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EFFICIENCY ANALYSIS AND EVALUATION MODEL DEVELOPMENT OF WATER DISTRIBUTION SYSTEM REBUILDING PROJECT USING DEA METHOD

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Abstract

The water supply facilities of Korea have achieved a rapid growth, along with the other social infrastructures consisting a city, due to the phenomenon of urbanization according to economic development. However, as an adverse effect of rapid growth, the quantity of aged water supply pipes are increasing rapidly, while pipe aging causes water suspension accidents and the scale of such accidents is getting large. Accordingly, the Ministry of Environment has been promoting the local water distribution system rebuilding project since 2017 to build a block system, pipe network maintenance work, leak management work, etc. Related projects are being promoted. In this study, analyzed the efficiency of the improvement of the revenue water ratio according to the DEA(Data Envelopment Analysis) method-based water distribution system rebuilding project, and develop an evaluation model for the water distribution system rebuilding project using the efficiency analysis results.

In this study, DEA analysis was performed by selecting 15 local governments that showed cost-effectiveness among 20 local governments that were carrying out the performance evaluation for the 2017 rebuilding project. In this study, DEA analysis was performed considering the number of DMUs secured three times or more than the sum of input and output factors suggested in Banker et al.(1984)'s previous study.

The input indicators of this study are the values derived by dividing the block system construction cost, pipe network maintenance cost, leak management cost invested for the local water distribution system rebuilding project from 2017 to 2021 by the lengths of the project target water distribution pipes. As the output indicators, the rate of increase in the revenue water ratio, which was changed according to the input project cost, was applied.

In addition, a project cost evaluation model was developed for the improvement of the revenue water ratio by using the optimal efficiency point derived through the efficiency analysis with the effect of improving the revenue water ratio as a calculation index. For model development, multiple regression analysis was performed according to the step-selection method that included only independent variables with high explanatory power that had an influence on the dependent variable in the regression model to develop the model.

As such, in this study, the efficiency analysis of local governments performing the local water distribution system rebuilding project was performed, and a project cost evaluation model was developed to improve the revenue water ratio. It is judged that the methodology and development model used in this study can be utilized in the analysis and evaluation of the project efficiency of the additional target area of the local water distribution system rebuilding project in the future.

Keywords
Water distribution system, Efficiency analysis, DEA, efficiency model.

1 INTRODUCTION

Since the 1970s, the water supply facilities in Korea have achieved rapid growth with rapid economic growth. However, due to the rapid economic growth, the deterioration of water supply facilities has been accelerating recently. It brings water suspension and water quality accidents and lowers the quality of water supply services. According to this current situation, the need to manage old water supply facilities that lower water supply services are continuously raised.

The Ministry of Environment in Korea has been carrying out a Water distribution system rebuilding project since 2017 to maintain water supply facilities. The performance guarantee of the local government where the project was carried out with priority is implemented. This study analyses the efficiency by calculating the optimal size of input and output by separately applying input-oriented and output-oriented models under BCC conditions based on DEA (Data Envelopment Analysis).

2 METHODS

2.1 Study area

In this study, the efficiency evaluation of the project implementation of the local governments performing the Water distribution system rebuilding project to be carried out was targeted at 15 county-level local governments that had conducted the Water distribution system rebuilding project from 2017 to 2018. The efficiency of project execution was evaluated using the cost of block system construction, pipe maintenance, leakage management as the annual increase rate of revenue water ratio and the composition of project costs.

2.2 Data Envelopment Analysis(DEA)

Data Envelopment Analysis(DEA) was proposed based on the study of Charnes, Cooper, and Rhodes in 1978. It is a model to evaluate the efficiency of a production organization that produces many output indicators, and a production effect by putting a plurality of input indicators. In DEA literature, the production organization is called the decision making unit (DMU). It is essential to secure the appropriate number of DMUs to perform efficiency analysis. Banker et al. (1984) verified that the number of DMUs to be evaluated should be three times greater than the sum of input and output indicators to be discriminatory. Therefore, in this study, efficiency analysis was performed by securing the number of 12 or more DMUs, which is three times the sum of three input indicators and one output indicator. Table 1 shows the input and output variables for the efficiency analysis based on the BCC model.

