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Decision method for rehabilitation priority of water distribution system using ELECTRE method

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ABSTRACT

The water pipe is an important component of the tap water facility, and plays a role as critical as that of the blood vessel in the body. However, accurate diagnosis of its condition is very difficult because it is buried under the ground, even as pipe aging frequently leads to phenomena that threaten water quality such as pipe damage and water leakage. In order to maintain and improve the performance of the existing pipe network, planned examination, operation, and maintenance, as well as technologies for proper renewal, are required. Accordingly, the present research proposes a method that can be used for the maintenance of the pipe network in each water distribution block (WDB). For this purpose, the weighted performance indicator (PI) determined by means of PI and the analytic hierarchy process technique which allows evaluation for individual water WDBs, was applied to the ELECTRE technique which is a multi-factor decision-making method. This result may be used as a reference for water leakage maintenance and for the renewal and change of a WDB. The frequency of pipe accidents is expected to be reduced by appropriate plans set up beforehand. The research was conducted by investigating the 60 WDBs of both Sujeong-Gu and Joongwon-Gu in Seongnam City. The water pipe rehabilitation ranking of the 60 WDBs could be determined as a result. In order to determine the best R model out of the 16R models, a comparison was made of the correlation coefficient, rate of ranking conformance, mean square error, and mean absolute error. The result showed that the R12 model was the most suitable model, while the priority in the maintenance of the pipe network for each block could be determined. As a result, the blocks least suitable for first maintenance were determined to be Blocks 22, 48, 38, 18, and 32, whereas the most satisfactory ones were Blocks 42, 55, 23, 12, and 41.

Keywords: ELECTRE method; AHP; Priority of rehabilitation; PI

1. Introduction

All living creatures owe their origin to water which is an essential element for life. However, water is a limited resource, which has raised many concerns over potential water shortages due to the worldwide difficulties in securing water resources. Our water works have a 100-year history since the first introduction of the modern system, which

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provides a hygienic, safe, and stable water supply with adequate hydraulic pressure, volume, and quality to 50,264,000 people accounting for 97.7% of the total population. In particular, waterworks have grown up to the extent where tap water reaches 99.9% of the citizens living in the seven largest metropolitan areas including the capital city of Seoul. As of late 2010, the total annual water supply of South Korea amounted to 5,910 million tons, of which water leakage, mostly from leakage in the water distribution networks, accounted for 10.8% at 638 million tons per year.

In addition, the water pipe is an important component of the tap water facility, and plays a critical role such as the blood vessel in the body. However, accurate diagnose of its condition is very difficult because it is buried under the ground; even as pipe aging frequently leads to phenomena that threaten water quality such as pipe damage and water leakage. In order to maintain and improve the performance of the existing pipe network, planned examination, operation, and maintenance, as well as technologies for proper renewal are required. In order to achieve this goal, an accurate concept of the aging factor of a pipe network needs to be established, along with a method for determining the proper times for damage and renewal as well as the range of objects.

Recently, an increasing number of studies have been conducted which are aimed at determining the proper time for the renewal of tap water pipes and the range of objects, in order to cope with their aging and associated problems. Regarding the damage risk rate of a tap water distribution network. Kim [1] determined the statistical probability of pipe damage by analyzing the contribution of each factor that influences damage, based on the data about the damage in the water supply and distribution pipes, and the resulting water leakage. Taking into consideration the economic benefit of companies as well as the effect of pipes on environments and local societies, Brito and de Almeida [2] assessed the risk ranking using multi-attribute utility theory, which offers a simple structure that is easily understandable and has clear logic. Koo et al. [3] reported the application of protection and reduction techniques of water leakage, conducted research on performance indicator (PI), and described a calculation method for the assessment of soundness for each water distribution block (WDB). Nevertheless, research remains insufficient on the appropriate level of PI, how the PI weighting should be calculated, and how to determine the assessment ranking of each block.

