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Practical Paper

Development of performance assessment method for drinking water infrastructure

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ABSTRACT

In Japan, many drinking water systems were developed during the 1960s and 1970s, and a considerable proportion of them is now showing various signs of aging or seismic vulnerability. The major issue for many drinking water utilities is how to update those facilities in the best way to improve their deteriorating/insufficient performance. The existing performance assessment methods for water supply facilities need relatively high technical knowledge and they are only applicable to evaluate individual facilities. The Japan Water Research Center (JWRC) has thus developed a performance assessment method for drinking water infrastructure which requires no special technical investigation or a complicated calculation. Thus, staff of small- and medium-scale drinking water utilities can easily carry out logical function evaluation for their facilities using performance indices and answering questions on daily operation and maintenance. This development is part of the *e-Pipe* research project that was conducted at JWRC from 2008 through 2010 with Health and Labour Sciences Research Grants from the Ministry of Health, Labour and Welfare.

Key words | aging facilities, function evaluation, performance assessment, prioritisation, renewal

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INTRODUCTION

In 1955, only 35% of the total population in Japan received public water services. By 1975, this percentage had grown to nearly 90% because of nationwide efforts to construct drinking water infrastructure. Numerous water supply systems were installed in the 1960s and 1970s, and around 60% of today's national purification capacity was established during this period. However, 40 to 50 years after their installations, many existing water systems are now showing various signs of aging. The majority of electricity, machinery and instrumentation equipment has been renewed, while reinforced concrete structures, which generally have a comparatively long life, are still in use in a deteriorated state. Many pipelines, installed in the same period, are in a similar state. Although the majority of asbestos-cement and grey-cast iron pipes has been replaced out of concern for their vulnerability to earthquakes, statistics suggest that a considerable proportion of aging or non-seismic-resistant pipelines still remains to be replaced or upgraded (JWWA 2011).

Since drinking water infrastructures involve malfunction risks with age, they must be improved or renewed appropriately and systematically in order to maintain a high reliability of drinking water systems. The investments necessary to improve or renew drinking water infrastructure in Japan, however, have been falling progressively over the past dozen years. Such a situation reflects the severe financial condition in utilities due to decreasing water demand and economic stagnation. Thus, to form well-structured improvement projects and ensure efficient investments, water utilities in Japan must understand their facilities' current performance urgently and accurately (MHLW 2008).

In such a social context, the Japan Water Research Center (JWRC) has issued a manual for water utilities to assess drinking water infrastructure performance and design a framework for its improvement schemes (2011a, b). This development is part of the *e-Pipe* joint research project that was conducted from 2008 to 2010 by JWRC (2011a, b).

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ASSESSMENT METHOD

The performance assessment method was developed through the great efforts of the research group that comprised a university professor, experienced engineers from water utilities and private companies, and JWRC researchers. Based on past research outcomes (MHLW 2005; JWRC 2008; etc.) and Performance Indicators in JWWA Q100 (2005a, b), a draft assessment method was first formulated by the group members through their vast experience. Then, the draft method was tested repeatedly through field trials in small- and medium-scale utilities, and was refined according to the opinions of their experienced engineers. The performance assessment method can be applied to purification plants, stations of intake, conveyance, transmission, and distribution, as well as their component facilities such as pipelines, basins, machinery, etc. The assessment is divided into four steps: data collection/classification, present function evaluation, judgement of function improvement necessity, and selection of optimal improvement method/strategy. Figure 1 shows these steps.

Sheets 1 to 4, the core tools in this method, are designed in such a way that they can be filled in using data and experience/knowledge obtained from daily management and operation. The responses given in the sheets will lead to the performance assessment results and the optimal improvement plan. This method's major feature is that it does not require a special technical investigation or a complicated calculation, and can be easily applied by the staff of water utilities.

