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CIVIL ENGINEERING

Defining cost standard and new algorithm for economic leakage level components in water loss management

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ABSTRACT. Methods and tools used to reduce leakage in distribution systems are often time consuming and costly and require special requirements. Therefore, cost-benefit analysis is very important for basic reduction methods applied in water loss management. In this study, cost and benefit analysis standards were developed for basic methods such as pressure management, number of teams, and pipe rehabilitation and active leakage control, in managing leakages. Moreover, a new cost algorithmic structure was developed and the economically recoverable water amount was determined by applying calculation tool developed to make detailed analyzes systematically and accurately. The most important advantage of this study is the development of an economic analysis model and algorithmic structure for basic reduction methods according to field data. It is thought that the cost analysis and algorithmic structures developed will make a significant contribution to the economic leakage level analysis and serve as a reference for sustainable water loss management.

Keywords: Leakage; economic analysis; cost benefit analysis; economic leakage level.

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Introduction

In the distribution systems (WDSs), leakages and apparent losses and unbilled losses are observed depending on various factors (Amoatey, Minke, & Steinmetz, 2018; Pearson, 2019). Especially in big WDSs where the network age is high, failures and leaks are at high levels, and the time to detect, locate and prevent leaks increases. Increasing failures lead to an increase in operating and repair costs, the frequency of interruptions and deterioration of operating conditions (Lambert & Thornton, 2012; Wyatt & Alshafey, 2012; Marchionni, Cabral, Amado, & Covas, 2016; Mutikanga, Sharma, & Vairavamoorthy, 2013; Haider et al., 2019; Moslehi, Jalili-Ghazizadeh, & Yousefi-Khoshqalb, 2021). (Hardeman, 2009) stated that reducing the non-reneue water (NRW) rate to 0 % was an unrealistic and costly target and stated that economic leakage level (ELL) should be calculated. (Deidda, Sechi, & Zucca, 2014) emphasized that what will be the target in WLM should be determined with the balance point and this can be a reference in determining the area to be intervened. Zamenian, Mannering, Abraham, and Iseley (2017) expressed that in WDSs, determining the damage potential of pipes, evaluating the current situation, estimating the failure rate and determining the priority areas in renewal is quite important and necessary. Sechi and Zucca (2017) enounced that the most appropriate replacement strategy and ELL should be developed, and a balance should be established between benefits and costs in reducing leaks. Haider et al. (2019) proposed a model for analysis of the economically recoverable leakage and ELL in arid regions. As can be seen, the most appropriate strategy and method should be determined to reduce the NRW to an acceptable level based on cost-benefit analysis and ELL with a certain standard for sustainable WLM. Therefore, in this study, a new cost algorithmic structure for cost-benefit analysis standards of basic methods such as PM, number of teams and pipe rehabilitation, and active leakage control (ALC) were developed. Moreover, the economically recoverable water amount was analyzed by using calculation tool developed. The most important advantage of this study is the development of an economic analysis model and algorithmic structure for basic reduction methods according to field data in WLM. Thus, it is possible to apply the basic methods in WLM integrated and simultaneously in cost-benefit analysis.

Material and methods

Development of cost standards for ell components

Four basic components such as PM, repair speed and quality, ALC and material management are commonly used for managing the leakages (Lambert, Brown, Takizawa, & Weimer, 1999). Since the physical, operating and environmental features and leakage rates of each system will differ, it is not possible to reduce leakages to the same level in all systems. In many cases, the investments are far from being economical since cost-benefit analysis is not taken as a basis. Therefore, an appropriate strategy should be determined for reducing the NRW to an acceptable level by considering the ELL analysis (Wyatt & Alshafey, 2012; Lim, Savic, & Kapelan, 2015; Molinos-Senante, Mocholí-Arce, & Sala-Garrido, 2016). In defining the ELL, the reduction methods should be well understood and analyzed. Each method will create a cost and also provide the benefits depending of the current condition of the network. Therefore, cost / benefit analysis standards were determined for each variable and the optimum pressure level for the system, the number of teams, and amount of water to be saved by methods were calculated. The flow charts were created for the economic analysis model of each methods in this section (Figure 1).