Accordingly, the present research was designed to suggest a method capable of being used for the maintenance of the pipe network in each WDB. For this purpose, the weighted PI determined by means of PI and the analytic hierarchy process (AHP) technique, which allows evaluation for individual water supply units, was applied to the ELECTRE (ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality)) technique, which is a multi-factor decision-making method. This result may be used as a reference for water leakage maintenance and for the renewal and change of a WDB. The frequency of pipe accidents is expected to be reduced by appropriate plans set up beforehand.

2. Background

2.1. Analytic hierarchy process

AHP is one of the multi-factor decision-making techniques developed by Thomas Saaty at the University of Pennsylvania in the early 1970s as a part of an alternative method for improving inefficiency in the course of his collaboration with world-famed economists and game theology specialists. This method first constructs a hierarchy of the problems of decision-making, and then measurements are made by the pair-wise comparison between the relative importances of alternative methods from a viewpoint of each evaluation criterion. Through this method, AHP can obtain the weights of the alternative methods at the bottom of the hierarchy or priority. The systematic assignment of weights to various properties using AHP is achieved through the following four steps: the formation of a hierarchical structure, preparation of the matrix of the pair-wise comparison of decision factors, calculation of weights, and examination of consistency. Based on a survey with a group of specialists and using the AHP technique, the present research determined the PI weighting for each WDB.

2.2. ELECTRE

In classic decision theory, the process to express preferences for options in the form of explicit or probable utility function and then select one that satisfies the condition of the maximum utility is referred to as the rational decision-making. It is, however, very difficult to clearly express the psychological preference of an individual in mathematic utility function. Moreover, a problem can occur in that the option chosen through the condition of utility maximization is not necessarily the best choice. Multi-attribute utility function technique is a classic method for decision-making and has the merit of a mathematically well-established theory. When it comes to the question of how it works in the real world, the theory can give rise to a problem that it does not match actual human decision-making. Further, the theory fails to assume the problems associated with incomparability of the options and non-transitivity of preference but is based on the assumption of a dual preference system where the assumption of being preference-independent and utility-independent is unrealistic. Based on such necessity, the European school centering around the Roy Bernard of LAMSADE research center at Paris Dauphine University proposed a concept of outranking the relation of the options to overcome the limit of objectivity faced by a decision-maker in the multi-criteria decision-making environment. One of the most widely recognized techniques exploiting the outranking relation concept is ELECTRE, whereby relatively inferior options are systematically removed based on outranking relation by means of concordance (CI) and discordance (DI) indices for evaluation criteria and comparative options.

2.2.1. ELECTRE II

ELECTRE II refers to a technique of assigning a ranking for each option by means of strong and weak relationships. The former means a clear preference by the decision-maker and the latter a somewhat unclear preference. Such outranking can be expressed by defining CI, DI, CI threshold, and DI threshold.

CI is the sum of weights ω_j ($j = 1,2,3, \ldots n$) based on the importance of each criterion where "n" is the number of criteria and is defined as shown in Eq. (1).

$$c(a,b) = \frac{1}{W}\sum \omega_j, \quad \forall_j\!: g_j(a) \geq g_j(b) \qquad W = \sum_{j=1}^{n} \omega_j \tag{1}$$

CI in Eq. (1) $c(a, b)$ is the sum of weights of the criteria for which performance results of option a are bigger than those of option b. It has a value between 0 and 1. Therefore, if CI is big, option a is preferred over option b. On the other hand, the concept of DI is used in the individual preference structure to exclude indifference relation and prevent a symmetric relation in preference among the options. DI is defined as shown in Eq. (2).

$$d(a,b) = \begin{cases} 0 & \text{if } g_j(a) \geq g_j(b), \quad \forall_j \\ \frac{1}{\delta}\max|g_j(b) - g_j(a)| & \text{if } g_j(a) < g_j(b) \end{cases} \qquad \delta = \max|g_j(b) - g_j(a)|, \quad \forall_j \tag{2}$$

DI in Eq. (2) $d(a, b)$ has a value between 0 and 1. As the difference between the performance results of option a and b grows, DI increases, making option b preferred over option a.

