

Development of Quantitative Evaluation Method regarding Value and Environmental Impact of Cities

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Recently, more and more organizations have been proposing and introducing infrastructure to realize a Smart City because there has been an increase in environmental impact associated with urbanization. On the other hand, it is becoming more important to introduce information and communications technology (ICT) to create new services by connecting infrastructure organically. At the same time, an index is needed for making city government officials understand the problems and solutions regarding infrastructure. In Fujitsu, we are focusing on both the value and environmental impact of cities as a whole, and enhancing a quantitative evaluation method for introducing ICT solutions to cities. We have developed a quantitative evaluation method focusing on the efficiency of a city (degree of smartness) and effect that ICT has on a city. This paper describes the evaluation method focusing on the new evaluation concept, framework, and items for integration. In addition, it explains the impact evaluation method and shows a case study of introducing ICT solutions.

1. Introduction

The United Nations Environment Programme says that, by 2050, some 6 billion people, or two-thirds of mankind, are expected to be urban dwellers, and this is assumed to cause air pollution and other forms of environmental destruction, traffic congestion and energy problems, leading to increased environmental impact.¹⁾ In order to address this issue, the concept of Smart Cities has recently been proposed and various measures and projects are being discussed and implemented. To realize Smart Cities, various types of social infrastructure are being introduced such as renewable energy including photovoltaic and wind power generation, power systems including smart grids, carsharing and charging stations for electric vehicles. Meanwhile, introduction of information and communications technology (ICT) including energy management systems such as a home energy management system (HEMS) and building energy management system (BEMS), medical network system, traffic location data system and environmental information sensor system will increasingly gain importance (**Figure 1**). With this situation in the background, it is important to clarify ICT's contribution to the smartification of cities. To that end,

indicators for quantitatively evaluating the effects of these are necessary.

At present, various methods for evaluating cities and districts are being discussed. The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) for Cities²⁾ provides a means of comprehensively and relatively evaluating the environmental performance of a city in terms of three aspects of "the environment, society and economy" plus "environmental impact." The Leadership in Energy & Environmental Design-Neighborhood Development (LEED-ND)³⁾ is used for rating the environmental performance of a district in terms of five aspects: "smart location and linkage," "neighborhood pattern and design," "green infrastructure and buildings," "innovation and design process" and "regional priority credit." There are also other methods such as the Global Power City Index,⁴⁾ which calculates scores for major cities in the world by using 20 indicators in six groups of vitality, culture, interaction, luxury, amenity and movability, and European Smart Cities Ranking.⁵⁾

These methods of evaluation have many indicators for relative evaluation, such as points calculated from the deviation values of respective cities, and

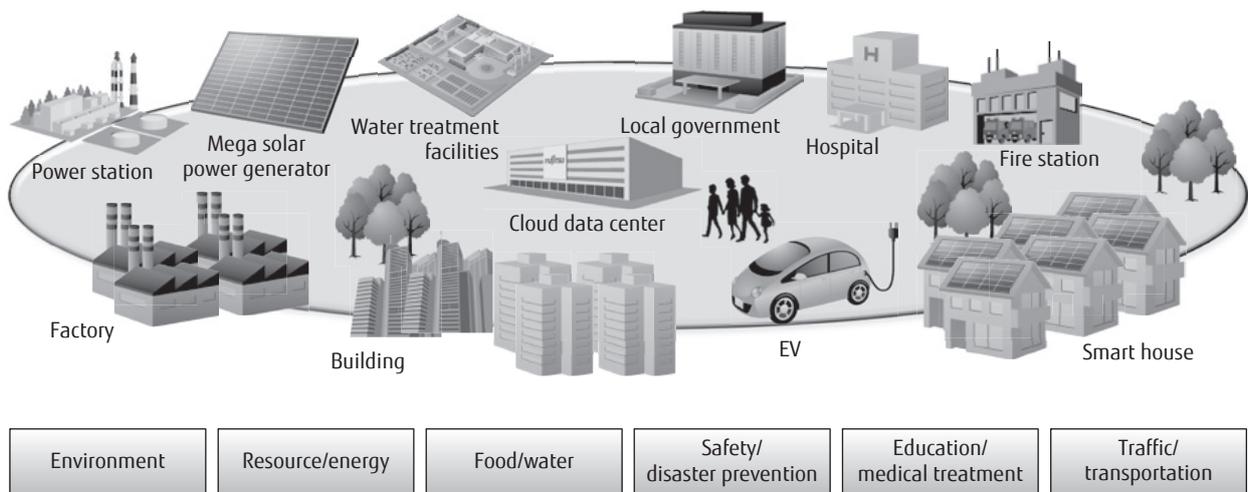


Figure 1
Issues with Smart City.

not many indicators allowing absolute evaluation. In addition, they provide evaluation mainly from the viewpoint of infrastructure such as buildings and facilities, and this has posed the problem of their inability to sufficiently evaluate the effect of the introduction of ICT.