Data collection and data-sheet

There are two types of evaluations available. One is an evaluation of the overall plant/station ('overall evaluation'); the other is an evaluation for an individual facility/pipeline that is a component of a plant/station ('individual evaluation'). To make either performance evaluation, the method's user must collect the necessary information from daily operation/maintenance documents. But only when making the overall evaluation does the user need to enter this information in the relevant data-sheet. As an example, part of the data-sheet for an intake station is shown in Table 1.

Overall evaluation for a plant/station (Sheet-1)

Overall evaluation of a plant/station (including pipelines) is made in Sheet-1 using performance indices to identify the potential for improvement of the plant/station/pipelines. Various performance indices have been prepared to assess essential items on safety, stability, and continuity.

The left column of Table 2 shows the performance indices used in the overall evaluation and their definitions. Each performance index value is calculated – based on its own definition – from the data in the relevant datasheet. Each performance index value is then assessed against the judgement criteria in the right column for an evaluation point.

Table 3 shows an example of Sheet 1, the result of evaluation for an intake station. It shows that the intake capacity is considerably stressed and the structure itself has deteriorated with age. It is possible to compare the overall evaluation score for the intake station with the scores of other plants/stations. This would be helpful to water utilities in designing improvement projects.

For smaller water utilities that have lost or destroyed the necessary operation/maintenance data or do not usually keep a record of such data, a 'simplified Sheet-1 for quick evaluation' is available to allow evaluation with a minimum data set.

Individual evaluation for a facility/pipeline (Sheet-2)

The individual evaluation for a facility/pipeline is made using Sheet-2. Depending on what is to be evaluated, 29 types of Sheet-2 are available for facilities, and two more for buried pipelines and water pipe bridges.

As an example, Table 4 shows part of Sheet-2 for rapid sand filter. For performance assessment, the sheet contains three to five questions for each of the following function items: 'water quality', 'water quantity and pressure', 'aging', 'earthquake/crisis management', and 'operation and management' for a facility or pipeline. According to the knowledge/experiences from daily operation and maintenance (O&M), the user must select appropriate answers to the multiple-choice questions to obtain evaluation points for each item. The evaluation points are converted into an evaluation score on a scale of 0 to 100. The evaluation scores represent quantitative performance