2.2.2. Outranking relation of ELECTRE II

If the CI threshold, which is the preference characteristics to express outranking relation, is $0 \leq c^- \leq c^0 \leq c^+ \leq 1$ and the DI threshold $0 \leq d_1 \leq d_2 \leq 1$, then the strong relationship (S^F) and weak relationship (S^f) can be defined as follows:

Strong relationship (S^F)

$$c(a,b) \geq c^+, \quad g_j(a) - g_j(b) \leq d_2 \ \forall_j, \quad \frac{P^+(a,b)}{P^-(a,b)} \geq 1 \tag{3}$$

Weak relationship (S^f)

$$c(a,b) \leq c^-, \quad g_j(a) - g_j(b) \leq d_2 \ \forall_j, \quad \frac{P^+(a,b)}{P^-(a,b)} \geq 1 \tag{4}$$

P^+ is the sum of the weights of the criteria on which option a is preferred to option b and P^- is the sum of the weights of the criteria on which option b is preferred to option a.

The process to determine the priorities of the options under evaluation by means of Eq. (4) consists of the following three steps. Firstly, if a relatively large number of weakly preferred options exist among those strongly preferred, high priorities are assigned. Secondly, after determination of the priorities for the strongly preferred options, the options having a relatively large number of weakly preferred options are ranked. Thirdly, steps 1 and 2 are repeated until all the options under consideration have been ranked.

3. Methods

3.1. Research area

This research involved both Sujeong-Gu and Joongwon-Gu of the Seongnam City in Korea, with a combined area of 71.29 km^2 and 68 small WDBs, as shown in Fig. 1. Nine reservoirs supply 157,000 m^3 of tap water for the study. Currently, the total length of water pipes is 1,281 km, comprised of 121 km of transmission main, 415 km of distribution main, and 745 km of service pipe. The largest portion of the pipes are DCIP (537.1 km, 41.91%), followed by stainless pipes (536.4 km, 41.86%), enamel-coated steel pipe (114.5 km, 8.93%), and then HI-3P (92 km, 7.18%). Most of the service pipes were buried 11–15 years ago, whereas the age distribution of both transmission mains and distribution mains were relatively even. A data investigation revealed that the proportion of the service pipes older than 21 years, is only 2% now, but that it will increase beyond 46% in 5 years, whereas in case of both transmission mains and distribution mains, it is anticipated to be as high as 27%. Therefore, it is considered necessary to establish a plan to cope with those old pipes in the future.

3.2. Data collection

The research was carried out by examining 60 WDBs of the 68 WDBs of both Sujeong-Gu and Joongwon-Gu in Seongnam City, excluding Blocks 58, 59, and 64, whose pipe data were not available, and Blocks 57, 65, 67, 66, and 68, whose data were partly missing. The 12 PIs used for the 60 small blocks were as follows: the average age of distribution mains, the average age of service pipes, the ratio of distribution mains older than 21 years, the ratio of the service pipes older than 21 years, the ratio of the non-corrosive pipes among the distribution mains, the ratio of the non-corrosive pipes among the service pipes, the number of water leakage accidents among the distribution mains, the estimated amount of water leakage from the distribution mains, the number of water leakage accidents among the service pipes, the estimated amount of water leakage from service pipes, the number of control valves for each length of distribution main, and the number of fire hydrants in each length of the distribution main. As for the data about the water leakage situation of each small group, the data of 2006–2008 was used. The index and its contents are defined in Table 1.

3.3. Research procedure

As part of the efforts to determine the priorities of replacement and rehabilitation of the water distribution lines in an economical and efficient manner, the following research was conducted.