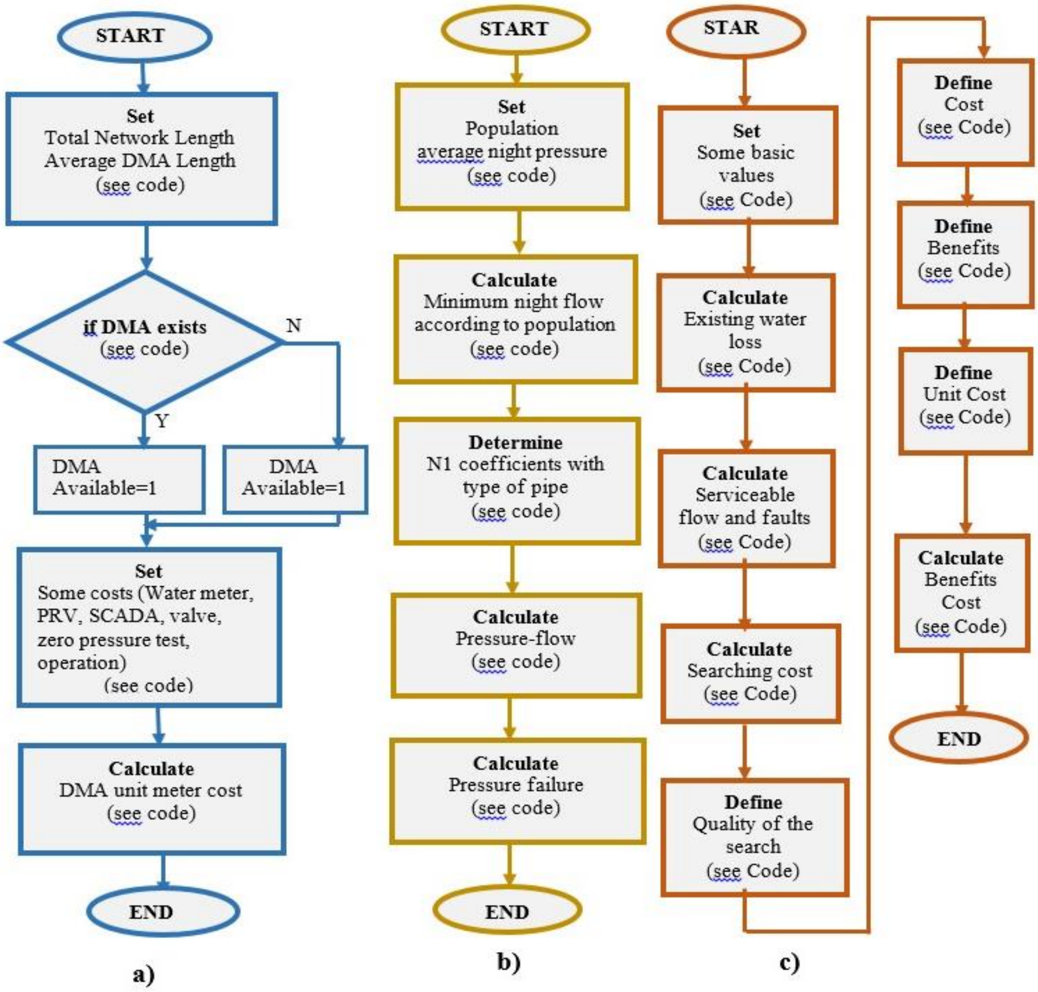

Figure 1. a) Flowchart for DMA design cost b) Flowchart for pressure control cost c) Flowchart for ALC cost.

