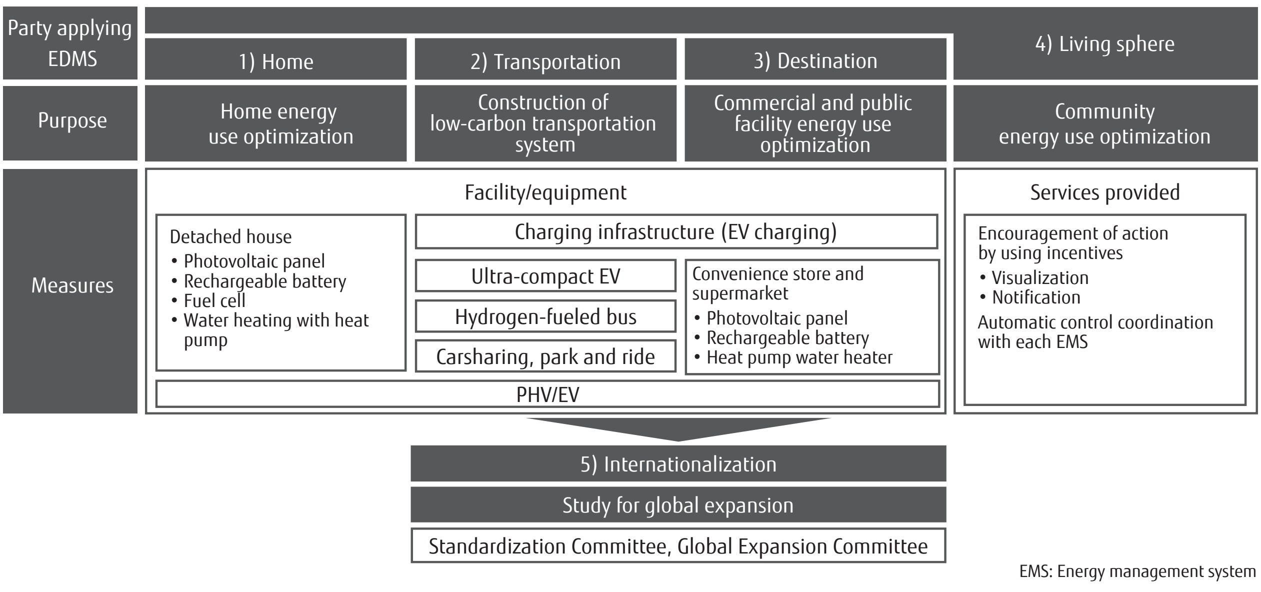


**Figure 1**
**Overall picture of Toyota City Verification and positioning of EDMS.**

became possible.

The following sections describe the EDMS in detail.

## 3. Toyota City Verification EDMS

The EDMS was capable of gathering one-minute-interval energy usage data from electrical energy sensors and home appliances, photovoltaic panels, rechargeable batteries, fuel cells, gas meters, water meters, and environmental sensors.

Fujitsu developed infrastructure for accumulating large volumes of data gathered by the EDMS which was also capable of converting and processing the data in real time into formats that could be easily processed by applications, and for offering the data through an application programming interface (API).

The data processed by the data infrastructure were provided to customers through EDMS applications as the following services.

1) Visualization

Data including the reduction in $CO_2$ emissions, the share of electrical energy from photovoltaic energy generation among the overall electrical energy consumption, and travel distance of a PHV/EV per kWh were provided for each home. Additionally, information such as rankings within the community to allow a comparison between households were offered.

2) Varying energy unit price

A pseudo energy rate menu was offered, providing an energy unit price that varied every 30 minutes based on the carbon factor for the region. The difference between the varying energy unit price offered by the EDMS and the energy unit price of the utility company that the resident was subscribing to was given as points that were convertible into electronic money.

3) Recommendation

Recommendation information, such as advice on energy-saving methods according to the season and timing of charging based on the usage situation of PHVs, was provided.

4) Target value service

Target energy usage during peak hours was set for each household and points were given if the target was continuously met for one month.

5) Automatic control

Based on the energy output, the energy usage, and PHV usage situation of each household, charging of the PHV and charging and discharging of the rechargeable battery were automatically controlled to balance the demand and supply within the entire community.

## 4. Data infrastructure architecture

This section describes the requirements for the data infrastructure developed by Fujitsu and its major configuration.

