Sustainable Cities and Society 42 (2018) 13–21

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Evaluation of technical performance of pipes in water distribution systems by analytic hierarchy process

Yusuf Kilinç[a], Özgür Özdemir[b], Cansu Orhan[c], Mahmut Firat[d,*]

[a] Ministry of Forestry and Water Management, Malatya Regional Directorate, Turkey
[b] Malatya Water and Sewage General Directorate, Malatya, Turkey
[c] Master of Science Student, Inonu University, Civil Engineering Department, Malatya, Turkey
[d] Inonu University, Civil Engineering Department, Malatya, Turkey

A R T I C L E I N F O

Keywords:
AHP
Water distribution system
Pipe performance
Performance evaluation

A B S T R A C T

Pipes with in poor condition in water distribution systems cause significant operational problems and water losses. Therefore, it is important to evaluate the technical performance of these pipes. In this study, the evaluation of technical performance of the individual water pipes by Analytic Hierarchy Process (AHP) according to various main-factors such physical, environmental and operational and sub-factors is aimed. The weight coefficients for the physical, environmental and operational main factors were calculated as, 0.43, 0.14 and 0.43, respectively. Physical Factor Score (PFS), Environmental Factor Score (EFS) and Operational Factor Score (EFS) were calculated to define the technical evaluation score of the water pipes. Finally, the Performance Evaluation Score (PES) was calculated using the weights and scores of the PFS, EFS and OFS and applied for 17 individual water pipes selected for testing the technical performance. It was determined that the structural condition and performance of ACP and PVC pipes was bad and the risk of damage was high. It is considered that the AHP model developed may be an important tool in the technical evaluation of pipes for water supply utilities.

1. Introduction

The pipe elements that already provide the service in water distribution system are damaged due to various factors. The leakage and water loss occur as a result of these failures or damages. Therefore, it is quite important to evaluate the technical performance of the pipes providing service in older water distribution systems and to replace the pipes having the potential damage risk. In practice, breakdown repair is performed at the local point, which is the fault point, rather than the street-based pipe rehabilitation policy in general. This leads to an increase in water losses and operational costs of the system. A lot of studies related in literature for estimating the failure rate and leakage and for analyzing the pipe risk and water losses etc. were carried out considering different methods and factors (Sargaonkar, Kamble, & Rao, 2013).

de Oliveira, Neill, Garrett, and Soibelman (2011) analyzed the physical condition of the network and the failure records to optimize the inversments in the physically poor condition network which have completed the life cycle and should be replaced. Tsitsifli, Kanakoudis, and Bakouros (2011) emphasized the importance of risk assessment methods such as monitoring, repairing and replacing materials in water distribution system as well as observation data to obtain more precise results. In their study, they aimed to predict possible failures in the network using the analysis and classification methods.

On the other hand, the AHP method has been applied in water resources management and urban infrastructure systems (Fraga, Medellin-Azuara, & Marques, 2017), water resources management (Buschke & Esterhuyse, 2012; Yilmaz & Harmancioglu, 2010), assessing the drought risk (Palchaudhuri & Biswas, 2016), managing the urban drainage system (Benzerra, Cherrared, Chocat, Cherqui, & Zekiouk, 2012), water quality assessment (Islam, Sadiq, Rodriguez, & Legay, 2016), prioritization of the watersheds (Chowdary et al., 2013), evaluating the groundwater pollution risk (Sener & Sener, 2015), designing the groundwater level network (Singh & Katpatal, 2017), selection of water port (Zavadskas, Turskis, & Bagočius, 2015), urban land-use planning (Mosadeghi, Warnken, Tomlinson, & Mirfenderesk, 2015). Ennaouri and Fuamba (2013) revealed the factors affecting the physical condition of sewerage systems and deterioration states of sewerage system according to hydraulic and structural characteristics. For this aim, a total of 15 factors were defined and analyzed using AHP method. The sewer pipe elements were evaluated based on the main and subfactors used in the analysis.

* Corresponding author.
E-mail address: mahmut.firat@inonu.edu.tr (M. Firat).

https://doi.org/10.1016/j.scs.2018.06.035
Received 18 March 2018; Received in revised form 26 June 2018; Accepted 26 June 2018
Available online 28 June 2018

Mamo, Juran, and Shahrour (2013) aimed to identify the maintenance strategies of the pipes in water distribution system that completed their useful life or need repair. In their study, the optimum maintenance strategies with minimum cost at repair and maintenance were developed using Fuzzy AHP methodology. Choi and Koo (2015) developed a risk evaluation model for water pipes in water distribution system to evaluate the failure probability, effect of failures on pipes and carry out risk assessment. Francisque et al. (2014) applied a decision support tool to prioritize the maintenance-repair or replacement strategies of water pipes. For this aim, a risk index approach was defined to help the managers for assessing the system performance several variables such as system failure, water quality, hydraulic capacity etc. Pagano, Giordano, Portoghese, Fratino, and Vurro (2014) proposed a methodology based on Bayesian Belief Networks to assess the vulnerability of water mains under extreme events. Zhang et al. (2014) applied fuzzy-AHP method to evaluate and monitor the Shield tunnels. They focused that the proposed fuzzy-AHP model will be useful for clarifying the tunnel health evaluation to both designers and administrators. Marlow, Gould, and Lane (2015) developed and proposed a model based on the decision support methodology for assessing the technical and economic risks of rehabilitation options of CI pipes. Kessili and Benmamar (2016) defined a total of 12 factors such as the structural, hydraulic, environmental, financial, social and technical for rehabilitation works of sewerage systems. They aimed to define the priority rank of regions to be rehabilitated by taking into account the factor weights calculated using AHP method. Rahmati, Zeinivand, and Besharat (2016) proposed and applied an integrated methodology covering the AHP and Geographical Information System methods to define the critical areas for flood risk by considering various factors.

