Benefit And Cost Analysis of Network and Service Connection Renewal In Distribution Systems For Sustainable Water Loss Management

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Water distribution network, Network renewal, Cost analysis, Benefit analysis

Abstract

Reducing the rate of non-revenue water (NRW) in water distribution systems (WDSs) has become one of the most important goals for utilities. Increasing water losses bring along social, economic and technical difficulties, which accelerates the work to be done to reduce water losses. Although water losses are managed by applying active and passive leakage methods, in some cases it may not be economical for the utilities to manage the network under current conditions and to continue the efforts to reduce water losses. The aging network and its equipment can now make it difficult to manage this system. In these cases, the method of rehabilitating the whole or partial parts of the network is applied. Due to the high level of pipe material, labor and construction costs, a detailed cost-benefit analysis and alternative solutions should be evaluated before the network renewal approach is preferred. The main purpose of this study is to define the cost benefit structure of the main line and service connection renewal in WDSs. For this aim, current failure rates, the cost components of the operation, maintenance and repair, water supply and energy, initial investment is considered. The current costs and benefits that will be encountered in case of renewal of the entire network (network + service connection), only subscriber lines or only network lines for a sample network are discussed. The results show that it is that the rehabilitation method to be chosen for different network conditions has a serious effect on increasing the planned benefit.

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1. INTRODUCTION

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In distribution systems (WDS), leaks are observed at different rates depending on physical, operational, environmental and hydraulic factors (Yilmaz et al., 2022). Depending on the malfunction and water losses, the operation of the network deteriorates and service quality decreases. Annual leakage rates in WDSs are between 25 and 30% (EU Commission, 2014), and the non-revenue water ratio is approximately 30% (Liemberger & Wyatt, 2019). A significant part of water resources is lost due to leaks in WDSs. In developed countries, the volume of these leaks is seen to be between 3 and 7% of the water provided, while in developing countries there is more than 50% leakage (Moslehi et al., 2021). In our country, the average water loss ratio is 42% (SUEN, 2020). Preventing and managing physical losses provides significant contributions in terms of water and energy efficiency, postponing the search for new resources, efficient use of energy and water resources, and reducing malfunction repair activities and costs. In the literature, it can be seen that many different methods are generally applied to monitor, prevent and control physical losses. These methods or tools have generally high costs including the equipment and labor, and require technical, technological and personnel infrastructure to be implemented in the field (Lambert et al., 1999; Haider et al., 2019; Salehi et al., 2017; Firat et al., 2021). Dighade et al. (2014) made an evaluation within the framework of the problems faced by developing countries in leakage management, inadequate infrastructure, metering policy, water delivery hours and operation pressure. It was stated that, first of all, the physical and operating characteristics of the existing network should be evaluated. The "network renewal" method, which involves replacing pipes and other fittings in the network and generally costs more than other active leak control methods, is preferred in many cases. However, failure rates under current network conditions, operation, failure repair costs, new resource and energy costs should be taken into consideration, and in case of network renewal, the initial investment and medium and long-term operating costs should be considered (Mamo et al., 2013; Al-Zahrani et al., 2016). Before choosing the network renewal method, a detailed cost-benefit analysis should be made and alternative solutions should be evaluated. The impact of environmental and operational factors that cause leakage should be reduced. It is emphasized that if the expected benefits cannot be obtained from these methods, determining priority regions in grid renewal will make significant contributions in terms of resource efficiency (Park & Loganathan, 2002; Suribabu & Neelakantan, 2012; Venkatesh, 2012; Mondaca et al., 2015; Francisque et al., 2017). Pipe material management and network renewal should be considered with extending the economic life of pipes and postponing renewals.

