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Development of an investment efficiency evaluation model for waterworks maintenance through data envelopment analysis

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ABSTRACT

To use the revenue water ratio and standardized leakage volume indicators as an output factor, this study developed a model that can analyze and evaluate the efficiency of four investment costs (expansion, renewal, labor, maintenance) for the maintenance of water supply facilities, utilizing data envelopment analysis. And this study would prepare measures for the implementation of the optimal maintenance efficiency by setting the priorities for investment, considering the efficiency of the investment using multiple regression analysis. Currently, the Korean Government is carrying out a waterworks modernization project for the improvement of deteriorated water utilities to convert the vicious circle of water supply service to a virtuous cycle. It is concluded that the efficiency assessment index and utilization methodology for investment costs for the maintenance proposed in this study can be reflected in the promotion of the relevant project. In addition, it is concluded that this study can be utilized to promote the efficiency of investment in the maintenance of water utilities.

Keywords: Data envelopment analysis; Efficiency analysis; Maintenance of waterworks; Optimal maintenance model; Waterworks utilities

1. Introduction

For an organization or company to perform successfully, the results of its business processes must be evaluated, and measures must be prepared for the improvement of unsatisfactory areas. Business performance can be measured and evaluated with various methods, but generally, it is expressed in terms of effectiveness and efficiency. Here, effectiveness is defined as doing what is right, and efficiency is defined as performing well [1]. Efficiency may be defined in various ways, but generally, it is described as the relationship between input and output. In other words, efficiency can be expressed as the aspect of production that maximizes output with limited resources in a project implemented by a specific organization, and is generally expressed as the ratio of input to output.

For the maintenance of water supply utilities, Korean water service providers invest substantial funds, to implement projects for the replacement and rehabilitation of aged pipes, the construction of district metered areas, and the construction of a system for the optimal management of the water pipe network. However, Korean water service providers experience difficulties in the maintenance of utilities because they cannot afford to re-invest with the increasing costs and, the small-scale of production, and the lack of skilled workers. Especially in the county, the necessary expenditures for maintenance exceed the revenue generated by the water billed, and budget transfers have been provided to cover the deficit. To solve these problems at the national level, the Korean Government started a large-scale government-invested project (Waterworks Modernization Project) for the improvement of aged utilities. However, how much, and what kind of investment is needed to maintain water

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supply facilities is not specifically understood. Thus, the project may misuse the funds allocated for the improvement of aged water supply utilities.

In terms of efficiency, the maintenance of utilities can be evaluated by comparing the output performances to the input costs. Currently, Korea uses the revenue water ratio (RWR), indicated by the ratio of the billed authorized consumption to the total supply as the output of the project for the maintenance of facilities, that is, as a performance evaluation indicator. However, the RWR may be affected by the conditions of the site, and by variables that cannot be resolved by the water service provider. As such, the RWR as an indicator has limitations in terms of evaluating the maintenance of facilities and setting the management objective.

In the past, many studies have proposed an indicator based on non-revenue water, such as the infrastructure leakage index, that can evaluate business performance [2]. Additionally, there are cases using performance indicators such as supply service coverage, water abstraction capacity, and storage tank capacity [3,4]. However, as indicators other than RWR have insufficient evaluation scores, or the provision of related information, these measures have difficulties in establishing measures to promote the efficiency of the maintenance of water supply facilities [5]. Therefore, many experts have suggested that another indicator supplemental to RWR be used to evaluate the efficiency of the water supply utilities.

To use the RWR and other supplementary indicators, this study developed a model that can analyze and evaluate the efficiency of investment costs for the maintenance of water supply facilities, utilizing data envelopment analysis (DEA), which can analyze various input variables and output variable, simultaneously. Utilizing the developed model, this study prioritized expense items for which water service providers should budget for optimal maintenance of water supply utilities.

Overall, this study would prepare measures for the implementation of the optimal maintenance efficiency of water supply utilities in the future by setting the priorities for investment, considering the efficiency of the investment, and considering the priority of investment from the perspective of national water welfare in the project for the improvement of large-scale decrepit water supply utilities promoted by the government.

2. Literature review

2.1. Data envelopment analysis for efficiency analysis

DEA is a linear programming technique, effective for evaluating the efficiency of organizations that provide similar services. A DEA method was proposed by Charnes et al. [6] based on the result of a study by Farrel [7]. DEA does not estimate parameters and assumes a specific form of a function in advance, unlike other methods of measuring efficiency. It uses a non-parametric method of measuring efficiency by creating a production frontier, using data between the input factors and the outputs of the target of evaluation based on linear programming, and then understanding how far the target of evaluation is from the production frontier.

Generally, the two most often utilized DEA models include the Charnes, Cooper, and Rhodes (CCR) model [6], and the Banker, Charnes, Cooper (BCC) model [8]. These two models are divided into an input-oriented one and an output-oriented one, depending on whether they are focused on input factors or outputs. Generally, in business performance, the selection of inputs comes to the fore as a major decision-making variable, so there is a tendency to select the input-oriented model.

Using the DEA model, efficiencies are divided into three types as follows: (a) technical efficiency, using the CCR model, assuming constant return to scale (CRS), (b) net technical efficiency, using the BCC model, assuming variable return to scale (VRS), and (c) scale efficiency (SE) of the individual decision-making unit (DMU), calculated by the difference between the production change representing CRS and the production change representing VRS.