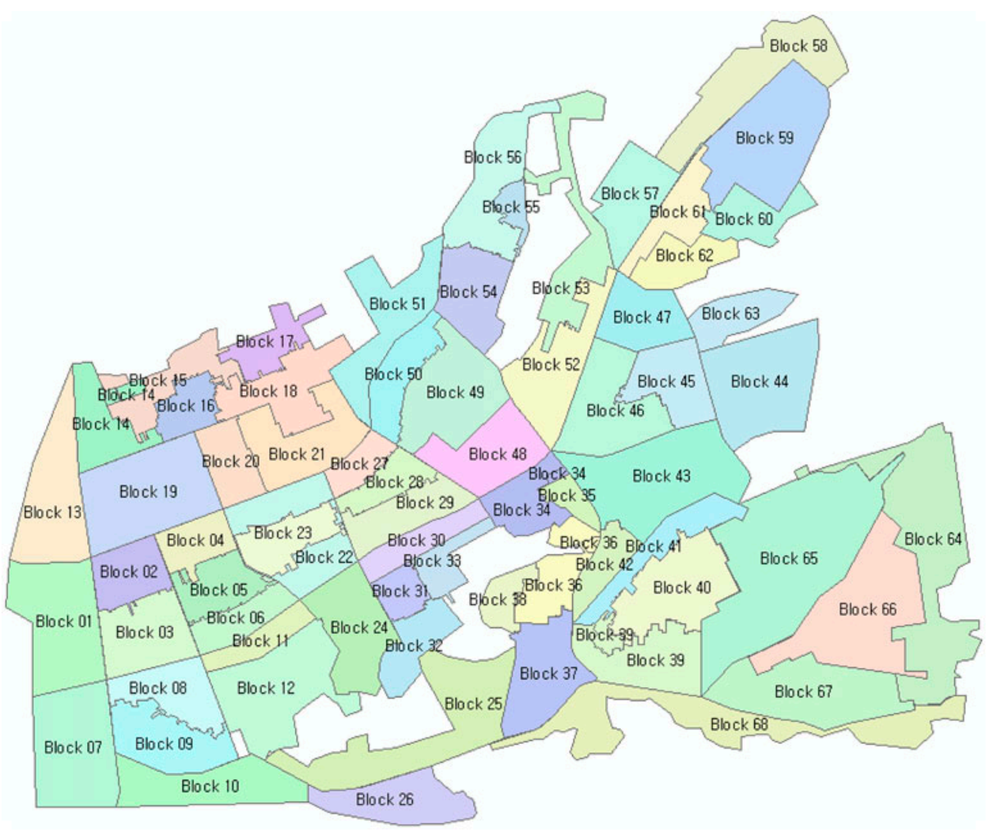

Fig. 1. Map of the research area.

Table 1
Division and definition of PI

Division			Symbol	Definition
Average age of pipe	Distribution main		A1	The average age of distribution mains is a basic index to decide how old the pipes of a specific region are. It is considered that the pipe failure or leakage risk is not a perfect linear relationship with the pipe age (use life) but there is a sufficient correlation between the two
	Service pipe		A2	The service pipes are very different from distribution mains in the pipe material or pipe diameter. Therefore, it is more desirable to analyze service pipes and distribution mains separately instead of integrating the former and the latter
Ratio of pipe aged (≥21 year)	Distribution main		B1	The average age of pipes in a block does not show how many old pipes are in the block. It is because that the failure risk can be concentrated on the pipes of old age
	Service pipe		B2	The rate of service pipes at the age of more than 20 needs to be calculated, considering the total length
Ratio of non-corrosive pipe	Distribution main		C1	It is considered to give priority to the replacement of gray cast iron pipes laid in the past among various materials of distribution mains because they have non-resistance to erosion and the older they are, the higher the accident risks are. The block with the high rate of gray cast iron pipes among many blocks is considered to have priority to rehabilitation
	Service pipe		C2	The water leakage occurs most frequently in the galvanized steel pipes with non-resistance to erosion among various materials of service pipes and thus the higher the rate of the galvanized steel, the higher the risk is. The rate of length of galvanized steel pipes needs to be calculated based on the above results
Event of leakages	Distribution main	Number of event	D1	Although the age of the pipes is low and the number of pipes with non-resistance to erosion is small, the leakage accidents can occur frequently for another reason
		Leakages	D2	Although the number of accidents is small, the amount of the water leakage can be large due to the big scale of an accident. In order to take it into account, the estimated leakage amount per total length of distribution mains needs to be calculated
	Service pipe	Number of events	D3	The number of accidents per length is calculated as well in case of service pipes like the case of distribution mains
		Leakages	D4	The estimated leakage amount is calculated per length of service pipes
Safety	Number of control valves for each length of distribution main		E1	In case that the conduit pipes have the appropriate number of control valves, the proper operation of the control valves can make sections where water supply cut-off is minimized, even if the leakage or water pollution accidents occur. In order to do so, an appropriate number of control valves needs to be installed in the suitable locations, but in the study the number of control valves installed is only taken into account
	Number of fire hydrants in each length of distribution main		E2	It is meaningful that if enough fire hydrants are installed in the region, there will be enough available water at hand when a fire breaks out

