Sigma J Eng & Nat Sci 38 (3), 2020, 1481-1494

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

DETERMINATION OF PRIORITY REGIONS FOR REHABILITATION IN WATER NETWORKS BY MULTIPLE CRITERIA DECISION MAKING METHODS

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Received: 17.02.2020 Revised: 24.04.2020 Accepted: 09.08.2020

ABSTRACT

Network rehabilitation and pipe material management could be shown as an important economic load for the Water Utility. For this reason, detailed analysis should be made and the worst regions should be determined before applying the methods. In this study, it is aimed to determine the priority regions for rehabilitation in distribution systems in order to prevent water losses. For this aim, a total of 28 factors that can be measured, applied and representing the problem were determined in the application area. Weight coefficients were calculated with the ENTROPY method to determine the degree of influence of these factors in decision making. The highest weight coefficient was obtained for the unreported leakages determined by active leakage control. ELCETRE I and PROMETHEE II methods were applied in determining the priority regions in rehabilitation. According to the results obtained with the ELECTRE I method, DMA 13, DMA 11, DMA 12, DMA 14 and DMA 5 regions were determined as the first 5 regions with rehabilitation priority. On the other hand, according to the PROMETHEE II method, the first 5 regions with rehabilitation priority were DMA 13, DMA 11, DMA 12, DMA 8 and DMA 15. When the results obtained by these two methods are compared, it is seen that the first region with priority of rehabilitation is similar. Thus, it is possible to provide a solution that requires investment priority and aims to increase water resource and economic efficiency. It is thought that the results obtained in this study will serve as a reference in terms of network and water loss management.
Keywords: Water distribution system, rehabilitation, ELECTRE, PROMETHEE, ENTROPY.

1. INTRODUCTION

Water distribution systems are one of the vital and highly important urban infrastructures. The long-term design of a water distribution network is a complex and multi-purpose problem that includes economic, social, environmental, health, hydraulic and other technical issues. Water distribution systems experience aging and deterioration over time, resulting in many difficulties in ensuring water supply and causing the structural and hydraulic capacity of the water distribution system to decrease. In order to protect water resources, prevent excessive water consumptions, use the water effectively and increase efficiency, the continuity of water distribution systems in a controlled manner should be ensured. In multiple infrastructure systems, creating an effective and quality maintenance program, identifying possible risks and determining the amount to ensure

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efficient performance in the system rehabilitation and infrastructure system are very important for effective urban water management.

In recent years, various approaches have been used in designing and operating water distribution systems, rehabilitation of water distribution networks and prioritizing risky areas [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. Kim et al. [11] proposed the most appropriate timing model for damage-based rehabilitation and considered fourteen distortion factors to determine the repair, rehabilitation, change, time and cost of existing pipes. Le Gauffre et al. [12] developed a module for determining rehabilitation priorities, monitoring the performance of the networks, estimating the service life of the pipes and determining long-term strategy to ensure effective rehabilitation and annual rehabilitation programs. Shahata and Zayed [13] aimed to develop a model using Genetic algorithm, DELPHI-AHP, Artificial Neural Network methods for rehabilitation of water and wastewater systems, recommending an optimum change strategy, risk analysis and performance evaluation.

Tabesh and Saber [14] aimed to create an integrated model for rehabilitation priority in the water distribution network and to offer an integrated model that includes hydraulic, empirical and physical sub-models. As a result of the study, the effect of pipe length, age, pressure and infrastructure indexes on water network rehabilitation was determined. Atkinson et al. [15] used EPANET2 program and NSGAII genetic algorithm method to provide mechanical and hydraulic reliability in water distribution systems, to provide comparable multi-purpose cost optimization and to determine the location of new pumping and storage tanks. Choi and Koo [16] aimed to determine and predict pipe burst possibilities, calculate leakage time and repair time in case of service failure, provide water supply service satisfaction to customers, predict water shortages (depending on the location of pipes and valves). Kabir et al. [17] used the Bayes Network Model to measure and evaluate the failure risk of water distribution networks, provide a ranking for maintenance, rehabilitation, replacement stages, and compare the failure indices of very large diameter pipes and small diameter pipes. As a result of the study, information about the most sensitive and most risky pipe level was found and risk indices and percentages of summer and winter seasons were determined.

Al-Zahrani et al. [18] used fuzzy-based decision support system and Fuzzy AHP methods in Al-Khobar city of Saudi Arabia to protect structural integrity and hydraulic capacity and identify weak areas in the water network. As a result of the study, the region is divided into several sub-regions and it is emphasized that asbestos pipes in the region can cause serious health problems. El-Abbasy et al. [19] used the methods such as fuzzy analytical network process technique, PROMETHEE II, Analytical Hierarchy Process, Multiple Linear, Regression used Artificial Neural Network, in order to provide maintenance and rehabilitation of the infrastructure system, to improve, to determine the critical factors affecting the pipelines, to calculate the weight of these factors, to determine the impact value of each factor on the pipes and elements. Uncertainties between main and sub-factors and dependencies between critical factors were evaluated for water distribution networks. Kessili and Benmamar [20] measured 12 criteria on 47 projects for the Algerian sewerage network and a ranking order was established for sewage rehabilitation priorities using AHP and PROMETHEE II.