If there is a difference between the technical efficiency calculated from the CCR model and the net technical efficiency calculated from the BCC model concerning a specific DMU, it means that there is scale inefficiency in the relevant DMU. In other words, if there is an economic feasibility of scale or poor economic feasibility of scale, the efficiency – the output to input ratio – can be changed by adjusting the scale. When the scale is not optimally adjusted, inefficiency appears because of the non-optimized scale. The efficiency that reflects whether the scale is optimal is called SE, and based on the input, it is defined using Eq. (1).

$$SE^k = \frac{\theta^{k^*}(CRS)}{\theta^{k^*}(VRS)} \tag{1}$$

where θ^{k^*} is the value at which all input factors can be reduced at the same rate till DMU k reaches production change.

The result of an evaluation by DEA provides a reference set for improving the efficiency of relatively inefficient DMUs. Here, the reference set refers to the target DMU in which inefficiency has been found and should be used as a benchmark to move to an efficient state, based on θ^{k^*}, λ^{j^*} (weighted value provided by the reference group), s^{-^*} (margin of input factor) and s^{+^*} (margin of output factor), obtained by conducting an analysis of efficiency.

In an efficient DMU ($\theta^{k^*}=1$), the reference set is itself, and in an inefficient DMU ($\theta^{k^*}<1$), the DMU's target for benchmarking ($\lambda^{j^*}>0$) is the reference set. Accordingly, the inefficient DMU can reflect the degree of inefficiency through the combination of weighted values provided by slack a variable and reference set related to input and output, and benchmark the cause of the inefficiency [9].

2.2. DEA for evaluation of waterworks efficiency

To analyze the efficiency of the maintenance of water supply utilities or that of a water supply service, previous studies using DEA are summarized in Table 1. The previous studies mainly considered the scale of the assets of utilities, such as water billed, water supplied, number of hydrants, or the length of pipeline. In Korea, the water supply service is a public work, which does not aim to maximize profits. Considering this,

Table 1
Literature review on efficiency analysis of waterworks using DEA

Reference	Factor		Decision-making unit
	Input	Output	
Aida et al. [10]	Number of employees, operating expenses, net plant and equipment, population, length of pipes	Water billed, operating revenues	19 DMU in Kanagawa, Japan
Garcia-Sanchez [11]	Total staff, treatment plants, net pipe kilometers, total cost	m^3 of water supplied, number of connections, analyses performed	113 towns of over 50,000 inhabitants in Spain
Ko et al. [12]	Cost of labor, cost of construction, cost of maintenance, reimbursement	Water billed, production quantity of tap water	160 waterworks in Korea
Renzetti and Dupont [13]	Labor expenditures, material expenditures, kilometers of distribution network	Sum of annual deliveries	64 municipal water supply agencies in Ontario, Canada
Romano and Geurrini [14]	Cost of materials, cost of labor, cost of services, cost of leases	Population served, Water delivered	43 Italian water utilities
Guerrini et al. [15]	Sum of amortization, depreciation and interest paid, staff costs, other operating costs, length of the mains	Population served, total revenue	64 water companies
Choi et al. [9]	Active leakage management cost, rapid and accurate leakage repair cost, appropriate pipe body management cost, indirect labor cost for pipe network management	Leakage-reducing effect	109 waterworks in Korea
Kim et al. [16]	Replacement rate of water distribution pipe, replacement rate of water supply pipe, rate of leakage detection and repair, replacement rate of water meter, installation rate of pressure reduction valve	Increment amount of revenue water ratio	28 DMA (district metered area) in Taebeak, Korea

studies by Choi et al. [9] and Kim et al. [16] limit the research category to leakage control, which is considered the maintenance of utilities, and then, conducted an intensive analysis.

As a result of examining the analyses of the previous studies, they showed tendencies of setting the expenses of investment in utilities, such as the pipe length and ratio of the improvement of aged water pipes as input variables, and analyzing outputs according to the inputs. However, to judge the efficiency of investment intuitively, it would be more appropriate to set the costs of investment in utilities as an input variable and to analyze outputs according to the input of the costs. If costs are invested in the maintenance of water supply facilities, the water leak rate would decrease, and accordingly, RWR would increase. This study would conduct an analysis of DEA according to these concepts.

3. Methods

This study proposes a methodology to analyze the efficiency of the maintenance of water supply utilities and set investment priorities. Fig. 1 shows the research flow.

3.1. Selection and investigation of target water utilities

As of the end of 2015, there are 162 water service providers in Korea, and this study selected 95 water service providers of local water service public enterprises that could provide reliable data by releasing accurate input costs in accordance with the Act on Local Public Enterprises as the subjects.

Investment costs for the maintenance of utilities were divided into four types, including expansion cost, renewal cost, labor cost, and maintenance cost. For each cost, the average of the most recent 3 years (2013, 2014, and 2015) was used, utilizing the accounting reports of local water service public enterprises and statistics of waterworks.