Firstly, attribute data for the water lines were collected using ArcGIS. DB was created based on the records of leakage and repair works. The resulting values of the selected PIs such as the average age of the pipelines, percentage of the pipelines older than 21 years, percentage of anti-corrosion pipes, leakage incidents, and stability were aligned to be in the same preference direction. To solve the problem of outliers and values distributed over a wide range, the resulting values were converted by means of normal scores.

Secondly, an expert group was chosen and polled to obtain weights of the selected PIs. Among the forms of survey returned, only those having a consistency index of less than 0.1 were used to determine the weights using the AHP technique.

Thirdly, replacement and rehabilitation priorities were determined for each small block of the 60 subject areas by means of the ELECTRE II method based on the resulting values of PI converted into normal scores and the weight for each PI calculated using the AHP technique.

4. Results and discussion

4.1. Calculated weight using AHP

An expert group of 25 professors, researchers, and industry officers were chosen to respond to a survey consisting of an evaluation index divided into three categories of large, medium, and small items for 15 d from 24 November 2008 to 3 December 2008. Eleven survey forms with a consistency rate of less than 0.1 were subject to final analysis using AHP. The medium and small items are shown in Table 2 as results of the weight analysis for the large items.

4.2. Results of ranking using the ELECTRE method

The evaluation index values based on the data collected from the subject areas were not consistent in the preference direction, had outliers, and failed to follow the normal distribution, as ascertained by the Kolmogorov–Smirnov test. In an attempt to align each PI in the same preference index and eliminate the outliers, the index was standardized using normal scores of Van der Waerden. From this standardization, it was determined that the average and the median were both “0,” which supported the normal distribution as ascertained by the Kolmogorov–Smirnov test and indicated that the evaluation index data followed the pattern of the standard normal distribution. These converted data were then applied to ELECTRE II.

CI and DI were calculated using Eqs. (1) and (2). Outranking relations are shown in Eqs. (3) and (4). It is a very important task to determine such preference thresholds as CI and DI thresholds because ELECTRE II changes the results of the evaluation affected by the subjective preference information of the decision-maker. In this study, therefore, the CI threshold was increased in increments of 0.1 from 0.5 to 1.0, while the DI threshold was set up between 0.1 and 0.9 to construct the 16 models shown in Table 3.

Table 4 shows the rankings of the 16 ELECTRE II models resulting from the changes in the preference characteristics.

Reversal in the evaluated ranks of the blocks, except the one block which ranked 37th, was frequent according to the changes in the CI and DI critical values. This phenomenon indicated that even in the same decision-making situation, the evaluation result can vary according to the parameters that contain the information about the priority in decision-making.

Table 2
The final weight for water pipe rehabilitation priority

Hierarchy 1	Weight	Hierarchy 2	Weight	Hierarchy 3	Weight	The final weight
Average age of pipe	0.136	Distribution main	0.612	–	–	0.083
	(13%)	Service pipe	0.388	–	–	0.053
Ratio of pipe aged	0.216	Distribution main	0.427	–	–	0.092
(≥21 year)	(22%)	Service pipe	0.573	–	–	0.124
Ratio of non	0.209	Distribution main	0.361	–	–	0.075
corrosive pipe	(21%)	Service pipe	0.639	–	–	0.134
Event of leakages	0.341 (34%)	Distribution main	0.730	Number of event	0.663	0.165
			0.730	Leakages	0.337	0.084
		Service pipe	0.270	Number of event	0.597	0.055
			0.270	Leakages	0.403	0.037
Safety	0.098 (10%)	Number of control valves for each length of distribution main	0.805	–	–	0.079
		Number of fire hydrants in each length of distribution main	0.195	–	–	0.019