Table 1. Input and output variables for efficiency analysis

Input	Output	DMU
Block system building cost within 2017-2021(100 KRW/number of block)	Increase in revenue water ratio within 2017-2021 years (%)	15 water utilities in Republic of Korea
Pipe management cost within 2017-2021(100 KRW/km)		
Leakage management cost within 2017-2021(100 KRW/km)		

Unlike other existing efficiency measurement methods, data envelopment analysis is a nonparametric method, not presuming a specific function form and estimating parameters in advance. It uses data between empirical input elements and the output of the evaluation target based on the linear planning method. After deriving the efficiency frontier change, the efficiency is measured by how far away the evaluation targets are from the efficiency frontier.

To evaluate efficiency, there are various methods of synthesizing input elements to construct a measure of productivity in the production process. In DEA analysis, the CCR model of Charnes, Cooper, and Rhodes (1978) and the BCC model of Banker, Charnes, and Cooper(1984) are used at most. These two models are distinguished by input or output oriented depending on whether they focus on input or output elements. To evaluate the performance of a general business, the input-oriented model is selected as the output effect versus the input cost is considered as a major decision-making factor.

The efficiency using the DEA model is divided into three categories: technical efficiency using the CCR model(assuming a constant return to scale), pure technical efficiency using the BCC model(assuming variable return to scale), and scale efficiency(SE, scale efficiency). Scale efficiency is calculated as in the following equation (1).

$$SE = \frac{\theta^*_{CCR(CRS)}}{\theta^*_{BCC(VRS)}} \quad (1)$$

$\theta^*$is the efficiency value of the CCR model and the BCC model of each specific DMU

There are local governments that have not been optimally implemented in the best state due to various realistic constraints such as local and operational conditions of water supply operators. As the unit of the cost in the project increased, constant returns to scale assumes that the revenue water ratiowill increase steadily. Variable return to scale assumes that the revenue water ratiowill increase significantly or small compared to the cost unit, and it assumes a return on scale. In the case of water flow rate, it is reasonable to follow the scale profit variable model since the technology to improve from 80% to 90% is larger than the technology required to improve from 30% to 40%. Therefore, this research performs efficiency analysis by applying a BCC model that applies calculations on the premise of VRS according to size.

2.3 Multiple regression model

There are many ways to estimate the regression equation. Typical examples are simultaneous input and step input methods. The simultaneous input method analyzes all independent variables considered by the researcher at once. The step selection method includes only variables that influence dependent variables when other variables exist in the regression equation. This study aims to perform regression analysis by the step selection method.

$$\hat{Y} = \hat{\beta}_1 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \cdots + \hat{\beta}_k X_k \quad (2)$$

The above equation is called the regressive equation, and $\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \cdots, \hat{\beta}_k$ is called the regression parameter. The purpose of the regression analysis is to estimate the value of the regression parameter from the relationship between variables obtained from the sample and to verify the hypothesis.

3 RESULTS

3.1 Efficiency analysis

Figure 1 below indicates the results of the analysis of technology efficiency according to CRS(Constant Returns to Scale), net technology efficiency according to VRS(Variable Returns to Scale), and SE(Scale of Efficiency) according to the input orientation of the BCC model.