3.2. Classification of water utilities and standardization of water balance

The water leakage volume and rate in waterworks statistics are calculated using the IWA top-down method, suggested by Lambert and Hirner [17]. Leakage is estimated by subtracting billed authorized consumption, which is charged, unbilled authorized consumption, which is the effective water amount but not charged, and apparent losses from the total input volume. Owing to the method of the calculation of leakage, some water service providers reduce the leakage by calculating unbilled authorized consumption and apparent losses excessively. To calculate the accurate leakage and leakage rate, it is necessary to standardize the leakage. For the standardization of leakage, it is necessary to standardize unbilled authorized consumption and apparent losses according to the conditions and characteristics of the water service providers.

For the classification of water providers, an analysis of clusters was utilized. The factors on which the cluster classification was based are those that can be expressed as the conditions of water supply facilities [18,19]. For the cluster analysis, Ward's hierarchical cluster analysis method, a method of starting from *n* clusters at first and gradually reducing the number of clusters, was used. A tree diagram (dendrogram) as a graphic expression of cluster steps shows that clusters with high similarities were classified.

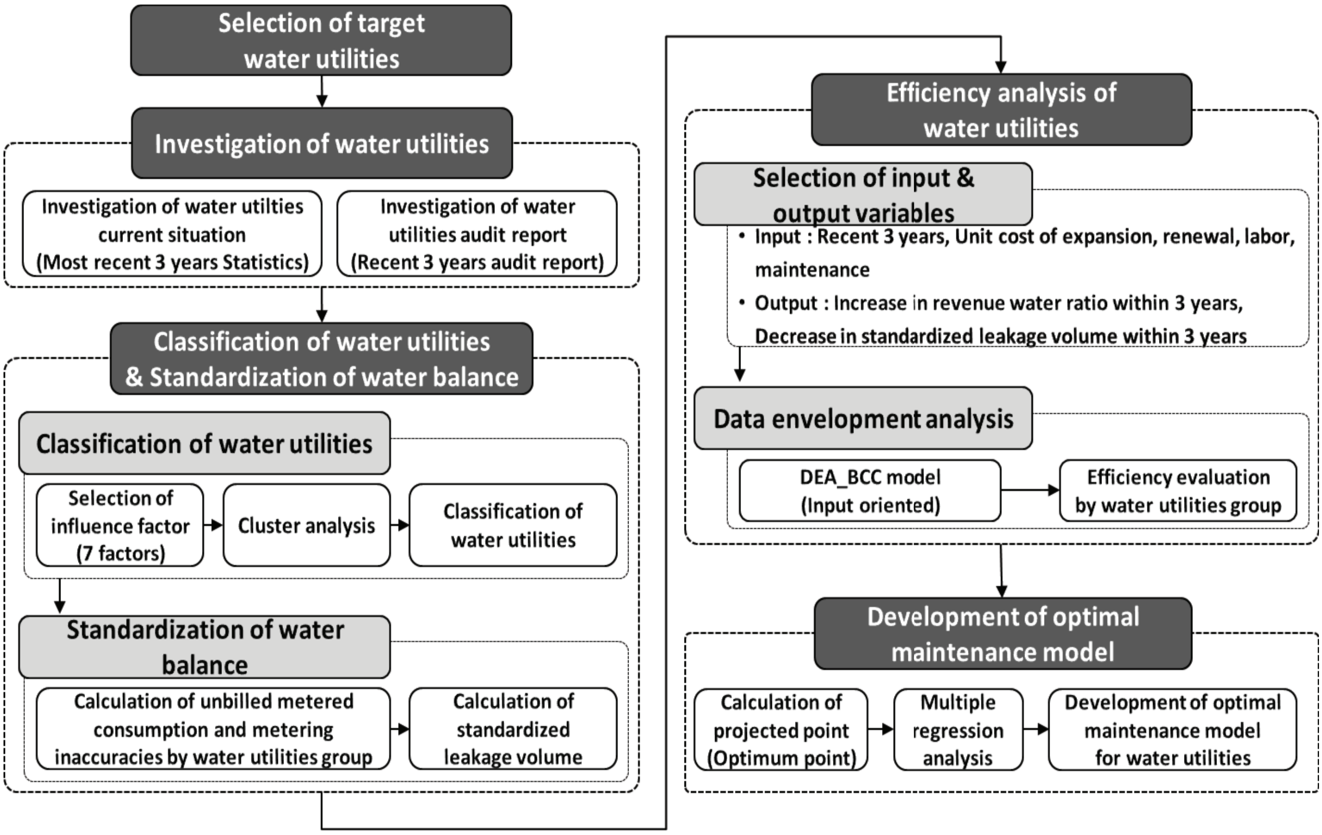

Fig. 1. Flow chart of the study.

For the standardization of each item of unbilled authorized consumption and apparent losses, water service providers' metering inaccuracies by revenue water volume, unbilled metered consumption by revenue water volume, and unmetered consumption by revenue water volume were first calculated. According to the classified water providers, standardized criteria were set based on the mean and median value of the relevant ratios. If more unbilled authorized consumption occurred than the standardized criteria, the unbilled authorized consumption was adjusted according to the criteria.

3.3. Efficiency analysis of water utilities maintenance

The efficiency of the maintenance of water utilities was analyzed using DEA for each water provider group. Water utilities are not operated under optimal conditions due to various constraints. Considering this, this study applied the BCC model that assumes VRS, reflecting the actual situation as a model of returns to scale. Input variables and output variables for DEA were set as given in Table 2.