Analyzing the factors that cause pipe damage in the network, reducing their effects and identifying the areas where damage occurs despite all prevention methods are important for efficiency. Tee et al. (2014) proposed an operation plan with budget, maintenance and renewal options, and the service life of the network. The best fit renewal option was defined by minimizing the risk of failure and the life cycle cost of the pipe with the help of genetic algorithm. Loganathan et al. (2002) aimed to define an economically sustainable fault rate threshold value for economical operation of the system and management of faults in network management. Maintenance, repair and renewal costs and the inflation rate were considered. There is a significant relationship between pipe diameter and failure rate threshold value. Zangenehmadar (2016) developed an estimation model for analyzing economic life of the pipes in drinking water networks according to the available budget. A statistical model has been proposed to predict the current state of a pipeline. Carriço et al. (2021) presents a MCDA support methodology for the selection and prioritization of the region and network to be rehabilitated in a WDS. It is suggested that before the network renewal and rehabilitation works, the current status of the network should be taken into consideration and a benefit/cost analysis should be carried out. Hu et al. (2021) emphasized that due to rapid urbanization, drinking water networks are often created without planning. For this reason, a very serious planning and project phase should be carried out before the drinking WDS is physically implemented in the field. While the network is applied to the field, the network life is shorter and the operating cost increases due to reasons such as inadequate engineering services, lack of control, and incorrect manufacturing. The main purpose of this study is to define the cost benefit structure of the main line and service connection renewal in WDSs. The current failure rates, the costs of the operation, maintenance and repair, water supply and energy, initial investment is considered. The current costs and benefits that will be encountered in case of renewal of the entire network, only subscriber lines or only mains for a sample network are discussed. The results show that the rehabilitation method to be chosen for different network conditions has a serious effect on increasing the planned benefit.

2. WATER LOSSES AND COMPONENTS

Water losses including the real and apparent losses refer to the loss given to the WDS. While some of the water supplied to the system is consumed by legal users, the remaining part constitutes water losses. Water losses cause loss of income for the administration and constitute the most important component of water resource inefficiency. The "standard water balance" was recommended by International Water Association to determine the amount and rate of water loss (Table 1). Water loss volume is obtained by subtracting the legal consumption volume from the system inlet volume. Apparent losses refer to the water supplied to the system and consumed by legally registered subscribers and/or unregistered users, but for which no fee is collected.

Table 1. IWA standard water balance

<table>
<tr><td rowspan="10">System Input Volume</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed authorized consumption</td><td>Billed metered consumption</td><td rowspan="2">Non-revenue water</td></tr>
<tr><td>Billed unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled authorized consumption</td><td>Unbilled metered consumption</td><td rowspan="8">Revenue water</td></tr>
<tr><td>Unbilled unmetered consumption</td></tr>
<tr><td rowspan="6">Water losses</td><td rowspan="3">Apparent losses</td><td>Illegal consumption</td></tr>
<tr><td>Losses due to meter inaccuracies</td></tr>
<tr><td>Losses due to reading errors</td></tr>
<tr><td rowspan="3">Real losses</td><td>Leakages in transmission and WDSs</td></tr>
<tr><td>Leakages in reservoirs</td></tr>
<tr><td>Leakages in service connections</td></tr>
</table>

Leakages express the volume (m^3/year) of leakage according to failures occurring due to various factors or overflows and cracks in tanks. This component constitutes a significant part of the volumetric water losses. Apparent and real losses are analyzed or estimated based on authorized consumptions and input volumes. In Türkiye, the "Control of Water Loss in Drinking Water Supply and Distribution Systems" regulation was published in 2014. This regulation aims to use water resources more effectively and efficiently, and monitor the performance. Basic methods such as pressure management, pipe material management, fault repair speed and quality and active leakage control are applied. Fault repair speed and quality refers to the rapid and high-quality repair of faults after locating reported or unreported faults in WDSs. Repair quality prevents re-occurrence of faults at the point of fault in the future. Material management refers to the processes applied and the strategy followed to minimize water losses occurring due to pipe material quality in WDSs. Material management includes choosing the most appropriate diameter and type of pipes according to the characteristics of the region, flow rate, and pressure conditions.

3. NETWORK RENEWAL

Network renewal refers to the replacement of network mains serving in WDSs. Since network renewal creates a high cost, it should be implemented as the last solution whenever possible. Valve renewal refers to the replacement of valves that have reached the end of their economic life. Since valve replacement creates costs, creating an asset management strategy and implementing a preventive maintenance program can extend the useful life. Service connection renewal refers to the replacement of subscriber connections serving between the mains and the building. Since a significant part of failures occur in service connections, the quality of materials and workmanship is quite important in the renewal. Network renewal generates high costs, and, it is preferred as a priority in many cases. It is possible to reduce losses by managing networks together with existing failures, operation, repair, new resource and energy costs (Mamo et al., 2013; Al-Zahrani et al., 2016).