Table 3
The CI and DI thresholds

Preference parameters	Model	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
Concordance threshold	c^+	1	0.9	0.8	0.7	1	0.9	0.8	0.7	1	0.9	0.8	0.7	1	0.9	0.8	0.7
	c^0	0.9	0.8	0.7	0.6	0.9	0.8	0.7	0.6	0.9	0.8	0.7	0.6	0.9	0.8	0.7	0.6
	c^-	0.8	0.7	0.6	0.5	0.8	0.7	0.6	0.5	0.8	0.7	0.6	0.5	0.8	0.7	0.6	0.5
Discordance threshold	d_1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.7	0.7	0.7	0.7
	d_2	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.7	0.7	0.7	0.7	0.9	0.9	0.9	0.9

The R model rankings resulting from the changes in CI and DI thresholds were compared with the coefficient of correlation, rate of ranking conformance, mean square error (MSE), and mean absolute error (MAE) to select the R models above each average. Among those selected R models, the one showing the highest frequency was selected as the optimum model.

Based on the values obtained as the result, Table 5 summarizes each PI, correlation coefficient, MSE, MAE, and the frequency of the R model that was selected whenever the priority was same and which was above the average.

As a result, the R12 model was judged to be the most similar to the evaluation items that were the measured values and, accordingly, to be the most optimum model.

Therefore, the priority of renewal and exchange for each small block based on the R12 model was same as the result of R12 in Table 4. The blocks that were in the worst condition and required maintenance with priority appeared to be Blocks 22, 48, 38, 18, and 32, while the blocks in the best condition appeared to be the Blocks 42, 55, 23, 12, and 41. However, actually measured data would be required to verify the suitability of the determined R12 model, as well as its ability to be used for determining the priority in the renewal and exchange of the WDBs. Of the data for verification, data about the revenue water ratio or leakage ratio were judged to be the most appropriate. In the present research, however, there were many blocks with no block isolation, which resulted in a very low accuracy of the revenue water ratio. If such data as revenue water ratio could be secured for verification, it would be effective for determining a more accurate R model.

4.3. Comparative analysis with existing research methods

Studies on setting the rehabilitation priority of the WDB have been actively conducted out, and various methodologies have been used. Among them, the score assessment method (SAM) can be applied most simply and is widely used. In this section, the results of the rehabilitation priority of the WDB using the ELECTRE method are analyzed and compared with those using SAM. The rehabilitation priority of the WDB using SAM was calculated in the same research object region, PI and weight as those of the ELECTRE method, and the calculation was conducted according to Eq. (5).

$$\text{Grade} = \sum_{i=A1}^{E2} [f_i \times \text{Score}_i] \tag{5}$$

where Grade, comprehensive assessment score; f_i, weight of ith PI; Score_i, score of ith PI.

The PI value by each WDB was divided into five equal parts: 5, 4, 3, 2, and 1 point(s) where a higher point was allotted to a worse condition of the WDB. The rehabilitation priority of the WDB was decided using the comprehensive assessment calculated by each block. A typical result is presented in Fig. 2 along with the result of the decision of the rehabilitation priority of the WDB using the ELECTRE method.

Fig. 2 reveals a dissimilarity between the two methods, because ELECTRE determined the ranking by comparing the PI value by the WDB, while SAM determined the ranking by fixing the score of the PI value to 5, 4, 3, 2, and 1 point(s) by the WDB. Consequently, if the scores of the PI value differed depending on a WDB in SAM, the result will also have differed. In situation, it was difficult to decide appropriate scores on the PI value, which proved that the ELECTRE method that determines the ranking through comparison of the PI value by the WDB is more logical than the method of determining the rehabilitation priority of the WDB by SAM. However, since the base that the method developed in this study being most accurate is lacking, further verification in future studies will be necessary.