As unit costs were used as the input variable, the result of dividing the input costs by the length of the pipeline of the target water utilities for the most recent 3 years (2013, 2014, and 2015) was applied.

The amount for RWR increase used as an output variable was calculated based on RWR change over 3 years, subtracting the RWR at the end of 2012 from that at the end of 2015. After calculating the unbilled authorized consumption standardized by each year, the amount of the standardized leakage volume reduction was calculated by subtracting that at the end of 2015 from that at the end of 2012, based on the standardized water leakage rate change over 3 years. This study conducted DEA using EnPAS software [20].

3.4. Development of optimal maintenance model

The calculation of the optimum efficiency point by calculating the excessive input cost with each investment cost to be reduced to operate a DMU efficiently can indicate measures for the optimization of maintenance.

This study sets an optimal efficiency point determined through DEA by each water provider group as an independent variable and developed a model for the optimization of maintenance through a multiple regression analysis of the output variable. Optimization models were selected by each water provider group, and a multiple regression analysis was conducted using SPSS 24.0. For producing the multiple regression model, a step-wise method was used.

4. Results and discussion

4.1. Results of classification of water utilities and standardization of water balance

Seven influence factors were selected for the classification of water provider groups (RWR, leakage rate, population

Table 2
Analysis method for DEA

Factor		Decision-making unit
Input	Output	
1. During most recent 3 years, unit cost of expansion (unit 1,000 KRW/km)	1. Increase in revenue water ratio within 3 years (unit: %)	95 water utilities in Korea
2. During most recent 3 years, unit cost of renewal (unit: 1,000 KRW/km)	2. Decrease in standardized leakage volume within 3 years (unit: m^3/km)	
3. During most recent 3 years, unit cost of labor (unit: 1,000 KRW/km)		
4. During most recent 3 years, unit cost of maintenance (unit: 1,000 KRW/km)		

KRW – Korea Republic Won.

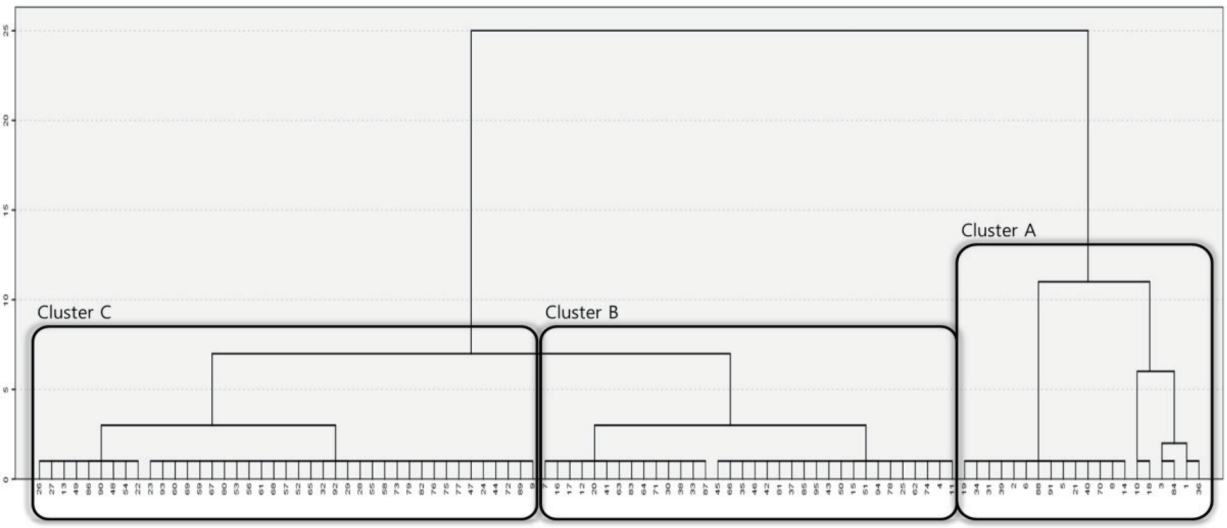

Fig. 2. Dendrogram of cluster analysis.

using water per length of pipeline, the ratio of aged pipes, the rate of the realization of water bills, unit cost of maintenance, and the number of management manpower to the length of pipeline), and through the relevant factors, water providers were classified. Fig. 2 is a dendrogram drawn as a result of a cluster analysis where three clusters were selected, which is judged to be a reasonable number considering the number of samples constituting one group.

Table 3 gives the mean and standard deviation of each water provider group for each influence factor used for the classification. Cluster A was composed of metropolitan city and large city water service providers with a relatively good condition of water supply facilities. The average RWR was over 85%, and the leakage ratio was under 10%. Cluster B was composed of city unit water service providers with a RWR of 75% and a leakage ratio of 15%. The population using water per length of the pipeline was 217.08 persons/km, lower than that of cluster A, so it turned out that they needed relatively more manpower for maintenance.

Cluster C was composed of small-scale city/district unit water service providers with a RWR under 70% and a leakage ratio over 20%. The population using water per length of pipeline was 115.83 persons/km, and as the length of the pipeline to be maintained was relatively long, it was expected that the efficiency of maintenance would drop, and it turned out that there were a large number of manpower inputs for maintenance. The basic unit of the maintenance costs of cluster C was 28.73% of that of cluster A. Despite relatively higher costs to consume, it turned out that they did not spend funds owing to financial conditions.