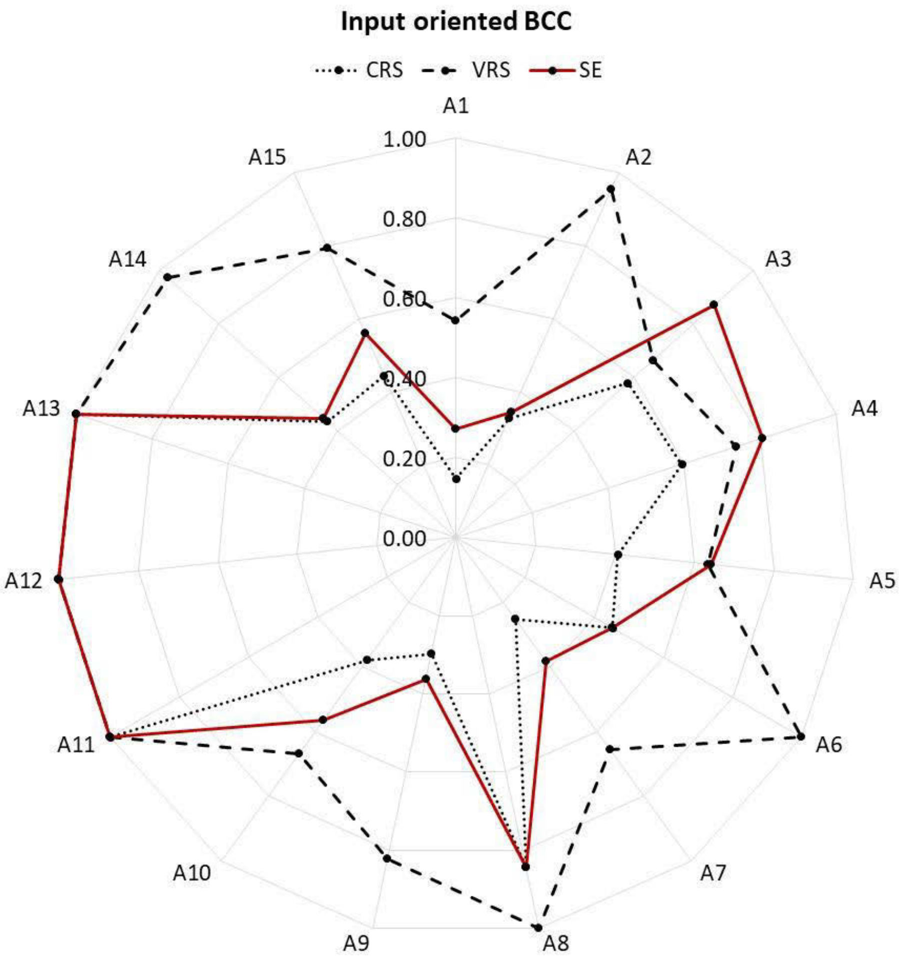

Figure 1. Result of DEA of water distribution system rebuilding project by Input oriented BCC

The efficiency of the input-oriented was analyzed for 15 local governments that implemented the water distribution system rebuilding project. The result shows that in the case of A13, A12, and A11 water suppliers, the technical efficiency under the insomnia of the scale and the net technical efficiency under the scale profit variable were derived as '1'. The efficiency of the scale is the maximum value of '1', which is the highest, and the performance of the project is efficiently achieved because of the effect of improving the revenue water ratio.

On the other hand, the efficiency of the project was low in the case of A9, A8, A2 and A14 water suppliers. Their effect of increasing the revenue water ratio was low compared to the cost invested and relative efficiency was higher than 0.95 under the VRS. However, the efficiency of the scale was small because the efficiency was low under the CRS. These results mean that if the current input cost is increased, it is difficult to see an increase in the output effect as much as the increased cost. Also, it indicates that the water service provider is not operating the optimal water supply facility maintenance.

Furthermore, in the case of A3 and A4 suppliers, the efficiency of each scale was relatively high, despite the low technical efficiency and net technical efficiency, which means that the result of the calculation is low compared to the cost. They may be considered that the cost of relatively input is excessive compared to other water suppliers.

The relative efficiency of local governments performing the water distribution system rebuilding project is shown in Table 2 based on the input-oriented and output-oriented analysis of the BCC model, which is a DEA analysis model.

Table 2. Result of efficiency analysis of water distribution system rebuilding project

Decision Making Units	Technical efficiency in CCR model	Pure technical efficiency in BCC model				Scale efficiency		Reference counts	
		Input-oriented		Output-oriented		Input	Output		
		Score	Score	Score	Score			Input	Output
A1	0.1477	0.5439	IRS	0.2666	DRS	0.2716	0.554	0	0
A2	0.3273	0.9534	IRS	0.3392	DRS	0.3433	0.9649	0	0
A3	0.578	0.6634	IRS	0.8595	DRS	0.8713	0.6725	0	0
A4	0.5939	0.7366	IRS	0.7748	DRS	0.8063	0.7665	0	0
A5	0.4078	0.6352	IRS	0.6122	DRS	0.642	0.6661	0	0
A6	0.4525	1	IRS	1	IRS	0.4525	0.4525	2	0
A7	0.2516	0.6552	IRS	0.3751	DRS	0.384	0.6708	0	0
A8	0.8435	1	IRS	1	IRS	0.8435	0.8435	5	0
A9	0.2967	0.8217	IRS	0.3529	DRS	0.3611	0.8407	0	0
A10	0.3781	0.6693	IRS	0.4829	DRS	0.5649	0.783	0	0
A11	1	1	CRS	1	CRS	1	1	0	10
A12	1	1	CRS	1	CRS	1	1	6	2
A13	1	1	CRS	1	CRS	1	1	10	10
A14	0.4343	0.9718	IRS	0.4458	DRS	0.4469	0.9742	0	0
A15	0.4437	0.7935	IRS	0.5492	DRS	0.5592	0.8079	0	0