Table 4
The water pipe rehabilitation priority

	B																													
M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
R1	37	15	33	16	58	57	9	44	46	52	53	24	32	36	38	3	20	43	2	4	5	7	8	12	18	19	21	26	39	40
R2	37	33	15	9	16	38	58	57	44	53	46	52	36	32	39	3	4	40	5	7	18	19	21	26	42	55	22	17	14	23
R3	37	33	15	16	57	38	9	58	52	44	46	53	36	32	18	39	40	4	5	7	21	26	42	55	3	20	43	17	24	14
R4	37	33	15	9	57	16	38	58	52	44	46	53	36	39	40	4	32	18	5	7	21	26	42	55	17	3	14	20	23	27
R5	37	33	15	38	16	9	58	44	53	57	32	52	36	4	3	5	8	19	20	39	40	43	46	2	7	26	55	27	22	17
R6	37	33	15	16	38	44	57	9	53	52	32	36	40	58	4	39	19	7	43	46	3	20	21	55	31	27	17	22	34	8
R7	37	33	15	44	38	57	16	9	4	53	32	39	36	40	52	58	31	46	7	27	19	34	5	43	3	17	1	8	20	21
R8	37	33	15	9	44	38	57	53	36	39	4	32	16	40	52	7	58	18	31	46	34	43	19	17	8	1	20	21	27	55
R9	37	33	15	44	38	9	53	58	32	57	52	36	40	7	16	39	3	8	19	20	27	31	46	2	26	55	22	17	4	21
R10	33	37	15	38	44	9	52	53	32	57	16	36	7	39	40	58	31	46	4	27	34	54	19	17	22	3	8	20	5	1
R11	37	33	15	44	38	53	7	39	9	36	57	16	40	52	32	19	46	4	31	58	27	1	34	18	17	54	8	20	6	43
R12	37	33	44	38	36	53	9	15	39	7	16	57	32	40	52	31	18	4	27	34	46	1	58	54	22	17	8	19	43	20
R13	37	33	15	38	44	9	53	58	52	32	57	7	36	16	40	39	31	17	19	20	22	27	46	2	55	54	26	21	3	5
R14	37	15	44	38	9	52	53	32	33	7	39	57	16	40	36	58	46	31	4	1	27	54	19	26	43	34	17	20	3	22
R15	37	15	38	33	9	53	44	52	7	16	32	57	36	40	39	22	46	58	31	19	17	4	26	34	54	1	27	18	43	20
R16	37	38	15	53	9	44	33	16	36	7	52	57	32	39	40	34	31	46	58	18	4	1	17	27	22	19	45	43	23	26
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	60	61	62	63
R1	42	54	55	22	27	34	17	14	23	31	56	11	49	60	29	10	1	6	51	30	35	28	45	41	47	48	13	25	59	50
R2	27	20	31	43	24	34	56	2	8	12	54	49	60	11	1	6	51	29	30	45	35	13	10	28	47	25	41	48	59	50
R3	23	27	31	34	56	22	8	12	19	54	49	60	2	1	6	51	11	29	30	35	45	13	28	41	47	10	25	59	48	50
R4	31	34	43	56	22	19	1	6	8	12	51	54	24	49	60	2	11	29	30	35	45	13	28	41	10	47	59	25	48	50
R5	31	21	23	24	54	34	42	56	14	49	12	18	1	60	45	11	6	30	35	51	29	10	13	47	28	25	41	48	59	50
R6	18	24	54	2	5	26	23	42	60	56	1	14	6	49	12	45	11	30	51	29	35	41	28	47	13	10	25	59	48	50
R7	22	55	18	54	26	23	56	42	45	60	49	2	6	14	24	12	30	11	51	35	29	41	47	10	28	59	13	48	25	50
R8	5	54	22	3	6	23	26	45	56	60	14	49	42	11	12	30	24	51	2	41	29	35	47	10	59	28	13	48	25	50
R9	43	54	34	24	5	60	12	18	23	42	56	1	11	6	14	45	49	30	35	29	10	51	47	25	28	13	41	59	48	50
R10	2	26	55	43	56	21	18	23	42	60	49	45	6	12	14	24	11	30	35	51	47	41	29	10	28	59	25	13	48	50
R11	22	3	55	23	26	14	21	45	2	60	5	49	56	11	12	42	51	24	35	30	41	29	47	10	59	28	13	48	25	50
R12	45	5	6	55	23	21	26	3	42	14	56	60	11	12	35	49	30	2	24	51	47	41	29	10	59	13	48	28	50	25
R13	56	24	4	23	34	8	18	42	60	11	12	43	1	14	6	35	45	49	29	30	47	51	10	25	28	41	59	13	48	50
R14	23	2	8	18	55	5	6	45	12	14	49	60	42	56	21	24	35	11	30	51	47	29	41	10	28	25	59	13	48	50
R15	23	3	2	55	21	45	5	6	14	49	35	11	42	8	12	56	47	60	24	30	29	41	51	10	59	13	28	48	50	25
R16	54	20	3	12	49	5	55	14	21	6	11	35	42	8	47	24	30	56	60	41	2	29	10	51	59	13	48	28	50	25