Matlab analysis tools which could calculate related for five different situations simultaneously, were created based on flowchart. This algorithmic layout can work synchronously to find the appropriate configuration for the network after the necessary network information is defined. In this way, common analyzes of different methods will be enabled. Moreover it is possible to determine which method will be more efficient under the same network conditions by defining all components of methods on the same platform. Making economic analysis and determining the most appropriate method based on cost-benefit analysis and ELL are quite important in terms of efficiency of water, energy, personnel and economic resources and long-term sustainable WLM. In the following chapters, details of flowcharts and model codes created for each method are presented.

Results and discussion

Cost analysis standard for DMA

In complex WDSs, ensuring water transmission, monitoring and controlling the system and developing a long-term WLM strategy are very difficult and costly. The DMA approach provides significant advantages in reducing leakage by decreasing the time of recognition and detection and allows for more effective implementation of basic methods (Vicente, Garrote, Sánchez, & Santillán, 2016; Kanakoudis & Gonelas, 2015; Al-Washali et al., 2016; Di Nardo et al., 2017). In DMA design, the main length (between 4 and 30 km and average 15 km) and the number of service connections (between 500 and 3000) should be also considered (Pearson, 2019). Gomes, Marques, and Sousa (2013) expressed that economic conditions are an important parameter in DMA design and proposed an algorithm in which the total cost is minimum while the benefit is maximized. Ferrari and Savic (2015) stated the necessity of economic analysis in planning the DMA for leakage reduction and energy and water efficiency and also expressed that the benefits to be obtained from the DMA depend on the number of zones and isolation valves. The cost components in DMA design can be given as; (i) flowmeter and pressure gauge equipment, labor and workmanship, (ii) flowmeter room construction, electricity, data transfer, (iii) field works for isolation and zero pressure test, (iv)workmanship, equipment and operating costs for leak detection, maintenance-repair (Table 1).

Table 1. Cost of flow meter room, mechanical equipment, field works and monitoring systems in DMA creation.

No.	Component	Unit	Quantity	Unit cost (₽)	Total cost (₽)
	Flow Meter Room and Mechanical Equipment Cost				
1	Flow Meter Room Construction	No.	1	9,250.00	9,250.00
2	PRV Installation (aver. Ø250 mm)	No.	1	17,000.00	17,000.00
3	Electromagnetic flow meter (aver. Ø250 mm)	No.	1	31,000.00	31,000.00
4	Actuator Valve (Ø250 mm)	No.	1	4,500.00	4,500.00
5	Strainer	No.	1	750.00	750.00
6	Electricity line (aver. 8 m)	No.	1	5,500.00	5,500.00
7	Panel and Remote Access Systems	No.	1	2,000.00	2,000.00
	Total cost				70,000.00
	Isolation Valves Location and Replacement Cost				
1	Excavation on all kinds of ground	m3	12	28.75	345.00
2	Supply and Installation of valves (16 bar)	No.	1	1,323.00	1,323.00
3	Fittings	No.	1	95.00	95.00
4	Detection expenses	No.	1	87.00	87.00
	Total cost				1,850.00
	Zero Pressure Test Cost (2 Hours)				
1	Engineer	h	3	28.15	84.45
2	Workmanship	h	3	15.75	47.25
3	Vehicle Expenses	h	2	136.65	273.30
4	Portable Manometer	No.	1	345.00	345.00
	Total cost				750.00
	Monitoring and Operating Costs				
1	Operating - Technical Support	No. /year	1	12,000.00	12,000.00
2	Monitoring System Installation	No. /year	1	13,000.00	13,000.00
	Total cost				25,000.00
	Unit Cost for DMA Design				
	Component	Unit		Unit cots (₽)	Total cost (₽)
A	Total main length (m)	60000		-	-
B	Average main length in DMA	15000		-	-
C	Number of potential DMAs (A/B)	4		-	-
D	Number of isolation valves required (B/2000)	8		1,850.00 ₽	14,800.00 ₽
E	Number of flow meter rooms (E=C)	4		70,000.00 ₽	280,000.00 ₽
F	Number of zero pressure test (C*3)	4		750.00 ₽	9,000.00 ₽
G	Monitoring system	12		13,000.00 ₽	13,000.00 ₽
H		1		12,000.00 ₽	12,000.00 ₽
				Total cost	328,800.00 ₽
				Unit Cost (TL/m)	5.48 ₽