The criteria applied to average unbilled authorized consumption for the most recent 3 years, apparent losses and standardization by each water provider group are given in Table 4. Table 5 gives the change of the average leakage ratio in each group according to the application of the standard benchmark. According to the application of the standard benchmark, it turned out that for 59 out of 95 water service providers, the leakage rate increased.

4.2. Results of efficiency analysis of water utilities maintenance

Fig. 3 shows CCR, VRS, and SE indicated for each water provider, determined by conducting DEA for each water provider group.

The number of water providers with efficiency under constant returns to scale and efficiency under VRS equal to 1 was 4 in cluster A, 10 in cluster B, and 10 in cluster C. The relevant water providers are those for whom it is expected that the amount of the RWR increase and the amount of the water leakage rate reduction would appear the highest if the cost input increases. Water utilities are maintained most efficiently in the relevant group.

The results of analysis suggest that the maintenance of water utilities with an optimal efficiency point can cause

Table 3
Result of cluster analysis

Factor		Cluster		
		A	B	C
Number of samples		20	34	41
Revenue water ratio	Average (%)	86.31	75.89	69.23
	Standard deviation	7.72	10.48	11.79
Leakage rate	Average (%)	9.19	16.98	22.42
	Standard deviation	7.50	9.50	10.67
Population per pipe length	Average (N/km)	510.23	217.08	115.83
	Standard deviation	220.15	136.64	59.59
Aged pipe ratio	Average (%)	10.82	15.25	14.52
	Standard deviation	11.83	14.58	12.00
Water rate realization rate	Average (%)	87.82	70.53	60.63
	Standard deviation	10.33	21.59	21.13
Unit cost of maintenance	Average (1,000 KRW/km)	14,283.56	8,808.04	4,104.56
	Standard deviation	5,576.39	3,165.15	3,449.14
Management personnel per pipe length	Average (N/km)	52.31	64.50	78.23
	Standard deviation	33.95	54.92	77.99

KRW – Korea Republic Won.

Table 4
Standard criteria for standardization

Ratio to revenue water volume	Actual average value (%)			Standard criteria (%)		
	Cluster A	Cluster B	Cluster C	Cluster A	Cluster B	Cluster C
Metering inaccuracies	4.55	5.53	6.20	5.0	5.5	6.0
Unbilled metered consumption	0.52	2.87	5.00	1.0	2.0	3.0
Unmetered consumption	0.05	1.37	1.61	0.5	1.0	1.5

Table 5
Changes in leakage rate according to standardized criteria

Cluster	Changes in leakage rate (%)		
	Most recent 3 years leakage rate (waterworks statistics)	Change	Standardized leakage rate
A	9.19	0.29	9.48
B	16.98	2.26	19.24
C	22.42	3.21	25.63

larger present outputs in the amount of the RWR increase and the amount of the water leakage ratio reduction by the water service providers.

Depending on the combination of DMU, the efficiency of the maintenance may differ in the present results. This is because the results of DEA represent relative efficiency, not absolute efficiency. Of the water provider groups classified according to the condition of water utilities in this study, cluster A is mostly large-scale water providers, while cluster C is mostly small-scale water service providers. Even if CCR and SE of the water providers belonging to cluster A are lower than those of the water service providers belonging to cluster C, it is difficult to assure that they maintain water utilities inefficiently. This is because the funds necessary for increasing the RWR of water service providers with a RWR of 85% by 3% are larger than the funds necessary for increasing that of those with a RWR of 60% by 3%.

In cluster C, in C14, CCR was 0.4803, and VRS considering SE was 0.8637, while returns to scale appeared as decreasing returns to scale. This means that under the assumption of returns to scale, outputs relative to the input costs are high, while under the assumption of constant returns to scale, outputs relative to the input costs are low. In this case, this means that when the current input costs are increased, it is difficult to expect an increase in outputs to match the increase. In other words, it is reasonable for C14 to consider a measure to apply the optimal cost allocation ratio of the reference group as a solution to increase distributional efficiency, rather than increasing the current input costs.

In contrast to C14, in C5, CCR was 0.1313, and VRS was 0.1339, so SE was estimated to be high. In this case, even if SE is at a maximum, this means that the output result is low relative to the input costs, so it can be interpreted that the input