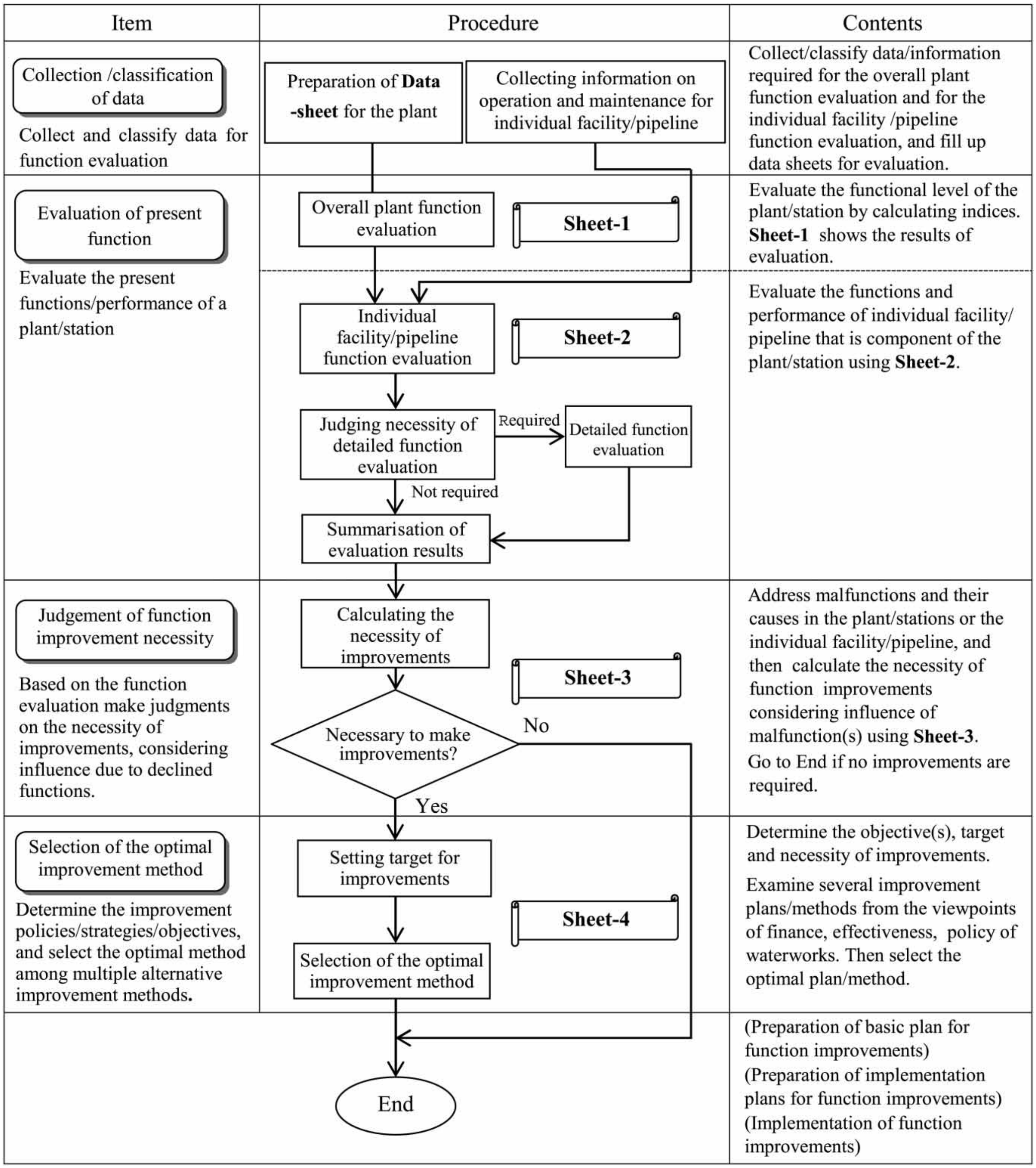

Figure 1 | Procedure of performance assessment.

levels of individual facilities and pipelines, marking aging, wear-out, or deteriorated facilities/pipelines with lower scores.

Figure 2 shows the result of an individual evaluation for a rapid sand filter and a disinfection facility. From these radar charts, it becomes clear that the rapid sand filter compares unfavourably with the disinfection facility in many functions, particularly in terms of 'aging' and 'risk management in emergency', which needs to be addressed.

As this table is part of the entire sheet, scores in this table are not calculated from the shown points.

Table 1 | Data-sheet for intake station

Item	Data	Unit	
Planned intake water	W1	1,000	m^3/day
Current intake water (Max.)	W2	1,000	m^3/day
Age of wells	A1	20	year
Age of civil structures	A2	20	year
Age of machinery/electricity/instrumentation	A3	10	year
Capacity of all pumps	C1	200	m^3/day
Capacity of earthquake proofing pumps	C2	200	m^3/day
Power demand in the station	P1	100	kw
Capacity of emergency power generator	P2	100	kw

Note: This table shows a portion of the data-sheet.

Necessity of improvements (Sheet-3)

The evaluation results are given in Sheet-3 along with the necessity of improving the evaluated facility, device, or pipeline. The level of improvement necessity is based on the importance of the evaluated subject, which depends on the potential impact on the water system in case they have trouble or malfunction. The necessity level is derived from the following equations:

$$\text{Necessity of improvements} = (\text{Range of influence}) * (\text{Duration of influence}) * (\text{Possibility of occurrence}) \quad (1)$$

$$\text{Range of influence} = (\text{Physical influence A} * \text{Physical influence B} * \text{Importance A} * \text{Importance B})^{1/4} \quad (2)$$

where Physical influence A: Number of affected household/people; Physical influence B: Influence to the entire plant/station/pipelines; Importance A: Influence on customers' health/life; Importance B: Influence on social activities such as medical care/industries.