Unit cost of DMA design with various network length

Total main length (m)	15.000	30.000	45.000	60.000	75.000	90.000	105.000	120.000
Unit cost (TL m^{-1})	7.47	6.14	5.70	5.48	5.35	5.26	5.20	5.15

The cost of DMA design, which could be defined based on the average length of 15 km recommended (Pearson, 2019), could be easily calculated through the analysis tool developed in MATLAB environment. Defining an expert system or an algorithmic flow under the system constraints during to cost calculation is required. In this study, an algorithmic structure (Figure 1) that works like an expert system and considers all the constraints of the system is proposed. The flowchart of economic analysis algorithm, which is flexible to be applied to the desired WDS for DMA design, was created (Figure 1a). The Matlab code fragments of the components, which will make a significant contribution to technical personnel, especially in terms of DMA planning that is the basis for ALC method, are presented with explanations. The total main and average DMA lengths should be defined into the developed tool to determine the unit cost of DMA creation. Moreover, the DMA and PM may have been applied in the working area before. In this case, whether there is an existing DMA approach and the total length of the network with DMA applied, if any, should be defined by the users in the analysis tool. There is a need to intervene the network every 2,000 meters on average to determine and isolate the boundaries of the region. Moreover, the zero pressure tests in 3 different periods for each zone should be performed after the isolation. Thus, DMA design costs per unit main length (m) could be calculated for a system. The unit costs for DMAs with various lengths of networks are calculated in the cost analysis (Table 1). For instance, when DMA design is performed in a network with a length of 60,000 meters, a total of 4 regions in total should be created by defining a DMA at each 15,000 meters. Due to the need to locate the isolation valves for every 2,000 meters in each zone, the system will be intervened approximately 8 times and assumed that the zero pressure tests will be made 3 times as a result of the studies. Thus, a total of 328,800.00 TL (Turkish Liras) will be spent for the DMA planning in the system with a network length of 60,000 meters (4 regions). It is also calculated that 5.48 TL m^{-1} will be spent per unit length. On the other hand, the leakage monitoring and fault repair costs in DMA design are defined in the developed tool. Later, it is analyzed whether the current DMA number is sufficient or not, and then, in case of need, the total and unit costs required to prepare a new DMA are calculated. The current number of DMA, which should first be defined by the users, is multiplied by the maximum DMA length (30.000 m) and compared with the current network length. In other words, it is determined whether it is within the limits suggested in the literature by defining the average DMA length of the existing network. Thus, the numbers of DMA, zero pressure tests and isolation valves are determined and the total cost is calculated by multiplying with the previously defined costs in developed program. The unit prices spent for creating DMA decreased with the increase of total network length due to the unit cost analysis results. The main reason could be explained by the fact that monitoring and operating expenses constitute a serious cost in relatively smaller networks than others. Unit monitoring costs decrease as the number of DMAs created increases since many DMAs can be controlled with a single system to be set up for monitoring purposes. DMA should be designed primarily in ELL analysis in order to control system inlet and outlet flow rates more accurately and to successfully implement and monitor basic leakage reduction methods.