Figure 1. Network renewal in the field

The pipe material should be selected by considering the climate and environmental, operating and hydraulic criteria. Since network renewal will result in very high costs in WLM, this method should be the last option. It is seen that the concept of useful life for networks comes to the fore in the literature. One of the important methods followed in determining the useful life is Loganathan et al. (2002). The failure coefficient (Brk) was calculated using the annual inflation rate (R), annual repair cost (C) and the network renewal cost (F). Firstly, the total renewal cost will be calculated. Unit repair costs will be calculated according to pipe diameter and type. The pipe type to be used in the renewal and the average pipe diameter of the existing network should be defined.

Figure 2. Service connection renewal in the field

4. COST BENEFIT ANALYSIS STANDARD AND RESULTS

The benefits and costs to be obtained in cases of renewal of only the mains, renewal of only service lines and renewal of network (service connection + main) were calculated. During these analyses, it was thought that if the entire network was rehabilitated, the loss level would decrease to the "Inevitable Loss" level. If the service connection and the mains are renewed individually, the benefit flow to be obtained when the existing faults are eliminated. Depending on the amount of leakage detected, the total number of faults and the resulting faults were differentiated by network and service connection type. A DMA was selected as study area (Table 2).

Table 2. Main data used for network rehabilitation

#	Parameters	Unit	Value
1	Total Network Length	m	15000
2	Total Number of Subscriber Connections	No.	300
3	Average Night Pressure	m	55
4	Unit Water Cost	TL/m^3	5
5	Annual Breakdown Amount (Service connection)	No.	80
6	Annual Breakdown Amount (Main)	No.	120
7	Average Fault Resolution Time	hour/No.	20
8	Physical Loss Volume	m^3/month	18000
9	Volume of Leakage from Tanks	m^3/month	150
10	Percentage of Ø 150 mm Small Pipe Lengths	%	80
11	Rate of Pipes (Ø 150 mm - 300 mm)	%	10
12	Rate of Pipes (Ø 300 mm - 500 mm)	%	0
13	Rate of Pipes (Ø 500 mm - 700 mm)	%	10
14	Rate of Pipes of Ø 700 mm	%	0

Kayseri is located in the Central Anatolia region. The active leakage control is applied in WDS. The DMAs were applied in field. The data monitoring system are regularly worked. The network data, failure and customers are obtained. In network renewal costs, basic costs for different pipe types for different pipe diameters were considered and the rehabilitation costs were calculated (Tables 3 and

4). The failure rate of mains is approximately 38% (Nicolini et al., 2014; Aydoğdu & Fırat, 2015; Boztaş et al., 2019). In network renewal costs, basic costs for different pipe types for different pipe diameters were considered.