The EDMS was required to be able to run multiple applications (subsystems), so that the system could provide services that met the requirement for each of the themes of demonstration. The EDMS also required data infrastructure that allowed data to be easily linked between applications for providing services. For example, data gathered by sensors were used for generating prediction data (such as a photovoltaic energy output prediction and demand prediction), and then prediction data were used to calculate energy unit price data. The EDMS was also required to provide a system in which a service could be offered while referring to the results of another service.

In addition, data acquired from the EDMS itself and also from other demonstration modules (other systems) were required to be available to other systems immediately after their acquisition. However, not all of these requirements were determined at the start of the demonstration and required a flexible architecture design.

In order to satisfy these requirements, the data infrastructure was first configured so that it was separated into two parts: the first part being responsible for storing and accumulating the enormous amounts of data gathered from sensors without modifications, while the second part was responsible for processing the data into forms that allow them to be easily used by the devices and systems connected to the EDMS. The data were accessed using the common API. These data also needed to be provided by using a common API.

The common API was designed to link the EDMS with other systems using an open Web API. The structure of the data infrastructure is shown in **Figure 2**. In developing the Web API, we focused on the data storage efficiency, since the EDMS was required to connect and acquire data from various modules in the Toyota City Verification. The database design was a combination of multiple databases and different

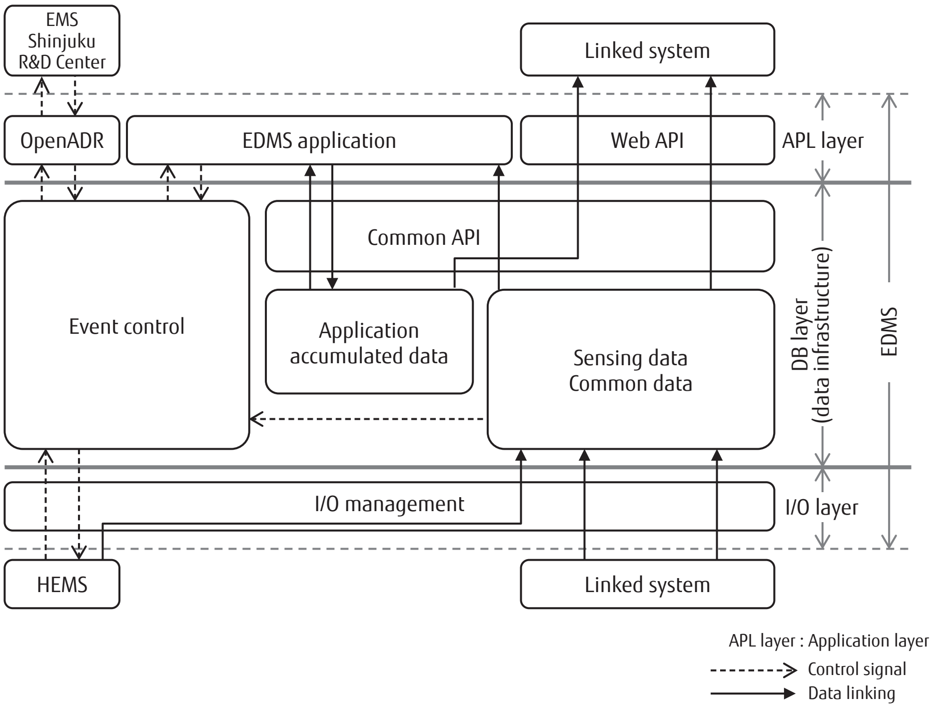


**Figure 2**
**EDMS function configuration.**

types of middleware to make the most of their respective features (such as response and storage efficiency). Considering the usability of application developers, the common API was designed such that the interface was independent of the internal mechanisms.

As the number of linked systems increased, we continuously improved the data infrastructure by dealing with sensing data-handling issues that we did not initially anticipate and new system requirements and demonstration themes that were added every year, while incorporating the findings obtained during the process.

After linking the EDMS with home energy management systems (HEMSs), we linked the data infrastructure with each manufacture-specific system in the Toyota City Verification, and also the DR Automation Server (DRAS)[3] in the EMS Shinjuku R&D Center, another demonstration project by METI. To provide an interface required for linking, we developed an external interface and enhanced the internal functions such as security functions. Concerning the data processing, which is the essential part of the data infrastructure, we continuously improved the capacity and accuracy of their generation and processing. The following presents the major events of the system development.