Cost analysis standard for PM

PM provides significant contributions in terms of decreasing the existing leakage volume and the risk of new failure and extending the economic life of pipes (Lambert et al., 1999; Lambert & Thornton, 2012; Karadirek, Kara, Yilmaz, Muhammetoglu, & Muhammetoglu, 2012; Meirelles, Manzi, Brentan, Goulart, & Luvizotto Jr., 2017). (May, 1994) developed the FAVAD approach (equation 1) describing the leakage-pressure relationship.

$$L0/_{L1} = (^{P0}/_{P1})^{N1} \quad (1)$$

L_0 : the leakage at pressure P_0, L_1: leakage at pressure P_1, P_0 : the average pressure, P_1 : regulated average pressure, and N_1 : leakage exponent (0.5 for constant area leaks), (1.5 for variable area leaks) (Lambert & Thornton, 2012). Tabesh, Jamasb, and Moeini (2008) evaluated leaks at different pressure levels and showed that leakage reduction can be achieved with PM. Thornton and Lambert (2008) stated that pressure zones should be created and the most suitable PRVs should be selected for PM. Creaco and Walski (2017) stated that there is no need for PM in areas with low leakage levels and operating costs. In PM, the room construction, device and equipment selection, and placement and automation systems for monitoring data create significant costs. Therefore, the current situation, necessity, and benefits and costs should be calculated in detail before PM. The changes in leaks and failures with PM are calculated to use in ELL analysis. The effect of pressure changes on leakages in networks with different pipe types can be analyzed by creating a graphic in this study (Figure 2a).