Especially in systems with high failure rate, pipe renewal works, which are a very costly way, are carried out. However, while renovating the entire water network at the same time creates significant costs for the Administration, on the other hand, it creates customer complaints due to excavation and construction works. For this reason, determining the priority region to be replaced in water distribution systems is very important in terms of reducing costs. In this study, it is aimed to determine the priority regions in network rehabilitation in water distribution systems to reduce the initial investment cost and prevent water losses and accordingly reduce the operating cost.

2. METHOD

2.1. ENTROPY METHOD

ENTROPY is used to calculate the weights of the determined criteria. The high value of the ENTROPY calculated for a criterion results from the small differences between the alternatives, indicating that this criterion is not very effective for decision making. Accordingly, the objective weights of the criteria are determined by how different the performance scores of the alternatives differ according to each criterion. In this method, the data matrix is created and standardized and indexes are made in the decision matrix to remove the effects of different index sizes for alternatives. In the decision matrix created, there are alternatives in rows and evaluation factors for each alternative in columns. The generated X data matrix (mxn size) and normalization are given by equations (1) and (2), respectively. Using these equations, each element in the X matrix is associated with the minimum and maximum values in the column where it is located. Criterion ENTROPY values are calculated using equation (3). With the help of this equation, the logarithm of each element in the R matrix is taken at the base e, and the values found are added together and multiplied by the ENTROPI coefficient (k) (equation 4) [21].

$$X = \begin{bmatrix} X_{11} & \dots & X_{1n} \\ & \ddots & \\ X_{m1} & \dots & X_{mn} \end{bmatrix} \tag{1}$$

$$r_{ij} = (x_{ij} - minx_j) - (maxx_j - minx_j) \tag{2}$$

$$E_j = -\mathrm{k} \sum_{\mathrm{j=1}}^{\mathrm{m}} r_{ij} * (\ln(r_{ij})) \tag{3}$$

i; alternative value, k; ENTROPI number $(\mathrm{k} = (\ln(\mathrm{n})) - 1)$, j: criterion value, r_{ij}: normalized value, w_j; weight value, x_{ij}; I. alternative j. shows the utility values given for the criterion. Calculated ENTROPY values (E_j) are subtracted from 1 and dj uncertainty is obtained (equation 4). By using the equation (5), the degree ENTROPY criterion weights are calculated as the importance degree of the j criterion.

$$d_j = 1 - E_j \;\; ; \forall_j \quad (\mathrm{i} = 1 \dots, \mathrm{m};\ \mathrm{j} = 1, \dots, \mathrm{n}) \tag{4}$$

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j};\ \forall_j \tag{5}$$

2.2. ELECTRE I

ELECTRE I, a multi-criteria decision making method proposed by Roy [22], ranks based on binary superiority comparisons for alternatives with the help of variables. In the ELECTRE I method, a prioritization relationship is created, concordance and discordant indices are calculated, alternatives are selected by creating harmony and incompatibility sets [23]. In this method, it is necessary to create a decision matrix (A) with alternatives in its rows and factors to be based on decision making in its columns (equation 6). Then, the normalized decision matrix (N) is calculated by dividing each element of matrix A by the square root of the sum of the squares of the column elements containing that element (Equations 7a and 7b).

$$A_{ij} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{6}$$

$$N_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{n} a_{ij}^2}} \qquad \text{i=1,2,…..,m ; j=1,2,….,n} \tag{7a}$$

$$N_{ij} = \frac{1/a_{ij}}{\sqrt{\sum_{i=1}^{n} 1/a_{ij}^2}} \qquad i=1,2,\ldots,m \;\; ; \; j=1,2,\ldots,n \tag{7b}$$

Weighted normalized decision matrix (Y) is obtained using the criteria in each column of the decision matrix and weights of that column (equation 8). The Y matrix is based on determining the sets of *concordance* (C_{kl}) ve *discordant* (D_{kl}) , each of the decision points are compared in terms of factors (equation 9). In ELECTRE method, each of the concordance corresponds to a set of the discordant (equation 10).

$$Y_{ij} = \begin{bmatrix} x_{11} * w_1 & \cdots & x_{1n} * w_n \\ \vdots & \ddots & \vdots \\ x_{m1} * w_1 & \cdots & x_{mn} * w_n \end{bmatrix} \tag{8}$$

$$C_{kl} = \{j,\ y_{kj} \geq y_{lj}\} \tag{9}$$

$$D_{kl} = \{j,\ y_{kj} < y_{lj}\} \tag{10}$$

Using the concordance set, the mxm-dimensional concordance matrix (C) is determined (equation 11). In addition, elements of the discordant matrix (D) with equation (12) are obtained [24].