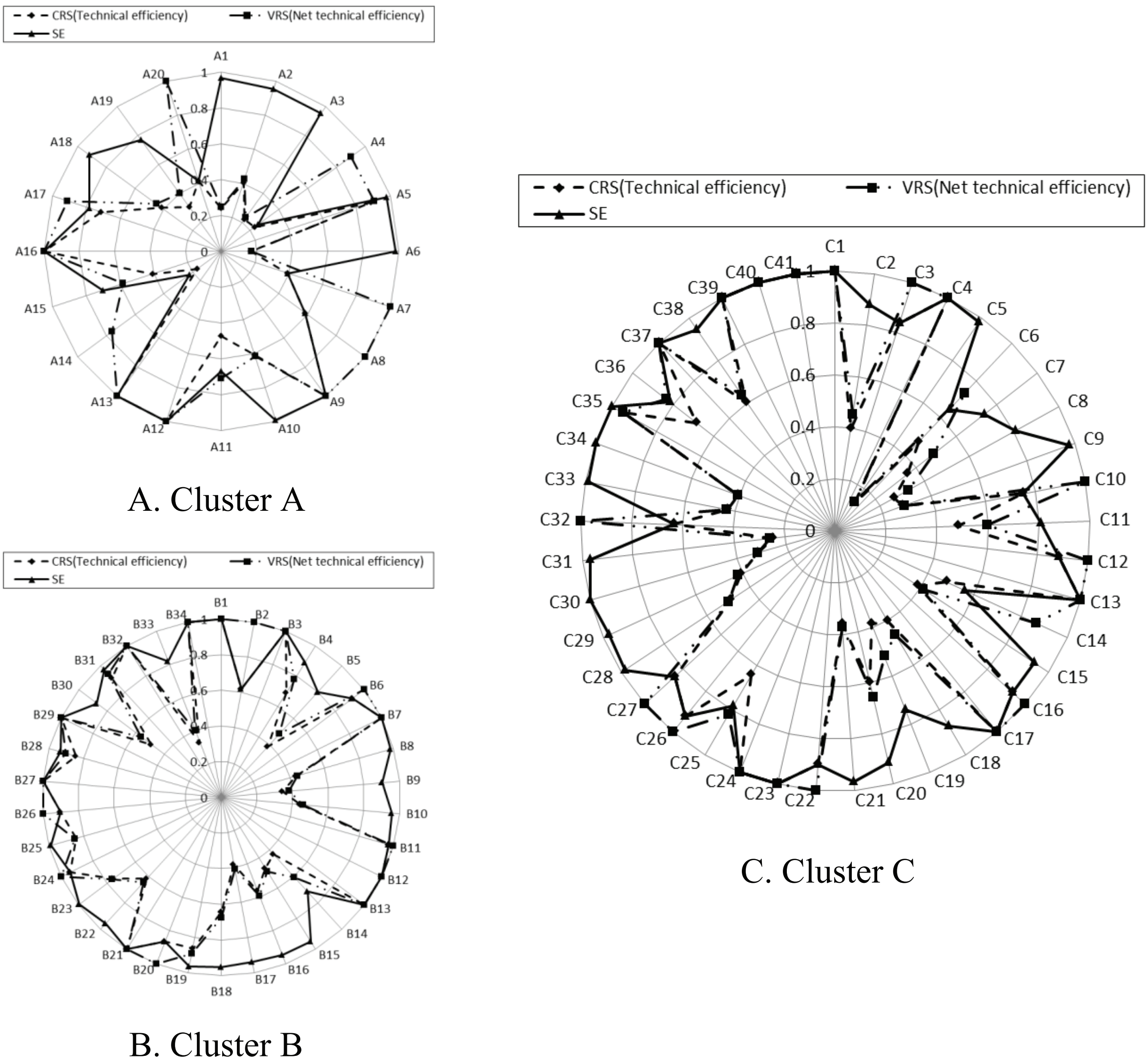

Fig. 3. Results of DEA.

in C5 is relatively excessive as compared with businesses in cluster C.

As in other cases, it turned out that CCR decreased in C32 owing to the inefficiency of scale. If the inefficiency of scale is removed, VRS appeared to be 1, the maximum value; hence, it turned out that it would be necessary to prepare a measure for the removal of the inefficiency of scale.

4.3. Results of optimal maintenance model

As described in the introduction, since RWR is very likely to be changed by various factors, this study developed a model for the optimization of maintenance, aiming to reduce the leakage by pipe length.

The independent variable utilized in a multiple regression analysis was the optimal efficiency point drawn from the result of an analysis of efficiency while the amount of the leakage was set as a dependent variable. The model for the optimization of maintenance drawn through the multiple regression analysis is presented in Table 6. Figs. 4, 5, and 6 provide the result of sensitivity analysis of each maintenance model.

It turned out that the model for the optimization of the maintenance of water utilities aiming at the reduction of leakage was significant when the model's correlation coefficient, statistical significance, and logical validity were examined. It is also judged that the utilization of the actual site would be higher under these conditions. The model presented in Table 6 is a model that can express the level of the cost to be invested by the water provider to reduce the leakage.

Table 7 presents the test results of the regression coefficient in each model and the standardized coefficient. All the

Table 6
Optimal maintenance model for leakage volume reduction

Cluster	Model	Correlation coefficient	Statistical significance
A	$Y_1 = 5,167.649 + (-1.192) \times X_3 + (-0.318) \times X_4$	0.944	Significant
B	$Y_2 = 3,820.662 + (-0.045) \times X_1 + (-0.180) \times X_2 + (-0.150) \times X_3 + (-0.276) \times X_4$	0.898	Significant
C	$Y_3 = 5,110.909 + (-0.696) \times X_3 + (-0.271) \times X_4$	0.777	Significant

Y: leakage (m^3/km), X_1: unit cost of expansion (1,000 KRW/km), X_2: unit cost of renewal (1,000 KRW/km), X_3: unit cost of labor (1,000 KRW/km), X_4: unit cost of maintenance (1,000 KRW/km).
KRW – Korea Republic Won.