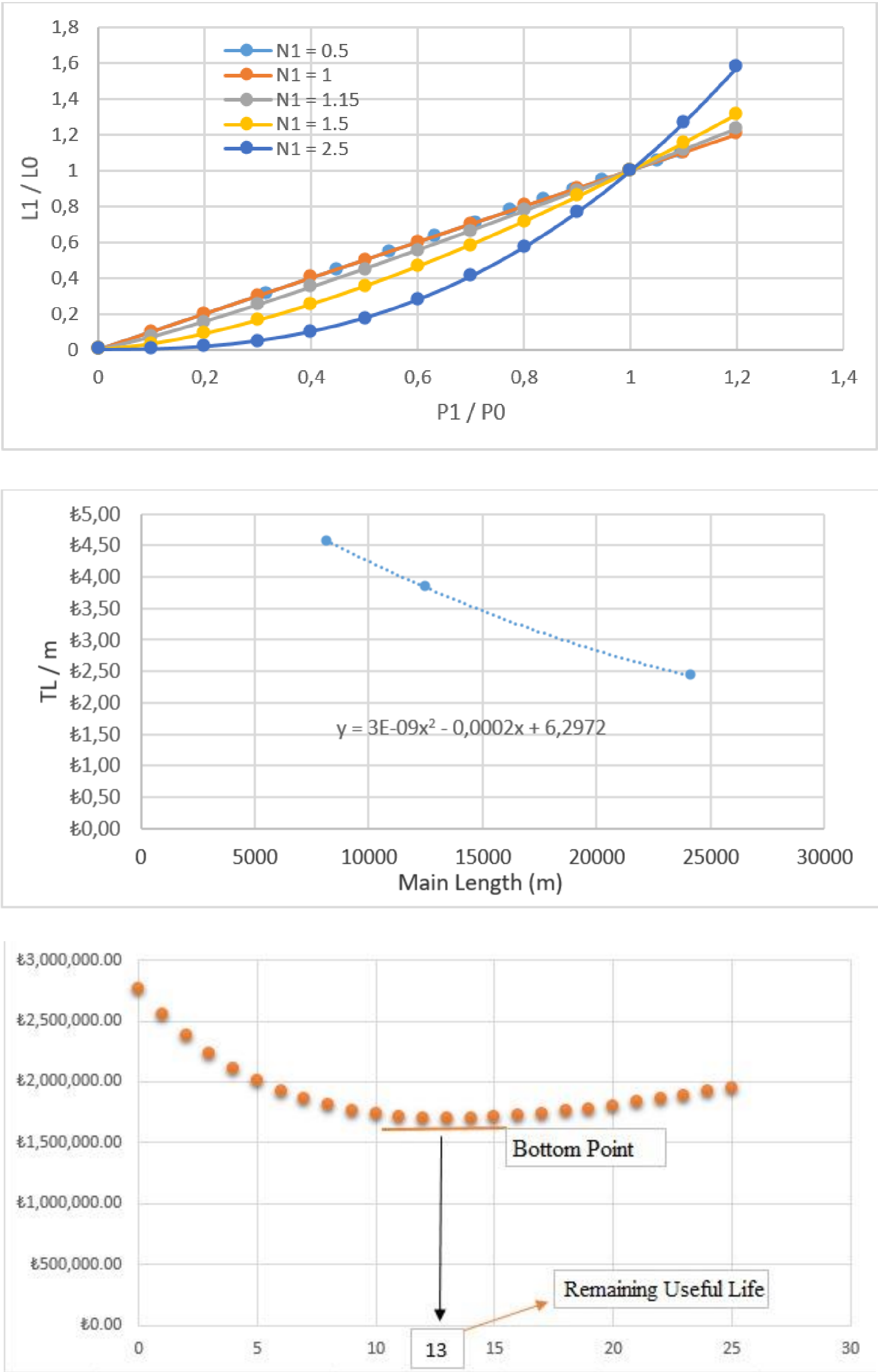

Figure 2. Reference curves for defining cost standards for active leakage control components. a) The effect of percentage change in pressure on losses b) Reference costs for network leakage monitoring and monitoring activities c) Calculation of useful life for networks.

The flow chart of the cost algorithm (Figure 1b) and code fragments of each component for PM is defined. The average pressure and population should be also defined in to make cost-benefit analysis for PM. Then, the lower and upper limits of the pressure required for pressure control are defined in the proposed algorithm to define the relationship between pressure and leakage. In Turkey, the minimum and maximum limits of the pressure were defined as 25 m and 65 m, respectively. The weighted pipe type of the network should be determined to understand the effect of pressure change on night flow. N1 coefficient in the FAVAD equation is determined based on the network information provided by the users is transferred to the generated code. Then the coding that calculates the reduction in leakage due to the change in pressure based on the FAVAD equation is generated below where the variable "a0fxd" refers to the value after the pressure change.

The failure frequencies in service connections and mains are examined before and after PM to analyze the pressure-failure relationship, and the change in fault frequency is expressed in terms of pressure change and N2 exponent (Pearson & Trow, 2005). Equation (4) calculates the change in the number of failures according to the N2 coefficient and pressure change is used to define the pressure-failure relationship.

$$B0/_{B1} = (P0/_{P1})^{N2} \quad (2)$$

$$Breakdown\ Frequency\ (BF) = BFnd + A * Pmaks^{N_2} \quad (3)$$

$$S = \left(1 - \frac{Reference\ Breakdown\ Count}{Breakdown\ Count}\right) * \left(1 + \frac{P1}{P0}\right)^2 \quad (4)$$

BFnd is the reference failure frequency not dependent on pressure, B_1 is the number of new failures after pressure change. The reference of failure frequencies considered in the UARL in a system with good condition is defined as 13 failures / 100 km / year (mains) and 3 failures / 1000 connections / year (connections) (Lambert et al., 1999; Pearson, 2019). It is thought that analyzing the changes in the leaks and failures due to any pressure level could serve as a basis for the calculation of fault repair, network monitoring and leak detection costs.

Cost analysis standard for ALC

The ALC plays an important role in recognizing, locating and repairing and reducing unreported leaks (Lambert & Fantozzi, 2005). Defining the DMAs makes a significant contribution to locate the leaks with acoustic equipment and reduce the recoverable leakages. The efficiency of the methods varies from region to region, depending on the physical and environmental characteristics of the networks and the field experience of the teams. Moreover, the benefits / costs of the methods applied in ALC should be calculated to define the ELL. Thus, the amount of water that could be economically saved by ALC will be determined. In this study, the cost components of ALC methods were calculated by taking the literature studies and field experiences (Table 2).