In this study, the evaluation of technical performance of the individual water pipes that already provide the service in water distribution systems using AHP method which is a multi-criteria decision analysis or decision method based on various factors such as physical, environmental and operational was aimed.

It is the strength of this study to evaluate the performance of pipes providing service in terms of physical, operational and environmental main factors and many sub factors, to group the sub factors and determine the weight coefficients and to form the evaluation structure accordingly. It is thought that the technical evaluation of the performance of the pipes will provide important benefits as follows; determination of the pipes which may be faulty or damaged potential, prioritization of the pipes in bad condition, prevention of water losses and reduction of operating costs by replacing pipes with failure risk etc.

2. Study Area

The water distribution system of the central Malatya city was selected as the study area. Malatya city has a surface area of 12.313 km^2 and total population of 769.544 people. The general view of the study area is shown in Fig. 1. Malatya is a developing city where the constant increase in the current population increases the need for water from day to day, and with the increasing drought in recent years. On the other hand, the flow rate of water resource has fallen and the water loss at water supply and distribution systems has become even more important.

The pipe elements in the application area are damaged according to the pipe characteristics such as pipe age, pipe material, pipe physical condition and the environmental factors such as soil type, traffic intensity, (the daily number of faults is about 30) and accordingly the non-revenue water ratio is observed at the level of 60%. This shows that the pressure resistance of the pipe elements is reduced and accordingly the economic life span. Therefore, it is very important to assess the technical performance of the pipe elements providing service at water distribution system by taking into account the various factors such as physical (e.g. pipe age, material, diameter and length), environmental (e.g. soil type, traffic, road conditions etc.) and operating (e.g. system pressure, number of water interruptions, failure rate etc.).

3. Method: analytic hierarchy process (AHP)

Multi-criteria decision analysis or decision making method could be explained as an approach that considers all variables or factors, which can be effective on the problem, and tries to put out the effect of these variables on the problem. In this study, Analytic Hierarchy Process (AHP) approach proposed by Saaty (1980) was applied for evaluation of technical performance of individual water pipes in water distribution system (WDS). Saaty (1980) proposed that a methodological procedure should be followed in order to apply the AHP method to the any problems. For this aim, a flow chart created for this study is shown in Fig. 2.

As mentioned in a lot of studies in the literature, one the most important steps in the AHP methodology is to define the main target. The first step to reach the defined target can be stated as identifying the factors and sub-factors related to the problem. The other important step in the AHP methodology can be illustrated as the definition and creation of hierarchical structure and its components. For this, the model structure is established according to the main and sub-factors defined for the problem. The weight coefficients and scores of the main and sub-factors were taking into account in calculating the performance evaluation score.

Standard values of relative importance between factors proposed by Saaty (1980) (Table 1) are used for composing the pairwise comparison matrices.

The relative importance of the main factors and sub-factors defined for this study are determined using standard scoring values given in Table 1 and the pairwise comparison matrices for all factors are composed taken into account the expert opinions. The sample form given for the main factors (Fig. 3) was used for composing the pairwise comparison matrices given in the flow chart (Fig. 2) and created according to expert opinions. Experts were asked to compare the factors with each other and their superiority relative to each other according to the criteria given in Table 1.

All sub factors are compared by experts according to the form in Fig. 3, based on the degree of relative importance shown in Table 1. The comparison matrices for all factors defined according to flow chart given in Fig. 2 can be written as in Eq. (1).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & \cdots & 1 \end{bmatrix} \tag{1}$$

The weight coefficients of all main and sub-factors constitute the most important component for calculating the rating scores and for evaluating the technical performance of individual water pipes. The weight coefficients are calculated based on pairwise comparison scores of these factors. For this aim, the sum of the pairwise comparison matrices and calculation of the weights are given in Eqs. (3) and (4), respectively (Ennaouri & Fuamba, 2013). In these equations, N is the numbers of factors to be compared in problem and the term of b_{ij} can be written as $b_{ij} = \frac{a_{ij}}{C_j}$.

Matrix B is formed by dividing the elements by the sum of the columns for the column that expresses an evaluation factor in the binary comparison matrix (Eq. (2)).

$$B = \begin{bmatrix} \frac{1}{1 + a_{21} + \cdots + a_{n1}} \\ \frac{a_{21}}{1 + a_{21} + \cdots + a_{n1}} \\ \vdots \end{bmatrix} \tag{2}$$

a_{ij} is the each element of the pairwise comparison matrix, b_{ij} is the each element of the preference matrix. The calculations are repeated for the other evaluation factors (columns) and matrix C called the standard