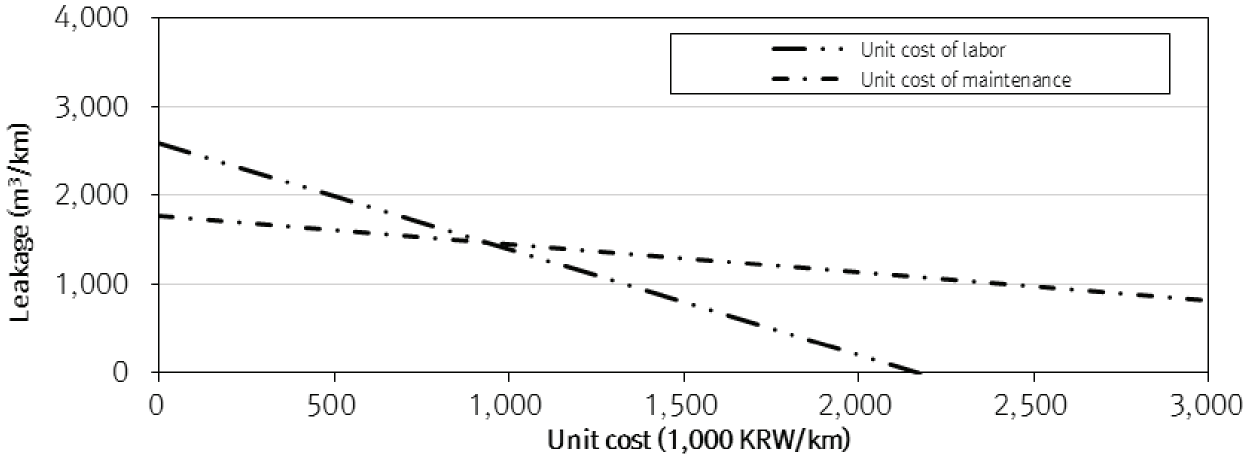

Fig. 4. Result of sensitivity analysis of optimal maintenance model (cluster A).

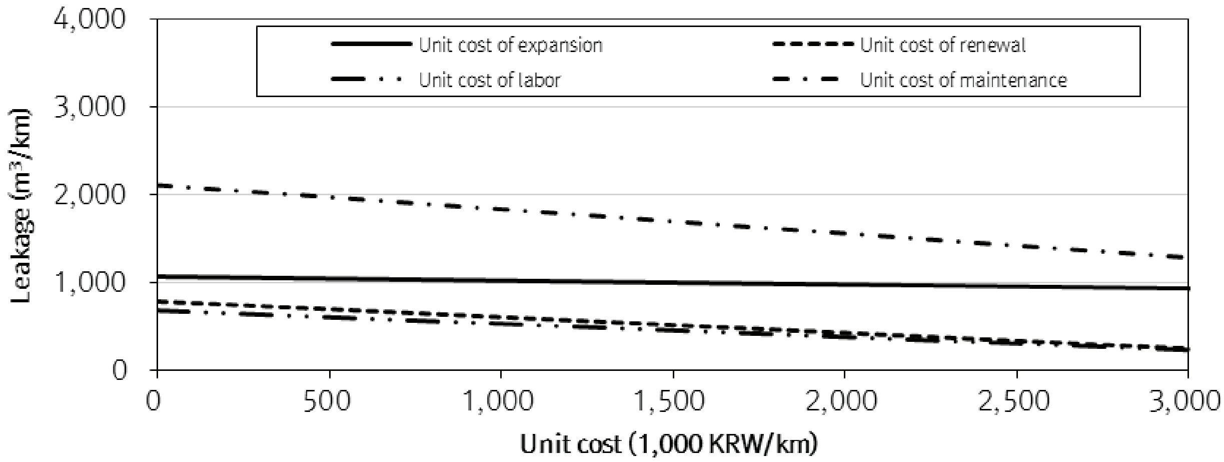

Fig. 5. Result of sensitivity analysis of optimal maintenance model (cluster B).

constants of the model of each group show a positive value (cluster A: 5,167.649, cluster B: 3,820.662, cluster C: 5,110.909). This means that unless costs are invested in maintenance for 3 years, the leakage naturally increases to 5,167.649 m^3/km, 3,820.662 m^3/km, and 5,110.909 m^3/km, respectively. In contrast, all the regression coefficients of the input variables were negative. This means that if an investment is made, the leakage can be reduced in linear proportion to the investment cost.

4.4. Results of prioritization of investment

The standardized coefficient given in Table 7 can be understood as the value that represents the importance of each item of cost. Table 8 provides the estimated priority of the execution of the budget, considering the importance of each item of cost when a water provider executes the budget.