1) FY2011
- Accumulation of unstructured data and large volumes of data
- Linking with HEMSs
- Common data
- Access interface (common API)

2) FY2012
- Strengthening of security functions in preparation for information disclosure
- Event control function

3) FY2013 to FY2014
- Linking with the EMS Shinjuku R&D Center located in Tokyo (OpenADR 2.0b-compatible)
- Linking with various modules within the Toyota City Verification

The following describes the issues that arose during the development of the data infrastructure and their solutions, and our approaches toward the cost reduction.

## 5. Handling of sensing data

This section presents handling of sensing data, which requires a different approach from business system development.

1) Quality of sensing data

Data acquired from various sensors utilized in the IoT are called sensing data. The number of sensing data types from homes in the Toyota City Verification was about 50. Each home was equipped with sensors, devices with integrating sensors, a HEMS linked with the devices, a home gateway, a wireless LAN router, and such like. These devices were used to gather sensing data and transfer data to the Toyota City Verification EDMS.

Occasionally, the sensing data gathered had data distortion such as missing data due to device failure. There were multiple causes of data distortion: device failure, energy outage due to lightning strikes, device operation error by residents, and such like. These unexpected events can occur when the system is deployed to the real world, which makes it necessary to build a system with the assumption that the number of data distortion cases will increase along with an increase in the number of devices deployed.

Applications that make use of the sensing data have a variety of data usage needs: some applications will require a simple data correction, while others want the data distortion to be kept as part of the data. Through Toyota City Verification, we discussed with other participating companies whether the decisions related to and the processing of the data modification should be made on the application side or the data infrastructure side. As these requirements became clear through discussions, we improved the quality of data and the application interface provided by the common infrastructure.

2) Added value of data infrastructure

The EDMS was located in the cloud system and it was responsible for linking with peripheral systems such as HEMSs, building energy management systems (BEMSs), and traffic data management systems (TDMSs). It was also responsible for accumulating, processing, and publishing data. The common infrastructure of the EDMS was divided into two layers: the DB layer (i.e., data infrastructure) and the I/O layer. The I/O layer for linking with peripheral systems was developed by Toyota Motor Corporation and the data infrastructure for accumulating, processing, and releasing data by Fujitsu. The sensing data shown in **Figure 3** were gathered in this data infrastructure. The sensing data could include abnormal values as described above and abnormal values could be those in excess of the upper limit, missing observations that have no value, or such like.

When we initially started providing the data infrastructure, each application was specified as being responsible for correcting abnormal values. However, as the specifications of the applications gradually became clear, it was found that the quality of the entire system could be maintained and the application development burden reduced by having the data infrastructure prepare and provide aggregate values for

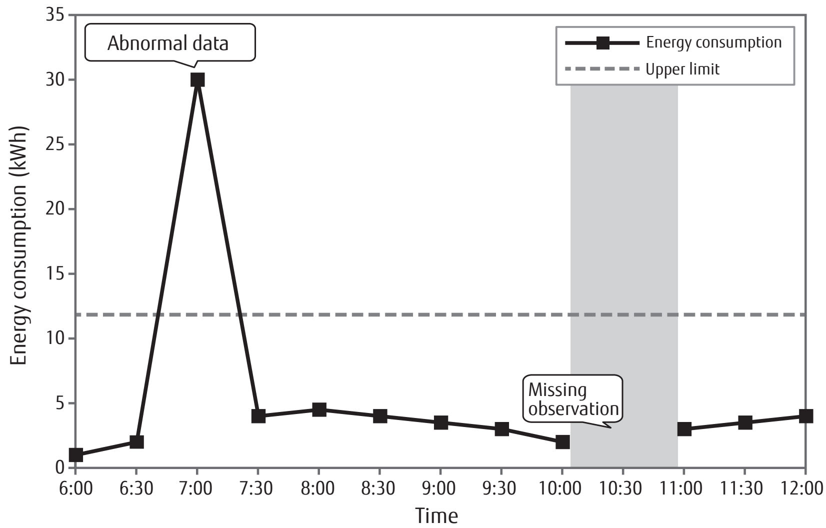


**Figure 3**
**Examples of abnormal data generated.**

1- and 30-minute periods as common data. In the end, abnormal values were corrected in the data infrastructure and common data were created there. Common data may be large unmodified values (including abnormal values) or aggregate values (calculated from corrected or uncorrected values) for periods of 1 minute, 30 minutes, etc. Of those, aggregate values for 30-minute periods, in particular, were the most often used out of all the common data provided by the data infrastructure. In terms of reducing the burden of application development and correction data, they were the common data that were rated especially high in the questionnaire obtained at the end of Toyota City Verification. The data infrastructure managed the data created by EDMS applications in addition to common data.