$$C = \begin{bmatrix} - & c_{12} & c_{1m} \\ c_{21} & - & c_{2m} \\ c_{m1} & c_{m2} & - \end{bmatrix} \tag{11}$$

$$D = \begin{bmatrix} - & d_{12} & d_{1m} \\ d_{21} & - & d_{2m} \\ d_{m1} & d_{m2} & - \end{bmatrix} \tag{12}$$

$$d_{kl} = \frac{max_{j \in D_{kl}} |y_{kj} - y_{lj}|}{max_{j \in j} |y_{kj} - y_{lj}|} \tag{12a}$$

In this method, mxm dimensional concordance superiority matrices (F) are created by comparing the concordance threshold value ($\underline{C}$) with the concordance matrix (C_{kl}). The discordant superiority matrix (G) is created by comparing the concordance threshold value ($\underline{d}$) of the concordance matrix (D_{kl}) [24]. The values of the C_p are ranked from high to small, and the values of the D_p are ranked from small to high, and the final ranking is obtained by comparison [24].

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \tag{13}$$

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \tag{14}$$

$$C_p = \sum_{\substack{k=1 \\ k \neq p}}^{m} C_{pk} - \sum_{\substack{k=1 \\ k \neq p}}^{m} C_{kp} \tag{15}$$

$$D_p = \sum_{\substack{k=1 \\ k \neq p}}^{m} D_{pk} - \sum_{\substack{k=1 \\ k \neq p}}^{m} D_{kp} \tag{16}$$

2.3. PROMETHEE-II

PROMETHEE is a multi-criteria decision making method that makes binary comparisons by basing the alternatives on the preference functions together with the selected criteria [20]. In the PROMETHEE method, alternatives and their evaluation criteria are determined by decision makers. By determining the importance weights of alternatives, a dataset is created. The data matrix is created based on the determined criteria, alternatives and criterion weights. Preference functions are created according to the structure of the evaluation factors and the main features of the alternatives. The advantage of the PROMETHEE method over other multi-criteria decision making methods allows the decision maker to restrict the alternatives with these criteria and values determined by using these preference functions. Binary comparisons of decision points are made for each alternative with determined preference functions and common preference functions are determined. Equation (17 and 18) is used for the common preference function of two decision points created as A and B [20, 25].

$$\mathrm{P(a,b)} = \begin{Bmatrix} 0, & \mathrm{f(a)} \leq \mathrm{f(b)} \\ \mathrm{p[f(a),f(b)]}, & \mathrm{f(a)} > \mathrm{f(b)} \end{Bmatrix} \tag{17}$$

$$\mathrm{p[f(a),f(b)]} = \mathrm{P(x)} \tag{18}$$

$$\mathrm{P(x)} = \mathrm{f(a)} - \mathrm{f(b)} \tag{18a}$$

Preference indexes are determined for each alternative pair by considering common preference functions. In the data set of the alternatives, the preference indices of the a and b alternatives evaluated by the criterion k with a weight of w_i (i = 1,2,3,…, k) are calculated [25]. In this step, positive ϕ + (a) and negative ϕ- (a) superiorities are determined for alternatives.

$$\pi(\mathrm{a,b}) = \frac{\sum_{i=1}^{k} w_i * P_i(a,b)}{\sum_{i=1}^{k} w_i} \tag{19}$$

$$\phi + (\mathrm{a}) = \Sigma\pi(\mathrm{a,x}), \quad \mathrm{x} = (\mathrm{b,c,d,} \dots) \tag{19a}$$

$$\phi - (\mathrm{a}) = \Sigma\pi(\mathrm{x,a}), \quad \mathrm{x} = (\mathrm{b,c,d,} \dots) \tag{19b}$$

With PROMETHEE II, the final priorities of the alternatives are calculated, and as a result, a ranking is made according to the final priority value calculated for different alternatives.

$$\emptyset^{+}(a) = \frac{1}{n-1} \sum \pi(a,b) \tag{20}$$

$$\emptyset^{-}(a) = \frac{1}{n-1} \sum \pi(a,b) \tag{21}$$

3. STUDY AREA

In this study, Malatya province was chosen as the application area for the determination of priority regions in network rehabilitation. The population of Malatya province is 780.000 people, its area is 12.313 km² and it is between 35 54 'and 39 03' north latitudes and 38 45 'and 39 08' east longitudes. In order to identify high-risk pipes and ensure their rehabilitation, data from the field of application are provided. In the application area, 16 sub-regions (DMAs) whose boundaries are isolated from other network elements were created without changing the network pipe and 16 DMAs were selected for this study [26] (Figure 1). The isolated region is the water distribution networks that are created by dividing them into small independent water distribution networks in order to control the system more easily. In the defining the isolated regions; water demand, network length, population, number of customer, number of connection to the network and valves to be closed are taken into consideration. Data and maps of these regions selected were obtained in MASKI GIS environment.