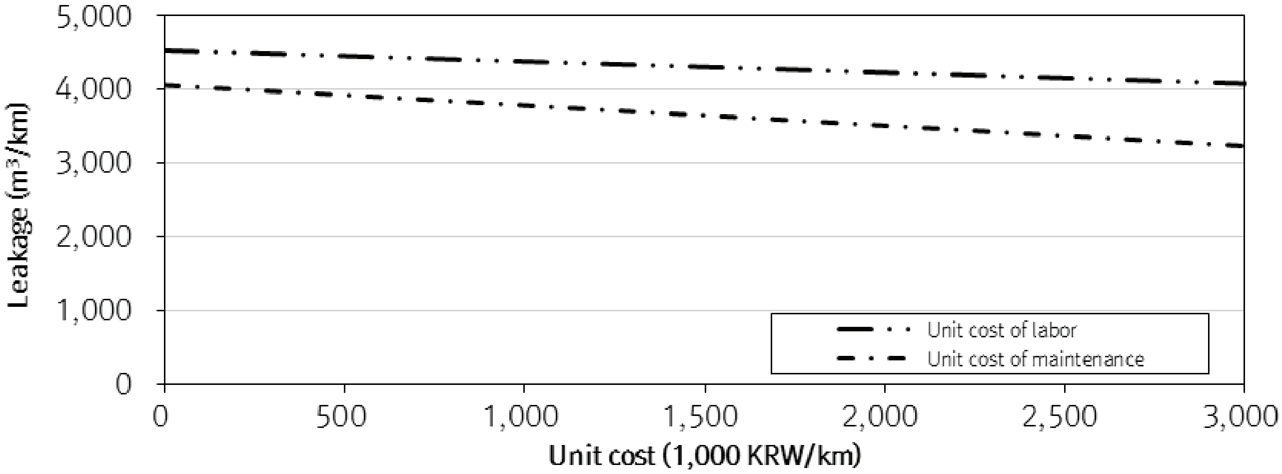

Fig. 6. Result of sensitivity analysis of optimal maintenance model (cluster C).

Table 7
Results of the regression coefficient t-test

Cluster	Input variable	Coefficient	Standardized coefficient	t-value	Sig.
A	Constant	5,167.649	–	9.967	0.000*
	Unit cost of labor	–1.192	–1.702	–10.970	0.000*
	Unit cost of maintenance	–0.318	–1.112	–7.166	0.000*
B	Constant	3,820.662	–	1.204	0.239
	Unit cost of expansion	–0.045	–0.417	–4.963	0.000*
	Unit cost of renewal	–0.180	–0.315	–3.203	0.003*
	Unit cost of labor	–0.150	–0.206	–2.404	0.023*
	Unit cost of maintenance	–0.276	–0.545	–5.580	0.000*
C	Constant	5,110.909	–	4.862	0.000*
	Unit cost of labor	–0.696	–0.558	–4.689	0.000*
	Unit cost of maintenance	–0.271	–0.326	–2.743	0.009*

*Significant in 95% confidence level.

Results showed that water provider group A should prioritize the input and maintenance of manpower for the maintenance of water utilities. It is judged that this is because the importance of investment costs is low as water utilities have been expanded at the highest level in cluster A, and a project for the continuous replacement of decrepit pipelines is implemented.

Results showed that water provider group B should make an investment in putting the priority on the maintenance of water supply facilities, and at the same time, on the installation of new facilities and the renewal of decrepit facilities.

The result from an analysis of water provider group C was the same as that from cluster A. However, it is judged that this result should be interpreted differently from the result from an analysis of cluster A. In other words, unlike cluster A with good financial condition, cluster C consists of relatively smaller water service providers. It would be desirable to invest funds in maintenance of water utilities with a poor condition, but cluster C lacks funds to consume for expansion and renewal.

Table 8
Prioritization of investment for individual water utilities

Investment category	Order		
	Cluster A	Cluster B	Cluster C
Expansion	–	2	–
Renewal	–	3	–
Labor	1	4	1
Maintenance	2	1	2

For the government that has to decide the budget of the whole country, it is desirable to invest in water providers that have a high efficiency of water utility maintenance, or to invest in water providers with low technical efficiency in terms of water welfare equality. Table 9 summarizes the results of estimating the investment priorities for cluster C with a RWR less than 75% and leakage rate more than 20%. It seems reasonable to invest in C1, C4, and C13, which have high maintenance efficiency, to have a greater impact on the

Table 9
Prioritization of investment for government (case of cluster C)

1. Prioritization based on scale efficiency (investment efficiency)			2. Prioritization based on technical efficiency (welfare equality)		
Rank	DMU	Scale efficiency	Rank	DMU	Technical efficiency
1	C1	1.0000	1	C5	0.1313
2	C4	1.0000	2	C31	0.2485
3	C13	1.0000	3	C8	0.2651
…	…	…	…	…	…
40	C32	0.6326	40	C40	1.0000
41	C14	0.5561	41	C41	1.0000

investment. If the investment is made first to C5, C31, and C8, which are provided with relatively low water service owing to low technical efficiency, it can be said that the equity of water welfare can be improved throughout the country.

5. Conclusion

This study developed a model for the optimization of investment costs for the maintenance of water utilities by each group of water providers through a DEA to analyze and evaluate the efficiency of the maintenance of utilities. In addition, as a prioritization, measures for utilizing the developed model for the optimization of maintenance were proposed.

In this study, the results are derived from the most reliable cost data that can be obtained, but more detailed cost data must be obtained to more specific efficiency evaluation. In addition, the result can be changed if the sample changed. Therefore, it can be concluded that various analysis can be performed by using the estimation scheme other than the estimation scheme proposed in this study.

Currently, the Korean Government is carrying out a Waterworks Modernization Project for the improvement of deteriorated water utilities to convert the vicious circle of water supply service to a virtuous cycle. It is concluded that the efficiency assessment index and utilization methodology for investment costs for the maintenance proposed in this study can be reflected in the promotion of the relevant project. In addition, it is concluded that this study can be utilized to promote the efficiency of investment in the maintenance of water utilities.

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