## 6. Data processing

For the EDMS, two processing methods for sensing data have been prepared. One is batch processing, in which data acquired from sensors and peripheral systems are handled as batches of data for periods of 30 minutes, 1 day, etc. The other is event-driven processing, which means timely processing of events that occur successively. In event-driven processing, in particular, EDMS applications and peripheral systems are linked for control according to the event generated. In the Toyota City Verification, control was provided to prevent the circuit breakers of the each home from tripping when the rechargeable batteries and PHVs of each home underwent a planned charge using the EDMS. The HEMS of each home monitored the energy consumption at home and, if conditions were met such as a value being in excess of the upper limit specified in advance, HEMS sent a notification to the EDMS. The EDMS judged whether or not it was necessary to perform subsequent processing based on the notification received, the immediately prior situation, and the conditions set in advance. If subsequent processing was found necessary as a result of the judgment, the business application to invoke was selected, and a notification was sent to it. The business application that received the notification then judged whether or not it was necessary to stop charging the storage battery or PHV. If it was necessary to stop charging, a control signal to stop charging was sent via the common infrastructure.

In Toyota City Verification, demonstration was conducted for two purposes: development of a charger and PHV charging control and the EDMS event control infrastructure and implementation of event-driven processing. In this way, we achieved a linkage down to the second with each home through the system in the cloud and we consider the usefulness of such event-driven processing to have been confirmed.

## 7. Management and operation of API

In the Toyota City Verification, the EDMS was linked with systems in the region such as the HEMSs, BEMSs, public chargers, consumer electronics controllers, and TDMSs, the sensors of various device vendors and the EMS Shinjuku R&D Center, which was conducting another demonstration project of METI. For the EDMS and each other system, connection targets were determined according to the purpose of demonstration specified for each fiscal year, and a consultation was held between systems to increase the targets of linking. From FY2013, the demand response (DR) linkage was implemented by using critical peak pricing (CPP).

The linkage between the EDMS and peripheral systems is shown in **Figure 4**. The actual values (such as the energy demand) acquired by sensors of the respective systems were gathered to the EDMS directly or indirectly via the center that supervised each device. The actual values gathered, weather prediction and DR signals from the upper-level system were used as

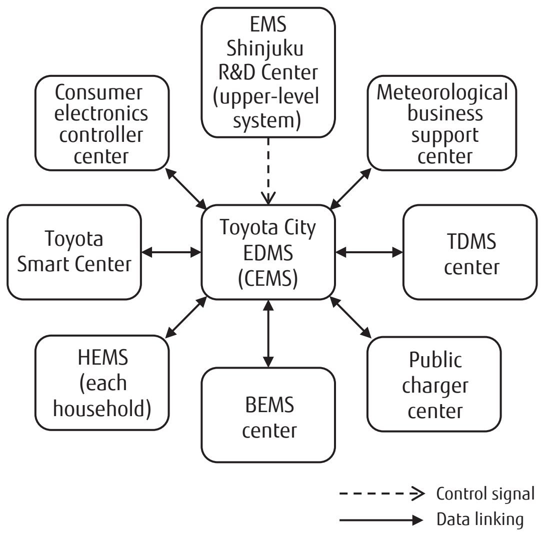


**Figure 4**
**Linkage between EDMS and peripheral systems.**

the basis for predicting future energy demand, and the energy unit prices for 30-minute periods intended for peak shaving and peak shifting were specified. The energy unit prices for 30-minute periods specified by the EDMS were transmitted to the respective systems, and the respective systems control the energy demand of devices under their management based on these unit prices. In this way, the energy demand of the entire region was controlled for the Toyota City Verification.

At the time of developing the interface to connect the peripheral systems with the EDMS in FY2013, simultaneous linking with multiple systems was implemented. For the EDMS, requirements from the each system were put together to release a Web API used in common by the each system from the EDMS, rather than individually dealing with each of the systems to be connected. In addition, to meet the need for quick development and ensured quality, we provided for an operation to support the development. The following lists the points that were considered and measures taken for offering the Web API.