The flowchart of the cost algorithm for ALC defined based on mathematical structure is presented in this section (Figure 2c). In this tool, the main length, the number of service connections, the current average pressure and unit water costs should be defined to generated code to calculate the expenses spent to gain a unit (liter) of water and the total leakage (l km hour^{-1}). In ALC method, the level of leakage that can be intervened as a result of the method should be defined regardless of the current leakage level of the system. For this aim, the background leaks (liter / day) with equation (5) and the reported leaks are determined (Lambert et al., 1999). Thus, the recoverable leakages should be calculated by subtracting the total leakage amount since these loss amounts cannot be reduced with ALC.

$$UBRL = (20 * Lm + 1.25 * Nc + 0.033 * Lp) * (\frac{AZNP}{50})^{1.5} \quad (5)$$

Lm; main length (km), Nc; number of service connections, Lp; service connection length on private property, AZNP; average pressure (m). In calculating the reported losses, unit leakage rates, which are 240 liters / hour / m pressure in mains and 32 liters / hour / m pressure in service connections proposed in literature are used (Lambert et al., 1999). In this study, if the total number of failures per year are defined to the model by user, it is possible to calculate the losses caused by the failures. These components are defined in the developed tool and calculation opportunity is provided for users. Moreover, the estimated number of failures that can be intervened with ALC should be calculated after determining the recoverable leakages. Then, the failure in main and service connection should be made depending on the amount of leakage detected. It was stated in the literature that the ratio of network failures to total failures is approximately 38% (Nicolini, Giacomello, Scarsini, & Mion, 2014; Aydoğdu & Firat, 2015; Boztaş, Özdemir, Durmuşçelebi, & Firat, 2019). Thus, failures in service connection and mains can be calculated with reference to the unit leakage rates suggested in the literature. Another step in benefit / cost analysis of ALC method is the determination of unit costs of network screening and listening activities in the field. For this purpose, a unit cost table was created with reference to ALC works carried out in KASKI and MASKI networks with different lengths (Table 3) and a graph was obtained to calculate these unit costs in each network (Figure 2b).

Table 2. Defining variables for ALC cost benefit and leakage screening and listening quality.

Component	Unit	Value	Description
Defining the components for ALC cost benefit analysis			
Component	Unit	Value	Description
Total main length	m		
Number of customers	No.		
Network failure/Total failure	%	38%	(Nicolini et al., 2014; Aydoğdu & Firat, 2015; Boztaş et al., 2019)
Service connection failure/Total failure	%	62%	Calculated
Repair cost of network failure	TL/failure	₱1,850.00	Defined based on field data
Repair cost of service connection failure	TL/failure	₱1,350.00	Defined based on field data
Average system pressure	m		
Working duration	day	180	Cycle duration of screened area (aver. 6 month)
Unit sale cost of water	TL $liter^{-1}$		Unit sale cost of water in Utilities
Defining the Network Leak Detection Quality			
Component	Unit	Value	Description
Failure rate found at the 1st screening result	%	40%	Determined by reference to field studies.
Failure rate found at the 2nd screening result	%	25%	
Failure rate found at the 3rd screening result	%	14%	
Failure rate found at the 4th screening result	%	9%	
Failure rate found at the 5th screening result	%	7%	
Failure rate found at the 6th screening result	%	5%	

Table 3. Costs for leakage listening and monitoring in network.