Table 3. Network rehabilitation benefit cost data

#	Parameters	Unit	Value
BM13a	Pipe Smaller than Ø150 mm in Network for PVC Pipe	TL/m	₺185,00
BM13b	Pipe Between Ø150 - Ø300 mm in Network for PVC Pipe	TL/m	₺580,00
BM13c	Pipe Between Ø300 - Ø500 mm in Network for PVC Pipe	TL/m	₺1.000,00
BM13d	Pipe Between Ø500 - Ø700 mm in Network for PVC Pipe	TL/m	₺1.600,00
BM13e	Pipe Larger than Ø700mm in Network for PVC Pipe	TL/m	₺2.250,00
BM14a	Pipe Smaller than Ø150 mm in the Network for Ductile Pipe	TL/m	₺420,00
BM14b	Pipe between Ø150-Ø300 mm in network for Ductile pipe	TL/m	₺775,00
BM14c	Pipe between Ø300 - Ø500 mm in Network for Ductile Pipe	TL/m	₺1.400,00
BM14d	Pipe between Ø500 - Ø700 mm in Network for Ductile Pipe	TL/m	₺2.100,00
BM14e	Pipes greater than Ø700mm in the Network for Ductile Pipe	TL/m	₺2.950,00
BM15a	Pipe Smaller than Ø150 mm in Network for HDPE Pipe	TL/m	₺210,00
BM15b	Pipe Between Ø150 - Ø300 mm in Network for HDPE Pipe	TL/m	₺610,00
BM15c	Pipe Between Ø300 - Ø500 mm in Network for HDPE Pipe	TL/m	₺1.100,00
BM15d	Pipe Between Ø500 - Ø700 mm in Network for HDPE Pipe	TL/m	₺1.600,00
BM15e	Pipe Larger than Ø700mm in Network for HDPE Pipe	TL/m	₺2.500,00
BM16a	Pipes Less than Ø150 mm in Network for Steel Pipe	TL/m	₺360,00
BM16b	Pipe Between Ø150 - Ø300 mm in Network for Steel Pipe	TL/m	₺720,00
BM16c	Pipe Between Ø300 - Ø500 mm in Network for Steel Pipe	TL/m	₺1.250,00
BM16d	Pipe Between Ø500 - Ø700 mm in Network for Steel Pipe	TL/m	₺190,00
BM16e	Pipes Greater than Ø700mm in Network for Steel Pipe	TL/m	₺2.750,00
BM17	Service connection	TL/No.	₺8.000,00

Table 4. Benefit cost calculation results

Parameters	Current	Main renewal	Service connection renewal	Main + Service connection renewal
Real loss volume (m^3/month)	18000	18000	18000	18000
Saved volume (m^3/month)	0	9105	2164	11269
Final Status (m^3/month)	18000	8895	15836	6731
Cost (TL/year)	₺0,00	₺870.000	₺88.000	₺958.000
Cost Reduction (TL/year)	₺0,00	₺546.300	₺129.840	₺676.140
+ / - (TL/year)	₺0,00	-₺323.700	₺41.840	-₺281.860

5. DISCUSSION

There is currently a monthly water loss of 18,000 cubic meters. It is seen that 9105 cubic meters of water can be obtained if the entire network is changed. The cost of this method is lower than the profit to be obtained. Therefore, it should not be preferred. It was seen that 2164 cubic meters of water would be saved if only the service connection lines were renewed. This method may be preferred because its cost is lower than its benefits. It is seen that if the entire water line is replaced, 11269 cubic meters of water will be saved. However, the cost of this method is lower than its gain. Therefore, it should not be preferred. Many variables such as the current network status, fault status, network lengths and number of subscribers are very important in the work to be done to reduce water losses. For this reason, it has been observed that the rehabilitation method to be chosen for different network conditions in water loss reduction studies has a serious impact on increasing the planned benefit.

6. CONCLUSIONS

In Turkey, utilities have become obliged to reduce the NRW rate to a maximum of 30% by 2023 and to a maximum of 25% by 2028. The average water loss of utilities is 40%. It is understood that the average may be much higher in the remaining provinces. Combating water losses in WDSs is of serious importance. Considering that all networks have their own characteristics and the countries they are connected to have different economic criteria, it will be seen that the economic leakage level is different for each network. For this reason, utilities need to manage the leakages by considering the current status of the networks. The methods to prevent water losses should be well understood. While every method to be used to reduce water losses will incur costs, it will also provide various benefits depending on the current status and characteristics of the network. Analysis and evaluations in detail should be made within the framework of economic components for the basic methods applied in leakage management in future studies.

However, considering both the costs of water loss reduction methods and their relationships with each other, the possible benefits to be obtained must be calculated before implementation. If the current network conditions are maintained, current failure rates, operation, repair costs, new water resource and energy costs, initial investment and medium and long-term operating costs in case of network renewal should be considered. Since pipe material, labor and construction costs are at very high levels, a detailed cost-benefit analysis must be made and alternatives should be evaluated. The current characteristics of the network and factors that cause damage to the pipe should be analyzed.

Conflict of Interest

Authors declare that there is no conflict of interest.

Contribution of Authors

The authors involved in this study, and they contributed to all the aspects of the study.

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