Table 2 | Performance indices and conversion to evaluation point

	Evaluation point			
Performance index and its definition	3	2	1	0
Water intake capacity = W2/W1	$120 \le v < 130$	$110 \le v < 120$	$100 \le v < 110$ $130 \le v$	$v < 100$
Pump station's earthquake resistibility = C2/C1	100	$80 \le v < 100$	$60 \le v < 80$	$100 < v$ or $v < 60$
Emergency power generator capacity = P2/P1	$90 \le v$	$50 \le v < 90$	$5 \le v < 50$	$v < 5$
Aging of intake station = Average of age to each lifespan	Evaluation point is a figure of rounded v			

Note: Symbols in definition refer to the ones in the data-sheet.
'v' means performance index value.
This table shows a portion of the entire table.

Table 3 | Sheet-1: Result of overall function evaluation for intake station

Performance index	P.I. value	Evaluation point
Water intake capacity	100	1
Pump station's earthquake resistibility	100	3
Emergency power generator capacity	100	3
Aging of intake station	63	2
Total point		9
Overall evaluation score for the intake station	(9/12) * 100 = 75	

Note: Overall evaluation score = (Total point/Perfect evaluation point)*100.
This table shows only a portion of Sheet-1.

Table 4 | Sheet-2 for rapid sand filter

Function item	Question	Answer (adopted point)	Evaluation point	Evaluation score
Water quality	Does turbidity in treated water meet the drinking water quality standards and/or the particular target quality of the plant?	3. Possible to function while meeting completely the drinking water quality standards or the target quality/value.	3	70
	If the raw water quality requires measures against Cryptosporidium, does the turbidity in treated water show the achievement of the target value (0.1 JTU or less) through continuous monitoring using a highly sensitive turbidity-meter, etc.?	2. Although not perfect, there is no significant problem.		
		1. Turbidity often comes close to the drinking water quality standards or the target quality/value; filtration may stop at that time.		
		0. Turbidity often exceeds the drinking water quality standards or the target quality/value; filtration stops at that time.		
Water quantity/ pressure	Is the planned filtered flow rate stably maintained while achieving the target quality/value of water?	3. There is no problem. 2. There are a few concerns, but they are insignificant. 1. There are problems, and they sometimes cause some difficulty in maintaining the filtered flow rate. 0. There are many problems, and the filtered flow rate cannot be maintained in a stable manner.	3	63
Aging	Do reinforced-concrete/steel structures, pipelines in plant, and surface-washing /backwashing pipes have a noticeable malfunction due to aging?	3. There is no problem. 2. There are a few concerns, but they are insignificant. 1. There are problems, and they sometimes cause difficulty in management. 0. A lot of malfunctions are noticeable.	1	30
Earthquake/ crisis management	Are reinforced-concrete/steel structures and pipelines in plant earthquake-proofed?	3. Earthquake-resistance evaluation shows high resistibility to level-2 earthquakes, or they are with anti-earthquake design. 2. As resistance evaluation to level-2 earthquakes on the similar structures show high resistibility, the objective structures must be earthquake-proofed. 1. Earthquake-resistance evaluation has not been performed. 0. Earthquake-resistance evaluation shows vulnerability to level-2 earthquakes.	2	38
Operation and maintenance	Are filter media (sand, gravel) properly maintained and improved by means of washing, surface levelling, particle size regulating, and replacement?	3. Investigation has been conducted, and improvements are being made; or no need of improvements. 2. Although no investigation has been made, improvements are being made systematically. 1. Although investigation has been made and there is the need of making improvements, no measures have been taken. 0. Neither investigation nor improvements have been made.	3	75

Note: Each item contains three to five questions.