1) Safe system linking
- Formulation of security policies
- Coordination with cooperating companies in conformity to the policies
- Formulation of operation at the time of system stop

2) Simple development methodology
- Provision of an easy-access Web API using uniform resource identifier (URI)
- Operation of a site for testing

3) Operation support
- Establishment of a contact desk and communication system

The examples given above are part of the measures taken to realize smooth operation. It has been demonstrated that, based on the energy unit prices for 30-minute periods specified by the EDMS, various systems linked together control the operation to optimize the regional energy demand. In addition to the purpose of technical demonstration, this activity provided many findings such as those related to prior consultation and support in the process of developing and operating the system in cooperation with many companies.

## 8. Activities for cost reduction

If a system like the EDMS described up to now is used in the future, the operation cost should be kept low. In the Toyota City Verification, we put the emphasis on economic efficiency and worked to improve the economic efficiency by calculating the system cost per participating household.

When we initially participated in the Toyota City Verification, we understood that linking with various modules was expected in the future, but there were unclear points such as the data format, data volume, and frequency of data output because the development of the each module began at the same time. The same can be said not only about the data gathered from HEMSs but also about the data generated by applications in the EDMS. Based on the assumption of handling a variety of formats and enormous amounts of data, we made it the development policy to build data infrastructure that is scalable and capable of handling unstructured data.

As described in Section 5, many similar types of data were created when the Toyota City Verification initially started. The data placement was not optimized, either, and the increase in the storage usage led to an increase in the system operation cost. Among the data management functions, the data infrastructure has a function of managing the placement of the data stored, and it allows data to be moved in a way that does not significantly affect business applications.

This function is intended for hierarchical storage management (HSM), or moving data that is used at a low frequency to storage that offers a high cost efficiency. The targets of application of this function were selected by analyzing the patterns of access to the data infrastructure. The ways of use were extracted as features from data with similar accessing methods and data with high/low access frequency to determine the targets of data replacement. For data with the same key (equivalent to an index in a relational database [RDB]), data were integrated in such a way that tables were joined laterally to decrease the volume. For data integration, a method was employed that migrated data while maintaining the same accessing method as before such as a view of the database management system (DBMS), in consideration of the impact on business applications. In this way, we have proposed a way to reduce and suppress resource usage in the data infrastructure every year and worked on improvement. **Figure 5** shows the system operation cost ratios of the data infrastructure: It uses as the reference the results of verifying the architecture that gathers, processes, and releases the HEMS data for 1,000 buildings using the data infrastructure of FY2012, and it plots the results of measuring the improvement made in each of the subsequent fiscal years.

We have reduced the system operation cost per building every year by evaluating the system processing capacity and data storage situation for every fiscal year and identifying the issues to make an improvement in the following fiscal year. As a result, the data infrastructure itself has been streamlined and the upper limit of the number of buildings that can be handled by the system has increased as well.

## 9. Conclusion

This paper has presented Fujitsu's approaches to the handling of sensor data peculiar to the IoT that need to be dealt with in the process of developing data infrastructure and to the requirements of the infrastructure as a social system, while also giving their results. At present, activities for connecting devices to the Internet are becoming widespread and expanding further. These movements are estimated to lead to lower prices of components such as sensors and communication devices and further accelerate the connection to the Internet of people and things. Such development of the IoT is raising expectations for changes to be brought about in society.

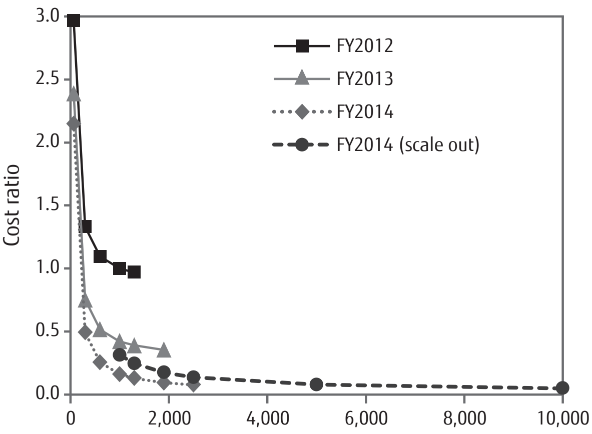


**Figure 5**
**System operation cost ratios of data infrastructure.**

Fujitsu now offers energy-related solutions that take advantage of the technology and know-how amassed during the five years of the Toyota City Verification. We intend to help realize a society that offers affluence in overall life in addition to a low-carbon society by using the solutions provided by Fujitsu.

Last but not least, we would like to extend our sincere gratitude to Toyota Municipal Government, which arranged the demonstration field of Toyota City, the administrative agent Toyota Motor Corporation, and the relevant companies that participated in the Toyota City Verification.

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