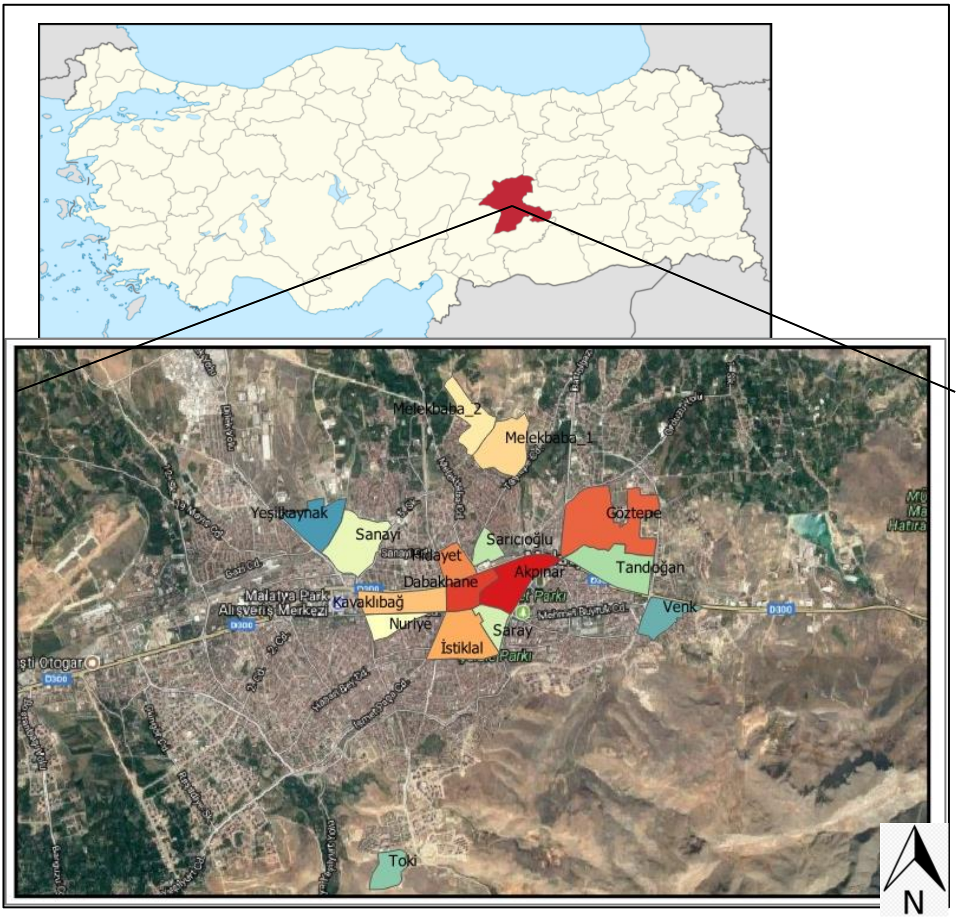

Figure 1. Application area and isolated regions (Gül, 2018; MASKİ, 2018)

4. FACTORS AND DATA

Effective factors have been identified for establishing a rehabilitation prioritization model and determining priority regions in the water distribution system. The determination of these factors is the decision maker in choosing the rehabilitation prioritization model and determining the current performance of the system. The weighted coefficients for the parameters affecting the water distribution systems will be calculated and the importance of these parameters on the system will be determined. This proposed model shows how effective each factor is in the deterioration in the water network and the increase in cost. Deciding on the rehabilitation of their networks is quite complicated due to the increasing number of factors affecting the system. For example, determining the physical parameters such as pipe age, pipe diameter, pipe depth and pipe material type used to evaluate the breakage of the pipes is very important in terms of improving the performance of the system. Therefore, these factors need to be explored separately in order to decide on rehabilitation priority. Risk management in the system will facilitate decision makers which variable should be emphasized for maintenance, repair and renewal. Data collection is the first step to determine rehabilitation priorities and to conduct risk analysis. In the literature, studies on failure analysis, water loss analysis, reduction and prevention of water losses, analysis and modeling of pipe damages in the network were examined in detail and it was observed that 156 different variables were used that would have an impact on network performance. However, using such a large number of variables in the model to be installed will increase the complexity of the problem and make it difficult to apply due to difficulty in collecting data. Therefore, in this study, variables were evaluated by considering four criteria (applicability, understandability, and measurability, comparability) to determine the current performance of the system and establish a decision model. As a result of these evaluations, the number of variables given in Table 1 was reduced to 28 in 156 [27]. MASKİ database was used for variables and data that are required, which may cause hydraulic, structural performance and failures [26, 27] (Table 2). Network length, number of customers, pipe diameter-age, pipe material type, operating factors and environmental factors for each region were obtained from the GIS database. The number of failures, water demands and operational data in the regions were also provided in the automation system. The ground properties map of the study area was obtained from MASKI General Directorate. Traffic intensity changes were based on the study carried out by Boztaş [28] (2017) and grouping was made taking into account the street widths. Important structures were determined by considering GIS building data and MASKI customer database.