At Fujitsu, we have studied methods of evaluating the environmental impact reduction achieved by ICT, and we have been developing a method to quantitatively evaluate the environmental impact reduction effect (CO₂ emissions reduction effect) produced by introducing ICT since FY 2004. We have certified and offered products and services that exceed certain standards as "environmental contribution solutions."^{6,7)} Up to now, more than 300 products and services across various fields and business categories have been evaluated. For products such as PCs and servers, we introduced in FY 2007 the "environmental efficiency factor" indicator that quantifies performance and functionality of products and combines them with lifecycle assessment (LCA) to represent the ratio of the product value to the environmental impact for new and old products. This helps promote the creation of products capable of offering higher value with lower environmental impact.⁸⁾ These are both intended for individual products and solutions.

Fujitsu is committed to realizing sustainable cities and has focused on performance items in terms of both value and environmental impact of an entire city. It has also developed a new method of quantitative

evaluation of the efficiency (degree of smartness) of a city and effect of introducing ICT by applying to an entire city a method capable of quantitatively evaluating the effect of introducing products and solutions that have been studied. This paper outlines this quantitative evaluation method and presents a case study of the effect of introducing ICT that makes use of the method.

2. Method of quantitative evaluation of Smart Cities

2.1 Concept of quantitative evaluation of cities

Cities have their own characteristics, are involved in a variety of activities and come in different sizes. In order to quantitatively evaluate the characteristics of cities, what aspects are used by the residents to see the value of the cities should be considered from the viewpoint of the residents. In addition, cities have a certain impact on the global environment through their activities. Quantitative evaluation of this impact on the environment as a burden should also be taken into consideration.

Generally, the more convenient and affluent life is in a city, the greater its environmental impact. That is, the value of a city and environmental impact of the city are contrary to each other. To evaluate the entire city, however, these mutually contrary elements must be considered and combined. And to do this, we propose

a concept in which the performance of a city is defined by dividing the value of the city by its environmental impact as the efficiency (degree of smartness) of the city. We think of this efficiency as an effective indicator for evaluating the degree of smartness of a city. In addition, we intended this evaluation of a city to be capable of quantitatively evaluating the introduction of ICT. Based on the concept that the evaluation reflects the value of a city for its residents, it should ideally be a relatively simple and straightforward indicator that can evaluate the process of improvement of a city, achieved by measures taken, and also be capable of quantitatively evaluating multiple cities under the same conditions in relative terms. That is what we aimed at as we embarked on the development of a method of quantitative evaluation of cities.

2.2 Value and environmental impact of city

For the value of a city, we used the triple bottom line, or environmental, social and economic concerns, proposed by the United Nations as the basic concept.⁹⁾ Based on this, we have extracted functions that provide the value of a city in terms of the following three aspects of environmental quality, society and economy to use as the evaluation items.

1) Environmental quality aspect

Air, water, land, etc.

2) Social aspect

Residence, food/energy, traffic/transportation, security/safety, disaster prevention, education, medical treatment/health, administration, community, vitality of the region, etc.

3) Economic aspect

Financial base of the administration as the economic strength of the city, economic strength of individuals, employment as the industrial strength, etc.

We have looked at the environmental impact of a city from three aspects: impact on climate change, resource depletion and biodiversity. Then we selected evaluation items that represent the degrees of impact for the respective aspects.

2.3 Framework of evaluation of cities

In order to integrate the value and environmental impact composed of multiple items, it is necessary to weight the respective evaluation aspects and items for integration. The method of evaluating the value and

environmental impact of a city is as described below.