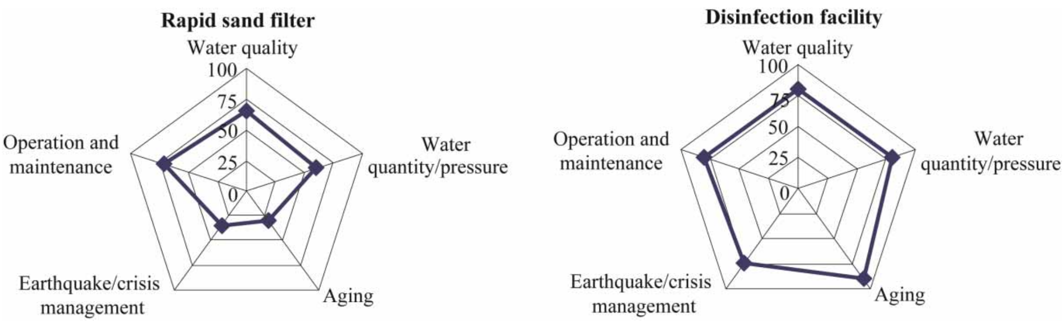

Figure 2 | Results of individual function evaluation.

The values of influence shown above are obtained through the questions in Sheet-3. These values finally lead to the necessity of improvements. Table 5 shows Sheet-3 for civil structures as an example.

Development of application for automatic scoring

The performance assessment and function diagnosis are made by filling in the data-sheets, calculating performance indices in Sheet-1 and answering questions in Sheet-2 and Sheet-3. To make this process easier, we developed an automatic scoring application based on tabulation software (MS-Excel); through calculation-free data-input and question-answering, the user can easily make the performance assessment of water infrastructure and judge the necessity of its improvement.

Selection of the optimal improvement method

There are many ways to improve drinking water systems, ranging from improving specific component facilities to renewing or integrating existing plants/stations. From possible alternatives, the water utility must select the best method for improvement.

In Sheet-4, the user determines objectives of improvements and selects the optimal improvement method from some alternatives. Improvement objectives should be set with respect to the number of malfunctioning facilities, improvement necessity level, and overall facilities' performance. The optimal improvement method should be the one having the highest judgement score of the alternative methods. The judgement score is the sum of the scores given, on the integer scale of 0 to 2, to three evaluation factors: expected effect, feasibility, and rationality of improvement. Feasibility considers compatibility with existing facilities, water supply reliability, duration of improvement work, cost, etc., while rationality looks at potential impacts of improvement on finances and management of the water utility. Because some items in Sheet-4 are not suitable for automatic calculation, this sheet is not included in the automatic scoring application.

VERIFICATION OF THE PERFORMANCE ASSESSMENT METHOD

We verified the validity of the performance assessment method through actual improvement plans. Figure 3 shows one example, which compares two prioritisation results for the same pipeline improvement; one is the result of the performance assessment method, and the other is from an existing drinking water utility. The utility evaluated pipelines according to equations in 'Guides for Renewal of Drinking Water Infrastructure' (JWWA 2005a), which requires calculation with a wider range of data, such as age and material, degree of deterioration, water pressure, surrounding soil, etc. Two prioritisation results show the same tendency; in addition, other field trials in small-scale water utilities also showed similar results. These outcomes verify the suitability of the performance assessment method for practical application.