Based on the studies examined in the literature, low traffic is 1; very heavy traffic is scaled to 3. The ground properties of DMAs are examined and divided into two as mobile and average grounds according to the type of land. In the studies conducted in the literature, some features of the water distribution system are scaled by decision makers [29]. Based on the studies examined in the literature, the average ground load is 1 by decision makers; the aggressive ground is scaled as 2.

Table 1. Variables considered in the study

Factors	Description
Total Network Length (m) (D1)	Depending on the network length, the number of connections, the rate of failure increases, and the system replacement cost is high.
PVC pipe rate (%) (D2)	Selecting the appropriate pipe material significantly affects the performance of the system.
Asbestos pipe rate (%) (D3)	
Pipe diameter <100 (mm) (D4)	If the pipe diameter is not selected properly, it increases the pressure loss in the pipe and shortens the life of the installation.
Pipe diameter 100 -250 mm (D5)	
Pipe diameter >250 mm (D6)	
The number of network failure (D7)	Faults in the mains and service connections cause the structural and hydraulic capacity of the distribution system to decrease. Detection of faults occurring in the network is a priority parameter in rehabilitation works. Since unreported leaks do not come to the surface, unless they are detected in the field, there is a great loss of water and maintenance-repair-operation costs increase.
Network failure rate (failure/year/km) (D8)	
The number of service connection failure (D9)	
Failure rate in service connection (failure/year /km) (D10)	
The number of customers (D11)	
The number of unreported leakage (D12)	
Pipe rate > 20 year (%) (D13)	Pipe age is one of the most important factors that affect faults.
The number of service connections (D14)	A significant part of the malfunctions are observed in the service connections and have an impact on operating costs.
The number of water interruptions in a year (D15)	The high number of water interruptions occurring in a region reduces the quality of service.
Topography (D16)	Topography can cause particularly pressure differences to occur and, accordingly, to increase the risk of failure.
Soil characteristics (D17)	It represents the ground feature of the region.
Street class (<20 m, >20 m %) (D18)	It refers to the width of the street served by the pipes.
Important customers (Hospital, School) (D18)	Hospitals, schools, in the region greatly increase the rate of water consumption. It is important that the water interruptions is minimal in the regions.
Traffic density (D20)	It is an effective parameter for damages that may occur on the pipe. It significantly affects pipe cracks and failures.
Pipe rate repaired (%) (D21)	It represents the proportion of pipes replaced on the street depending on the failure.
The number of valves defined (D22)	The valves are one of the elements that ensure the safe operation of the network, which helps to evacuate the system in case of failure.
Operating pressure (D23)	Pressure fluctuations and changes in the system cause pipe damage, excessive pressure affects the system negatively.
Water loss rate (%) (D24)	Water losses have an impact on operating and water production costs.
Operating cost (TL/year) (D25)	
Population (D26)	Represents the population served.
Water demand in a year (m^3/year) (D27)	Water demand refers to the amount of water needed by a certain population over a period of time. Water losses can be reduced by appropriate rehabilitation methods in the lower measurement areas.
Water demand (l/person. Day) (D28)	

Table 2. Data related to factors in regions

DMA ID and Name		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
DMA 1	Hidayet	4350	72.4	22.1	0.66	94.53	4.81	70	1.61	207	4.76	1405	10	78.5
DMA 2	Sarıcıoğlu	7543	61.3	20.7	0.45	67.67	31.88	63	0.84	78	1.03	1321	14	62.8
DMA 3	Saray	7991	83.5	2.9	0.76	86.43	12.81	148	1.85	112	1.40	2515	8	85.3
DMA 4	Kavaklıbağ	6705	74.8	19.6	1.68	89.43	8.89	228	3.40	37	0.55	2832	36	54.0
DMA 5	Dabakhane	9710	43.7	29.6	2.81	55.84	41.35	221	2.28	91	0.94	2872	44	76.4
DMA 6	Toki	27383	46.1	17.3	15.97	72.85	11.20	7	0.03	28	0.10	1565	0.1	83.0
DMA 7	Yeşilkaynak	29778	83.5	14.1	0.78	96.10	3.12	128	0.43	54	0.18	770	7	75.3
DMA 8	Akpınar	19798	71.2	20.2	10.90	82.74	6.37	336	1.70	54	0.27	4507	29	67.9
DMA 9	Nuriye	13205	57.5	25.1	0.23	76.29	23.47	194	1.47	44	0.33	2446	6	51.7
DMA 10	Venk	5004	87.3	2.9	1.94	95.04	3.02	98	1.96	91	0.10	1282	0.1	85.7
DMA 11	İstiklal	14825	46.4	17.0	14.05	74.13	11.81	339	2.29	137	0.92	5655	35	87.0
DMA 12	Tandoğan	2739	0.1	0.1	1.24	98.76	0.10	181	6.61	184	6.72	2382	21	0.1
DMA 13	Göztepe	13386	72.2	16.1	1.38	88.32	10.29	330	2.47	159	1.19	2836	20	80.1
DMA 14	Sanayi	19543	31.1	7.6	10.50	61.73	27.78	210	1.07	76	0.39	1510	36	32.3
DMA 15	Melekbaba1	19122	74.7	11.7	1.74	96.85	1.41	93	0.49	190	0.99	1183	2	53.8
DMA 16	Melekbaba2	22775	55.9	14.3	15.91	76.44	7.65	102	0.45	190	0.83	604	4	77.6