1) Value of cities

First, in the value evaluation process, the integrated value V_{total} can be represented by the formula below using an aspect of value V_i and weighting coefficient w_i with i as a category of evaluation items.

$$V_{total} = \sum w_i V_i$$

The aspect of value V_i has multiple evaluation items and, with a classification of evaluation items as k , it can be represented by the formula below using an individual evaluation item V_{ik} and weighting coefficient a_{ik} .

$$V_i = \sum a_{ik} V_{ik}$$

When the environment, society and economy are considered as the aspects of value of a city, with the environmental aspect of value of the city as V_1 , social aspect as V_2 , economic aspect as V_3 and weighting coefficients as w_1 , w_2 and w_3 respectively, the total value V_{total} can be represented by the formula:

$$V_{total} = w_1 V_1 + w_2 V_2 + w_3 V_3$$

2) Environmental impact of cities

Then, in the environmental impact evaluation process, the integrated environmental impact B_{total} can be represented by the formula below using an aspect of environmental impact B_j and weighting coefficient g_j with j as a category of environmental impact evaluation items.

$$B_{total} = \sum g_j B_j$$

An aspect of environmental impact B_j can be represented by the formula below using an individual evaluation item B_{jm} and weighting coefficient b_{jm} with m as a classification of evaluation items.

$$B_j = \sum b_{jm} B_{jm}$$

When three aspects of the environmental impact of a city, namely climate change, resource depletion and biodiversity, are considered and with B_1 as the impact on climate change, B_2 on resource depletion and

B_3 on biodiversity and g_1 , g_2 and g_3 as weighting coefficients respectively, the total environmental impact can be represented as:

$$B_{\text{total}} = g_1B_1 + g_2B_2 + g_3B_3$$

To weight the value and environmental impact of a city, various methods are discussed. Weighted estimation by the analytic hierarchy process (AHP),¹⁰⁾ which is used in CASBEE for Cities, distribution of the degree of impact by added value using monetary value conversion¹¹⁾ and distribution of impact by LCA¹²⁾ can be used.

3) Integration of value and environmental impact of cities

Now, the value and environmental impact of the city can be integrated so that the efficiency (degree of smartness) of the city can be evaluated by using the formula:

$$\text{Efficiency (degree of smartness) of a city} = V_{\text{total}}/B_{\text{total}}$$

2.4 Evaluation items

This subsection describes the concept of evaluation items for evaluating the value and environmental impact of a city and integration.

1) Value of cities

As explained above, the value of a city (V_i) can be seen from three aspects. First, the environmental aspect (V_1) is intended for measuring the quality of the environment and can be classified into the quality of the natural environment of the region including air (V_{1-1}), water (V_{1-2}), land (V_{1-3}) and targets of evaluation other than air, water and land (V_{1-4}) and evaluation items for measuring the performance of the respective types of value can be selected. Second, for the social aspect (V_2), residence (V_{2-1}), food and energy (V_{2-2}) and traffic/transportation (V_{2-3}) can be seen to represent the value of a city required for lifestyle comfort and convenience in living environment for people. As the value of a city that provides a sense of security with regards to traffic accidents and crime, safety/security (V_{2-4}) and disaster prevention (V_{2-5}) can be seen as important value and used as evaluation items. Regarding services available in the region, education (V_{2-6}), medical treatment/health (V_{2-7}) and administration (V_{2-8})

can be regarded as the basic services. In addition, for livability of the region, community (V_{2-9}) and vitality of the region (V_{2-10}) are adopted as evaluation items. For the third economic aspect (V_3), financial base of the administration (V_{3-1}) for soundness of the administration, economic strength of individuals (V_{3-2}) for soundness of individuals and employment for the industrial strength (V_{3-3}) can be considered as evaluation items. These evaluation items for the value of a city are listed in **Table 1**.

2) Environmental impact of cities

Next, three aspects can be considered for the environmental impact (B_j) of a city. One major indicator representing impact on climate change (B_1) is greenhouse gas emissions (B_{1-1}). For the impact on resource depletion (B_2), final disposal volume (B_{2-1}), recycling (B_{2-2}) and use of resources (B_{2-3}) can be selected as evaluation items. For the impact on biodiversity (B_3), impact on the human body (B_{3-1}) and impact on the ecosystem (B_{3-2}) can be selected as evaluation items for measuring the degree of impact. These evaluation items for the environmental impact are shown in **Table 2**.