This study divided and analyzed the input-oriented model and the output-oriented model of the BCC model, which are the efficiency measurement model based on the VRS. As a result of analyzing the efficiency measurement model, three of the 15 water suppliesrs(A11, A12, A13) had an efficiency of '1' in both the input-oriented model and the output-oriented model. The average efficiency of input orientation was 0.5437, and the average efficiency of output orientation was 0.6705.

Furthermore, the input-oriented model of the variable return to scale that the BCC model presupposes was analyzed as 12 IRSs, 0 DRSs, and 3 CRSs. In the output-oriented model, 2 IRSs, 10 DRSs, and 2 CRSs were analyzed. The DRS increased in the analysis of the output-oriented model. This means that the excess shortage of the revenue water ratio, the output factor, is greater than the excess input, and the output effect is not derived compared to the investment. In this case, advanced technology is required to improve the revenue water ratio in addition to the cost investment. The operation and maintenance of the water distribution system should be upgraded to increase the calculation even if the same cost is invested.

3.2 Appropriate project cost calculation model to improve the revenue water ratio

The appropriate project cost calculation model (Y_A) was developed using the optimal efficiency point derived through efficiency analysis using three input indicators and the effect of raising the revenue water ratio as a calculation index. Developing an appropriate project cost estimation model to improve the revenue water ratio, an optimization model was established by performing multiple regression analysis according to the step selection method including only the independent variables with high explanatory power that have an influence on the dependent variables in the regression equation. The developed model is shown in Equation (3).

$$y = 0.035 + 0.020x_1 \quad (3)$$

x_1 is leakage management cost(100KRW/km)

The analysis result of model variance showed that the significance probability of the developed regression model was 0.012, which is smaller than 0.05. It indicates that the developed regression model is statistically significant. The following Table 3 is the result of the significance analysis of the regression coefficient of the developed regression model.

The coefficient values of the model constant and independent variables were statistically significant, as below 0.05. The R-value of the model was 0.631. In the final regression model, the basic unit of leakage management cost was included as an independent variable.

Table 3. Result of the ANOVA of the cost evaluation model to improve the revenue water ratio

Division	B	Std.error	t	p
Constant	0.035	0.008	4.395	0.001
x_1	0.020	0.007	2.936	0.012

4 CONCLUSIONS

In this study, the efficiency of the input-oriented model and output-oriented model was compared and analyzed to evaluate the business efficiency of the water distribution system rebuilding project which has been implemented since 2017 through large-scale government support in Korea. The result of the analysis shows that the overload of the output element is larger than the overload of the project cost being invested in the current water supply facility scale. It suggests that it is necessary to apply more advanced water supply maintenance technology rather than facility expansion and improvement-oriented maintenance.

Through data enveloping analysis, the optimal efficiency points to improve the revenue water ratio of local governments performing water distribution system rebuilding project was derived. Based on the optimal efficiency point, this study developed a model for calculating the appropriate business cost to improve the revenue water ratio. As a result of testing the developed regression model, the correlation of the model was 0.631, indicating good explanatory power. If the number of related samples increases due to the increase of local governments in the performance guarantee stage of the water distribution system rebuilding project in the future, it has higher explanatory power than the model developed in this study. It leads to the development of a model for calculating the appropriate business expense considering various business details such as block system building cost and pipe management cost. It is expected that this study will be applicable in the implementation of the projects related to the improvement of the revenue water ratio through government support projects such as the water distribution system rebuilding project.

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