Table 2. Data related to factors in regions (cont.)

DMA	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28
DMA 1	301	12	0.9	2	1.6	3	2	8	12	55	33.29	48054	6565	160358	66.9
DMA 2	315	10	1.2	2	0.75	1	1	5	23	52	76.27	50154	4121	136660	90.9
DMA 3	454	8	2.4	2	0.85	3	1	4	23	58	45.29	72389	2883	137149	130.3
DMA 4	522	18	2.5	2	1.39	6	2	17	27	42	39	83433	988	8.645	24.0
DMA 5	510	3	1.6	2	1.07	1	1	3	14	51	36.87	81349	3391	300900	88.7
DMA 6	380	26	0.1	1	1.49	4	2	15	32	40	30.57	4.06	10457	321888	84.3
DMA 7	537	73	2.9	2	0.96	1	2	20	27	62	56.22	85343	2506	80668	88.2
DMA 8	678	7	2.1	2	0.75	5	1	14	21	58	34.69	107935	1683	250.359	407.6
DMA 9	384	10	3.8	2	1.07	2	1	15	24	41	35.42	61212	2927	262174	245.4
DMA 10	527	28	5	1	0.85	4	2	25	37	44	32.79	310	21186	1127945	145.9
DMA 11	1179	6	3.5	2	0.75	6	1	2	74	41	56.44	187588	5241	282987	147.9
DMA 12	829	48	2.6	2	0.75	1	1	45	72	46	32.81	132694	8440	458237	148.7
DMA 13	1467	37	3.8	2	0.85	5	2	10	65	59	53.69	233351	9207	376041	111.9
DMA 14	1054	22	1.6	2	0.85	1	1	15	28	56	57.24	167545	3545	331341	256.1
DMA 15	949	19	6.6	1	0.96	4	1	25	40	43	68.29	150778	5204	202057	106.4
DMA 16	575	36	4.3	1	1.07	1	1	5	10	45	68.29	91381	6928	202057	79.9

5. ANALYSIS AND EVALUATION

5.1. DETERMINATION OF WEIGHTS

Since the effect and importance of the variables that affect a system are not equal, the weight coefficients of each variable should be determined and examined. To achieve the best rehabilitation scheme, the effects of the combination of different rehabilitation schemes should be explored. By determining the significance coefficients of the variables, various distortions and system performance analyzes can be made on the pipes. In the proposed model, each parameter is considered as an input and the order of importance is determined in order to determine the priority of rehabilitation. In this study, ENTROPY, ELECTRE I and PROMETHEE II methods were used to renew water distribution systems based on hydraulic variables in determining and prioritizing risky areas in system. With these methods, MATLAB based decision support system has been developed in order to perform the analysis easily. The developed system can prioritize the water distribution system for 16 regions in order of risk. Detailed data of the application area (network, water consumption, fault records, physical data of the region, pipe type, number of failures, and average age of the pipe, average population, average pressure, ground feature, and operating cost) were obtained. The weights of the criteria were determined using the software developed later by the ENTROPY [27] (Table 3). ENTROPY is an objective evaluation method since it calculates the weight of the criteria by taking the data of the decision makers into consideration in determining the importance levels of the criteria without creating a hierarchical structure in multi-criteria decision making problems.