CONCLUSIONS

The first thing to do in addressing the vulnerability of aging drinking water infrastructures is to understand their present

Table 5 | Sheet-3 for civil structures

Main item		Judgement item	Judgement	Judging score	Necessity of improvements
Range of influence	Physical influence A	Number of affected household/people	4. Have fatal influence on water supply.	3	$(3*1*1*4)^{1/4}*2*3 = 11.2$
			3. Have serious influence on water supply. 2. May have influence on water supply. 1. Influence on water supply is small or negligible.		
	Physical influence B	Influence on the entire plant/station	4. Have fatal influence on capacity or O&M of the plant/station. 3. Have serious influence on capacity or O&M of the plant/station. 2. May have influence on capacity or O&M of the plant/station. 1. Influence capacity or O&M of the plant/station is small or negligible.	1	
	Importance A	Influence on customers' health/life	4. Acute or serious damage may happen to the health of customers. 3. Not acute or serious, but damage may be caused to health. 2. Daily water use of customers may be disrupted. 1. There is no influence on health/life.	1	
	Importance B	Influence on social activities such as medical care/ industries, etc.	Score is the number of applicable items in affected water supply area among the following kinds of influence: 3 items or more: 4 points; 2 items: 3 points; 1 item: 2 points; nil: 1 point Influence on base medical centers such as hospitals listed in a regional disaster preparedness plan. Influence on the bases for responding activities in case of a disaster, such as disaster countermeasure bases, evacuation shelters, and bases of emergency water supply. Influence on important facilities that support the functions of cities such as governmental and administrative functions. Influence on important factories/plants that support the economic activities of the region.	4	
Duration of influence		Duration of time required to restore	4. It takes a long duration for the suspended functions to restore normality. 3. It takes a certain duration for the suspended functions to restore normality. The duration of trouble lasts for several days. 2. It takes a short duration for the suspended functions to restore normality. 1. It takes a very short duration for the suspended functions to restore normality.	2	
Possibility of occurrence		Situation of degradation	4. Extreme deterioration: Corrosion cracks, detachment, exfoliation, and lean steel materials can be seen. 3. Medium deterioration: No emaciating materials, but progress of corrosion cracks, detachment, and exfoliation can be seen. 2. Early deterioration: Corrosion cracks can be seen. 1. Latent deterioration: No deterioration can be seen in appearance and concrete neutralisation depth is less than the limit, however, corrosion has started.	3	

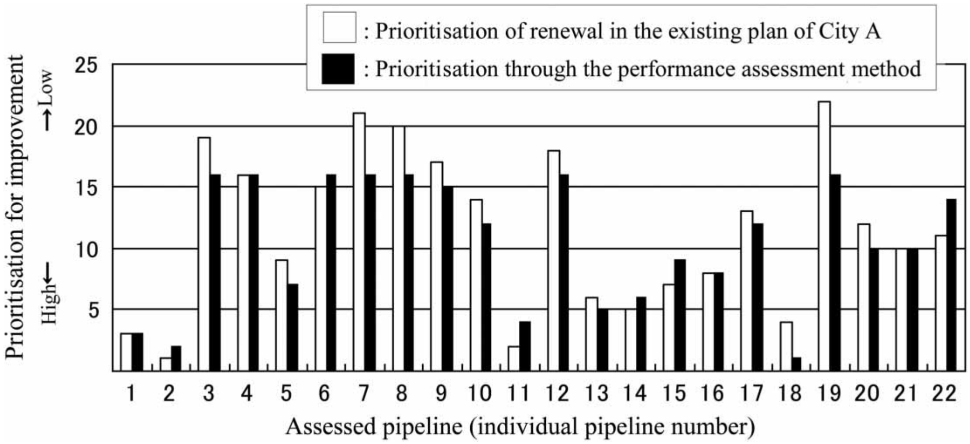

Figure 3 | Comparison between the prioritisation through the performance assessment method and actual prioritisation in the renewal plan at a city.

functions accurately. From that point, it is possible to suggest the optimal improvement plans specific to each water utility. On the other hand, many of the Japanese water utilities are having financial difficulties making such evaluations, which is particularly true for small-scale utilities with limited resources. The performance assessment method, therefore, has been designed to be a cost-effective and simple but reliable tool that can be used even by operators and managers of small-scale utilities.

We strongly hope that all the drinking-water utilities, irrespective of the size of population served, can implement systematic and reasonable improvement by using this performance assessment method.

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