3) Integration of value and environmental impact of cities

In the formulae for evaluating the efficiency (degree of smartness) of a city mentioned above, to focus only on climate change in B environmental impact, we evaluate only climate change items (B_1) as the evaluation items. For evaluating climate change (B_1) and resource depletion (B_2) as the B items, the two items can be evaluated. It is also possible to focus only on V value by evaluating V alone and, of V, evaluate only the crime rate for safety/security (V_{2-4}) and the number of doctors for medical treatment/health (V_{2-7}) as required. In order to evaluate the overall efficiency (degree of smartness) of a city, the necessary items can be selected for evaluation. Naturally, more items must be included to evaluate a city in a more multifaceted manner. If we use many evaluation items selected by the evaluator for evaluation, we can indicate the degrees of value and environmental impact for the respective items by having multifaceted representation of the evaluation results using radar charts as well as integration of the results as the efficiency (degree of smartness) of a city. A city has been used as the target in the evaluation method described up to now, but the

Table 1
Evaluation items and evaluation indicators of value of cities.

	Aspect of value	Value evaluation item	Evaluation indicator
V Value of city	V ₁ Environmental quality (EQ)	V ₁₋₁ Air	NO _x , SO _x , photochemical oxidants, SPM, CO, etc.
		V ₁₋₂ Water	Hydrogen-ion concentration (pH), biochemical oxygen demand (BOD), suspended solids (SS), dissolved oxygen (DO), coliform bacteria count, etc.
		V ₁₋₃ Land	Rate of green field, rate of brown field, rate of forest area, abandoned cultivated land, etc.
		V ₁₋₄ Item other than air, water and land	The number of complaints/accidents, etc.
	V ₂ Society (SC)	V ₂₋₁ Residence	Comfortable living space, floor area per person, etc.
		V ₂₋₂ Food and energy	The number of stores offering food/energy/daily necessities, open hours, etc.
		V ₂₋₃ Traffic/transportation	Access to public transportation systems, length of traffic congestion, travel time, speed for movement of goods and persons, etc.
		V ₂₋₄ Safety/security	The number of crimes/fires/traffic accidents that occurred, etc.
		V ₂₋₅ Disaster prevention	Enhancement of disaster prevention functions of the region concerned, etc.
		V ₂₋₆ Education	The number of students per teacher and the number of teachers of elementary, junior high and senior high schools, etc.
		V ₂₋₇ Medical treatment/health	The number of doctors and beds, medical expense, average life expectancy, metabolic syndrome rate, time required for medical examination, etc.
		V ₂₋₈ Administration	The number of staff members per resident, time from application for document to reception, etc.
		V ₂₋₉ Community	Use of public facilities such as community halls and opportunity of social participation, etc.
		V ₂₋₁₀ Vitality of region	Natural increase/decrease of population, social increase/decrease of population, etc.
	V ₃ Economy (ECON)	V ₃₋₁ Financial base of administration	Annual local tax revenue, debt expenditure ratio, budget/fiscal balance, etc.
		V ₃₋₂ Economic strength of individuals	Taxable income per person, etc.
V ₃₋₃ Employment		Employment rate, etc.	

Table 2
Evaluation items and evaluation indicators of environmental impact of cities.

	Aspect of environmental impact	Environmental impact evaluation item	Evaluation indicator
B Environmental impact	B ₁ Impact on climate change	B ₁₋₁ Greenhouse gas (GHG) emissions arising from industrial, civilian, transportation and energy conversion sectors	Emissions (t-CO ₂), emissions (t-CO ₂)/population (the number of persons), etc.
		B ₁₋₂ Impact in life cycle	Impact of activities in the target region on climate change (LCA-type evaluation), etc.
	B ₂ Impact on resource depletion	B ₂₋₁ Final disposal volume	Final disposal volume (kg), final disposal volume per person (kg/person/day), etc.
		B ₂₋₂ Recycling	Recycling volume (kg), recycling volume per person (kg/person), recycling rate, etc.
		B ₂₋₃ Use of resources	Types of resources used, resource usage (kg), resource usage per person (kg/person), etc.
	B ₃ Impact on biodiversity	B ₃₋₁ Impact on human body	Converted toxicity of toxic chemicals emitted into the air in the target region, etc.
		B ₃₋₂ Impact on ecosystem	Population and distribution of species, inhabitability of organisms, size and quality of ecosystem, impact of activities in the target region on ecosystem outside the target region, converted toxicity of toxic chemicals emitted into the air in the target region, etc.

method can be applied to cities of various sizes and to the evaluation of towns and villages as well.