Table 3. Criterion weights determined by ENTROPY method

Criteria	Weights	Criteria	Weights
Network failure rate (failure/year/km) (D8)	**0.0536**	The number of service connections (D14)	0.0192
The number of service connection failure (D9)	**0.0266**	PVC pipe rate (%) (D2)	0.0169
Failure rate in service connection (failure/year /km) (D10)	0.1095	Asbestos pipe rate (%) (D3)	0.0317
Pipe diameter <100 (mm) (D4)	0.1071	Traffic density (D20)	0.0103
Pipe diameter 100 -250 mm (D5)	0.0022	Pipe rate repaired (%) (D21)	**0.04511**
Pipe diameter >250 mm (D6)	**0.0663**	The number of valves defined (D22)	0.0277
The number of customers (D11)	0.0274	Operating pressure (D23)	0.0019
The number of network failure (D7)	0.0311	Water loss rate (%) (D24)	0.0120
Leakage amount (D12)	**0.0677**	Operating cost (TL/year) (D25)	**0.0420**
Pipe rate > 20 year (%) (D13)	0.0157	Population (D26)	0.0446
The number of water interruptions in a year (D15)	**0.0489**	Water demand in a year m3/year (D27)	**0.0477**
Topography (D16)	0.0304	Water demand l/person*day (D28)	0.0315
Total Network Length (m) (D1)	0.0298	Soil characteristics (D17)	0.0059
Important customers (Hospital, Scholl etc.) (D18)	0.0409	Street class (<20 m, >20 m %) (D18)	0.0056

According to the table, the highest weight coefficient was obtained for the unreported leakage determined by active leak control. In addition, it is observed that the weight coefficient calculated for the failure rate (service connection and network) variable is quite high. In systems with high unreported leaks, significant cost items such as monitoring the network, detecting and repairing leaks occur, and unless these leaks are detected, the rate of physical loss increases. For this reason, the high rate of breakdown and unreported leaks increase the water loss rate and operating cost and disrupt normal operating conditions. Therefore, it can be said that these results are similar to the nature of the problem. According to the results in the table, it can be said that the coefficient calculated for the annual water interruption number resulting from the failure rate and leaks not reported is also high. In regions where water interruptions are high, the desired amount of water is not regularly transmitted to subscribers, thus creating a socially negative impact. In addition, since the system is exposed to sudden pressure changes continuously, in the system where there is a continuous interruption, negative results such as the occurrence of new failures and leakages and an increase in operating costs occur. Another variable with a high weight coefficient is the percentage of renewed pipes in the region. Since this variable shows the street-based pipe replacement rate depending on the failure rate, the pipe replacement rate will increase in the regions where the fault is frequently observed and therefore the system cost will increase. It is not possible to bring long-term solutions since the application performed in this way will produce solutions locally and will not provide material integrity. As a result, it can be said that the calculated weight coefficients are compatible with the physical structure of the system and the representation rate of the variables reflects the nature [27].

5.2. DETERMINATION OF PRIORITY REGIONS

The ELECTRE I method ranks alternatives based on binary superiority comparisons based on specific criteria. The analysis was made with the ELECTRE I method using the field data of the DMAs and the weight coefficients calculated with the ENTROPIY method. Similarly, based on the field data and weights of the regions, the analysis was carried out with the PROMETHEE II method and ranking was performed. The C and D matrices of the ELECTRE I method were obtained in the MATLAB environment, and the precise regions of concordance and discordant were determined with the help of the total dominance matrix (E) created based on binary comparison. According to the results obtained, regions such as, DMA 13, DMA 11, DMA 12, DMA 14 and DMA 5 are the regions with rehabilitation priority, while DMA 9, DMA 2 and DMA 3 are regions that are in better condition than other regions [28] (Table 4). On the other hand, PROMETHEE-II method establishes negative and positive superiority relations regarding decision points, and determines the priority regions by comparing decision points. DMAs are listed according to the PROMETHEE-II method by following the procedure steps given in the method section (Table 5).

Table 4. Final Ranking of Regions by ELECTRE I Method

DMA	Result	Ranking	Net Concordance Matrix (C)		Net Discordant Matrix (D)	
			DMA	Result	DMA	Result
DMA 13	5.74	**1**	DMA 13	5.74	DMA 12	-9.58
DMA 11	5.02	**2**	DMA 11	5.02	DMA 11	-5.96
DMA 12	3.03	**3**	DMA 12	3.03	DMA 1	-5.37
DMA 14	2.08	**4**	DMA 14	2.08	DMA 14	-4.97
DMA 5	1.34	**5**	DMA 5	1.34	DMA 16	-4.60
DMA 8	0.61	**6**	DMA 8	0.61	DMA 6	-3.40
DMA 15	0.12	**7**	DMA 15	0.12	DMA 5	-2.65
DMA 4	0.11	**8**	DMA 4	0.11	DMA 8	-2.59
DMA 16	-0.54	**9**	DMA 16	-0.54	DMA 10	0.79
DMA 7	2.89	**10**	DMA 10	-0.83	DMA 7	2.89
DMA 10	-0.83	**11**	DMA 3	-1.54	DMA 2	3.19
DMA 6	-1.95	**12**	DMA 6	-1.95	DMA 4	3.99
DMA 1	-2.54	**13**	DMA 1	-2.54	DMA 13	4.22
DMA 9	6.67	**14**	DMA 9	-2.94	DMA 9	6.67
DMA 2	-3.77	**15**	DMA 2	-3.77	DMA 15	8.59
DMA 3	8.77	**16**	DMA 7	-3.95	DMA 3	8.77