Table 5
The frequency of the R model

R1	R2	R3	R4	R5	R6	R7	R8
22	15	23	15	24	18	17	17
R9	R10	R11	R12	R13	R14	R15	R16
22	22	23	25	16	24	24	23

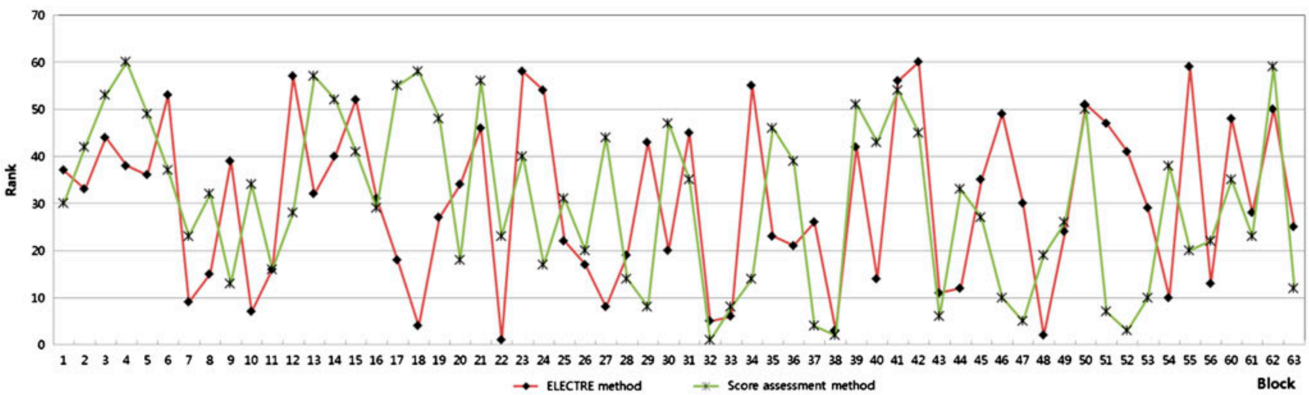

Fig. 2. Comparison of results for the ELECTRE method and SAM.

5. Conclusion

In this study, weights were set using the AHP technique, and rehabilitation priorities for each block were determined by applying the ELECTRE technique. The water pipe rehabilitation ranking of the 60 WDBs could be determined as a result. In order to determine the best R model out of the 16R models, the correlation coefficient, rate of ranking conformance, MSE, and MAE were compared. The result showed that the R12 model was the most suitable, while the priority in the maintenance of the pipe network for each block could be determined. As a result, the blocks least suitable for first maintenance were determined to be Blocks 22, 48, 38, 18, and 32, while the most satisfactory ones were Blocks 42, 55, 23, 12, and 41. To verify the method developed in this study, a comparison was made with the existing SAM, but the necessary inclusion of many assumptions rendered the comparative analysis inappropriate. Application of the proposed method in real-field settings was therefore judged to be difficult and future verification will be required in various ways. The reliability and accuracy of the developed model are expected to be increased by verification using the revenue water ratio and infrastructure leakage index or by comparison with other more advanced methods. Following full verification of its accuracy and credibility, the present model will be of great help in determining the priority in the renewal and exchange for each WDB.

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