As the methods of evaluating the respective items of CO₂ emissions, resource depletion and biodiversity as aspects of environmental impact, we have made use of quantitative evaluation techniques that have so far been developed and applied ones such as the LCA method, environmental impact assessment method,¹³⁾ resource efficiency assessment method¹⁴⁾ and integrated biodiversity assessment method.¹⁵⁾ We have also used basic unit databases and results of evaluation examples.

2.5 Concept of evaluation of ICT solution introduction

When ICT solutions are introduced to a certain city, contribution of the solutions can be quantitatively evaluated from three perspectives of "improvement of the value of the city," "reduction of the environmental impact" and "efficiency (degree of smartness) of the city" by using the evaluation indicators described up to now (V, B and V/B).

Introducing ICT solutions makes it possible to evaluate the improvement of value V of the city by looking at changes in evaluation items that measure the performance of value aspects V. For environmental impact B, introduction of ICT can indicate a reduction of impact as an influence on the impact. Furthermore, for the overall efficiency (degree of smartness V/B) of the city, how the efficiency (degree of smartness) of the city changed by the changes in value and environmental impact between before and after the introduction of ICT can be quantitatively represented as the efficiency factor.

2.6 Concept of ICT contribution to city

To evaluate the contribution of ICT to a city, it is ideal to evaluate changes in value V, environmental impact B and overall efficiency (degree of smartness) V/B of the city, both before and after the ICT introduction in the entire city, though this is generally difficult to do. Accordingly, as a trial calculation and estimation of the effect, we present a method of evaluation for an entire city based on the effect of introducing one ICT solution in a certain field (such as a hospital, factory and company) for the purpose of estimating the effect of ICT on the entire city. The evaluation method includes the

following steps.

1) Grasp effect of one ICT solution in one field

This step is intended to find the effect of introducing one solution in terms of the value and environmental impact of the city by using the methods mentioned earlier including the environmental impact assessment method.

2) Grasp effect of introduction of multiple ICT solutions in one field

When more than one solution is simultaneously introduced in one field, overlapping of the effects needs to be evaluated. When there is any overlap, it is necessary to deduct such overlap from a simple total of the effects.

3) Grasp effect on entire city based on effect on one field

In order to calculate the effect on the entire city based on the effect on one field, it is necessary to define a size coefficient and multiply the effect on one field by the size coefficient. The size coefficient should indicate the size ratio of one field to the entire city, and it may be based on the number of trucks, doctors/hospitals or workers or size of business.

3. Case study of evaluation of ICT introduction effect

This section describes examples of evaluating the environmental impact, value and efficiency (degree of smartness) of a city by assuming that solutions have been introduced to a city (City A). City A is assumed by referring to a representative city in Japan with a population of 1.5 million. Based on a precondition that ICT was not sufficiently utilized before the introduction of the solutions, extension of the effect on City A has been studied.

3.1 Evaluation of environmental impact of cities

This subsection presents a specific example of extending to an entire city the effect of introducing traffic, medical treatment and office solutions provided by Fujitsu to reduce the impact caused by climate change.

The eco & safety drive evaluation system TRIAS/TR-E&S, which is a traffic solution, is capable of accurately evaluating (visualizing) drivers' efforts and ingenuities for eco & safety drive and its introduction offers a mileage improvement effect of approximately

20%. On the assumption that about half of the employees in the road freight transportation industry in City A use trucks, multiplying the total number of trucks in City A by the CO₂ reduction effect per truck gives an estimated CO₂ reduction effect per year in the entire City A of 28 102 t-CO₂.

FUJITSU healthcare solution HOPE EGMAIN-GX, an electronic medical record system, is a medical treatment solution that can improve the quality and efficiency of medical treatment by computerizing medical records and having centralized management using databases. It achieves a CO₂ reduction effect of approximately 30% by reducing the office space and goods. The CO₂ reduction effect per hospital bed can be multiplied by the total number of hospital beds in City A to give an estimate of 349 t-CO₂ as the annual CO₂ reduction effect of the entire City A.

The document management system "FUJITSU integrated ERP package solution GLOVIA smart information sharing Documal" is an office solution that computerizes application forms and reports generated in the process of office operations and is capable of improving efficiency, speeding up and reducing the cost of operations by providing a paperless information sharing system. The reduction of person-hours required for documentation offers a CO₂ reduction effect of approximately 75%. When this effect is extended to offices located in City A, the CO₂ reduction effect per employee can be multiplied by the number of employees in offices in the manufacturing industry of City A, to give an estimated annual CO₂ reduction effect in the entire City A of 156 t-CO₂.