Table 5. Final Ranking of the PROMETHEE II Method Regions

DMA	Result	Ranking
DMA 13	0.3786	1
DMA 11	0.2405	2
DMA 12	0.0833	3
DMA 8	0.0476	4
DMA 15	0.0452	5
DMA 14	0.0452	6
DMA 4	0.031	7
DMA 10	0.0214	8
DMA 7	-0.031	9
DMA 5	-0.0333	10
DMA 3	-0.0571	11
DMA 16	-0.0762	12
DMA 1	-0.0976	13
DMA 9	-0.1357	14
DMA 6	-0.1857	15
DMA 2	-0.2762	16

According to the results obtained, regions such as, DMA 13, DMA 11, DMA 12, DMA 8 and DMA 15 are the regions with rehabilitation priority, while DMA 9, DMA 6 and DMA 2 are regions that are in better condition than other regions. When the results obtained by these two methods are compared, it is seen that the first region with the priority of rehabilitation is common (DMA 13, DMA 11 and DMA 12). It is aimed to provide efficient and effective management of infrastructure systems, to rehabilitate risky pipes, to observe historical data in a water network and to add new data, to create a combination of renewal repair and change by producing different scenarios in water network rehabilitation, and to provide rehabilitation of water networks at an affordable cost. It is thought that this study will form and contribute to the rehabilitation works to be carried out in water networks. The outputs from this study are considered to be a reference for the Water Administrations and Municipalities. In addition, it is thought that determining the most risky regions in the network and starting rehabilitation from the most risky regions will provide significant gains and contributions in terms of using resources (water resource, personnel and workman, financial resources) more efficiently.

6. RESULTS

In this study, it is aimed to determine the priority regions for rehabilitation in distribution systems in order to prevent water losses. For this purpose, applications were carried out for 16 regions in Malatya province's water distribution system. A total of 28 variables were determined and ENTROPY method was applied to calculate the weights of each variable. The highest weight coefficient was obtained for the unreported leakages determined by active leakage control. In addition, it was observed that the weight coefficient calculated for the failure rate (service connection and network) variable on the surface is quite high. The high rate of breakdown and unreported leaks increase the water loss rate and operating cost and disrupt normal operating conditions. Therefore, it can be said that these results are similar to the nature of the problem. The weight of the number of annual water interruption is also high. In the system where there is a continuous interruption, since the network elements will be constantly exposed to sudden pressure changes, negative results such as the occurrence of new malfunctions and the increase in operating costs arise. Based on the weight coefficients calculated in the study and field data of the variables, priority regions in rehabilitation were determined by ELECTRE I and PROMETHEE II methods. According to the results obtained with the ELECTRE I method, DMA 13, DMA 11, DMA 12, DMA 14 and DMA 5 regions were determined as the first 5 regions with rehabilitation priority. On the other hand, according to the results obtained with the PROMETHEE II method, the first 5 regions with rehabilitation priority were DMA 13, DMA 11, DMA 12, DMA 8 and DMA 15. When the results obtained by these two methods are compared, it is seen that the first region with priority of rehabilitation is similar. It is aimed to provide efficient and effective management of infrastructure systems, to rehabilitate risky pipes, to observe historical data in a water network and to add new data, to create a combination of renewal repair and change by producing different scenarios in water network rehabilitation, and to provide rehabilitation of water networks at an affordable cost. The similarity and compatibility of the results of two different methods applied in this study can be evaluated as follows; choosing the variables correctly, representing the field of the data of these variables, determining the weights with the field data, determining the priority regions based on these weights etc. It is thought that these outputs will serve as a reference for the Water Administrations, determining the most risky regions in the network and starting rehabilitation from the most risky regions will provide significant gains and contributions in terms of using resources (water resource, personnel and workforce, financial resources) more efficiently. Priority regions in rehabilitation are especially important in terms of planning investment programs and pipe material management. In addition, it is considered important to determine long-term network management and pipe replacement programs in Water Administrations considering many factors, and long-term planning of the regions to be invested. In the next stage of this study, the economic life estimation and determination of the priority regions according to the failure rates, pipe age and water loss rates in the next 5, 10 and 15 years will offer important gains for practitioners and researchers.

Acknowledgement

This study was produced from Master of Science Thesis completed by Şeymanur GÜL in 2018. The authors thank Malatya Metropolitan Municipality Water and Sewerage Administrative General Directorate for technical support and Inonu University, Scientific Research Project Funding (IUBAP) for their financial support [Project number: IUBAP 2017/583].

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