To consider a case in which the three solutions mentioned above have been introduced simultaneously, the environmental impact reduction effect is provided separately in three areas of traffic, medical treatment and offices (manufacturing industry) and the estimated effects are assumed to never overlap. Accordingly, simultaneous introduction of the three solutions above leads to an estimated annual CO₂ reduction effect of the three solutions for the entire City A of 28 607 t-CO₂.

3.2 Evaluation of value of cities

In this subsection, we present a specific example of extending to an entire city the effect of introducing multiple medical service solutions to improve the

city's value from a social aspect. One evaluation item for value in the medical service field is the number of doctors. The medical image information system "FUJITSU healthcare solution HOPE DrABLE-EX" computerizes images owned by medical institutions. When medical images are computerized, person-hours can be reduced by approximately 60%. The community medical network "HumanBridge HER" solution securely links patients' medical information between multiple medical institutions to contribute to the enhancement of community medical services. It is capable of improving the efficiency of operations by computerizing referrals and replies and allowing them to be exchanged via the system, which reduces doctors' person-hours by approximately 70%.

By introducing the two solutions above, the person-hours spent on the existing operations can be reduced, which allows the staff to engage in other operations. This can be interpreted as an increase in the apparent number of doctors. Making an estimation using the numbers of hospitals and clinics in City A, we see that introducing these two solutions is expected to increase the apparent number of doctors by 63 from the current 119.

3.3 Evaluation of efficiency (degree of smartness) of cities

Lastly, we present an example of evaluating the value and environmental impact of a city to calculate the efficiency (degree of smartness) of the city. MICJET MISALIO, which is a resident information solution in view of cloud, provides a resident information system that makes use of cloud computing. It can reduce the total cost of ownership of the system, improve the efficiency of operations, significantly streamline operations by eliminating use of paper and also achieve environmental improvement.

Here we show how the effect of introducing the solution to City A has been estimated. The number of staff members of the city is 952 and we have applied the method of estimating the effect of introducing the solutions mentioned above. The result is that, with MICJET MISALIO introduced to City A, the apparent number of staff members is estimated to increase by 47 from the current 952. In addition, paper resource consumption and power usage can be reduced by introducing the solution, which is shown to allow the CO₂

emissions to be reduced by 106 t-CO₂ from 833 t-CO₂ to 727 t-CO₂. The increase in the number of staff members can be seen as a value item that improves the quality of administrative services and CO₂ emissions can be interpreted as an environmental impact indicator. It means that, by finding the ratio of these two indicators, the factor of the efficiency (degree of smartness) of the city can be estimated. For City A, introduction of MICJET MISALIO is estimated to improve the efficiency (degree of smartness) of the city from 1.143 before the introduction to 1.375 after the introduction and the efficiency factor after the introduction with reference to before the introduction is estimated to be 1.20.

4. Conclusion

To build a sustainable society in the future, it will become more important to solve environmental, social and economic issues over a wide area including cities, towns and villages. To solve these issues, cross-industrial measures are required and ICT will be more important than ever. At present, many measures are discussed and implemented for solving issues and, for evaluating the effects of such measures, it is essential to be able to evaluate them quantitatively. In this paper, we have looked at the characteristics of a city from two aspects of "value" represented by environmental quality, society and economy and "environmental impact" represented by climate change, resource depletion and biodiversity. At the same time, we studied the method of finding the efficiency of a city in the form of a ratio of value to environmental impact and representing it as a factor. Introducing ICT not only reduces the environmental impact of a city but also improves its value. We described these effects by presenting some examples and the effects.

To have quantitative evaluation in terms of environmental impact and value, it is necessary to weight multiple items for integration. More convincing weighting is required for more accurate integration, and we plan to further study this in the future. For this paper, we have shown the result of evaluation with the focus on some evaluation items in examples. We intend to increase the number of examples to achieve comprehensive evaluation of a city by further adding evaluation items in the future. The methods of evaluation of cities and of the effect of introducing ICT provide an important theme for discussing future Smart

Cities, sustainable cities and environmental future cities and implementing more effective measures.¹⁶⁾ In the future, we intend to establish a practical method of quantitative evaluation for realizing sustainable cities by promoting cooperation with various industries including the transportation, construction, energy and civilian (household and operations) industries as well as the ICT industry and discussion by standardization organizations such as ISO, IEC and ITU.

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