Reference Costs for Leakage Listening and Monitoring						
Screened Quantity (m)		Total Cost (TL)			Unit cost (TL/m)	
8139		37,284.00			4.58	
12456		47,836.00			3.84	
24156		58,587.00			2.43	
Failure repair costs						
No.	Component	Unit	Quantity	Unit cost (₱)	Total cost (₱)	
1	Service connection failure	No.	1	₱1.350,00	₱1.350,00	
2	Network failure	No.	1	₱1.850,00	₱1.850,00	
Cost Benefit Analysis						
	1st Screening	2nd Screening	3rd Screening	4th Screening	5th Screening	6th Screening
Total spent value (A)	A1	A2	A3	A4	A5	A6
Water saved (B)	B1	B2	B3	B4	B5	B6
Unit cost (liter TL^{-1}) (C)	C=A1/B1	C=A2/B2	C=A3/B3	C=A4/B4	C=A5/B5	C=A6/B6

It is observed that as the length of the network controlled by acoustic equipment increases, the cost of leakage control and monitoring unit decreases. The main reason for this is that the initial investment costs of the equipment required for ALC are used in larger areas with increasing quantities. Another important parameter in ALC method is screening and monitoring quality, which expresses the rate of failure detected and repaired in the network. The experience of the screening teams on this parameter is quite important and the efficiency of the system varies in line with the performance put forward for this parameter. The screening quality parameters calculated in line with the studies in the literature and field studies/experiences in different Utilities are given in Table 2. As a result of inspecting the whole system as a round, it is seen that 40% of the total existing failures can be detected in the first time, and 25% of the initial failure rate can be detected after scanning the entire network for a second time (Table 2). In the system, it is predicted that 95% of the failures in the system can be repaired by screening the same area 5 times and eliminating the failures. The natural deterioration rate of the network and the resulting increasing number of failures are also evaluated within the in this analyses since the system is screened at different times. In addition, costs defined for the repair of failures in main and connection could be changed in the developed tool. Consequently, the total cost (including screening and failure repair) and the total benefit (the amount of water gained in return for detected and repaired failures) are calculated first for each screening cycle in order to calculate the unit cost (Table 3). Thus, the resulting cost ratio against the amount of water saved for each listening and screening period could be calculated. It can be determined which listening periods are economical since the unit production cost of water in water production is also known. While calculating the total spent amount given in Table 3, firstly the screening cost was obtained by multiplying the unit screening cost by the main length. Then, the calculated total numbers of service connection and main failures are multiplied by the failure rates found in the screening and listening quality table (Table 2), and the number of failures planned to be detected for each screen are calculated. These failures are multiplied by the unit failure repair costs given in Table 3, and the total amount spent as a result of the first screening is obtained. To define the amount of prevented water, how much of the recoverable leakages can be prevented according to Table 2 are calculated and multiplied by the total working time given in Table 3. Thus, the total amount of water saved as a result of the first screening is obtained. The amount to be spent to reduce the leakage per liter will be calculated by dividing the total costs obtained by the total benefit. These analyses are continued up to the point where the amount spent for unit leakage control is higher than the unit water production cost. Thus, the amount of water that can be saved economically as a result of ALC will be found.

Cost analysis standard for network renewal

Since, the network renewal involves the replacement of pipes and creates more cost than other methods, the current failure rates, operation, the costs of maintenance and repair, new resource, energy and initial investment and operating should be considered and analyzed (Al-Zahrani, Abo-Monasar, & Sadiq, 2016;Venkatesh, 2012; Mondaca, Andrade, Choi, & Lansey, 2015; Francisque et al., 2017; Cavaliere, Maggi, & Stroffolini, 2017). The useful life focuses on situations where leaks cannot be managed economically through failure repair, PM and other methods. In other words, it can be evaluated as 'completed its useful life' for the network in cases where the cost spent for the unit pipe in the network operation is higher than the cost spent for the replacement of the pipe. In the ELL analysis, the remaining useful life of the network should be calculated and leakage reduction methods should be selected according to the result. One of the methods used in determining the useful life was introduced by (Loganathan, Park, & Sherali, 2002). The failure coefficient (Brk) is calculated using the annual inflation rate (R), annual failure repair cost (C) and the total rehabilitation cost (F) of the network. The flowchart (Figure 3) for the cost algorithm of network renewal and codes in Matlab environment for each component was created.

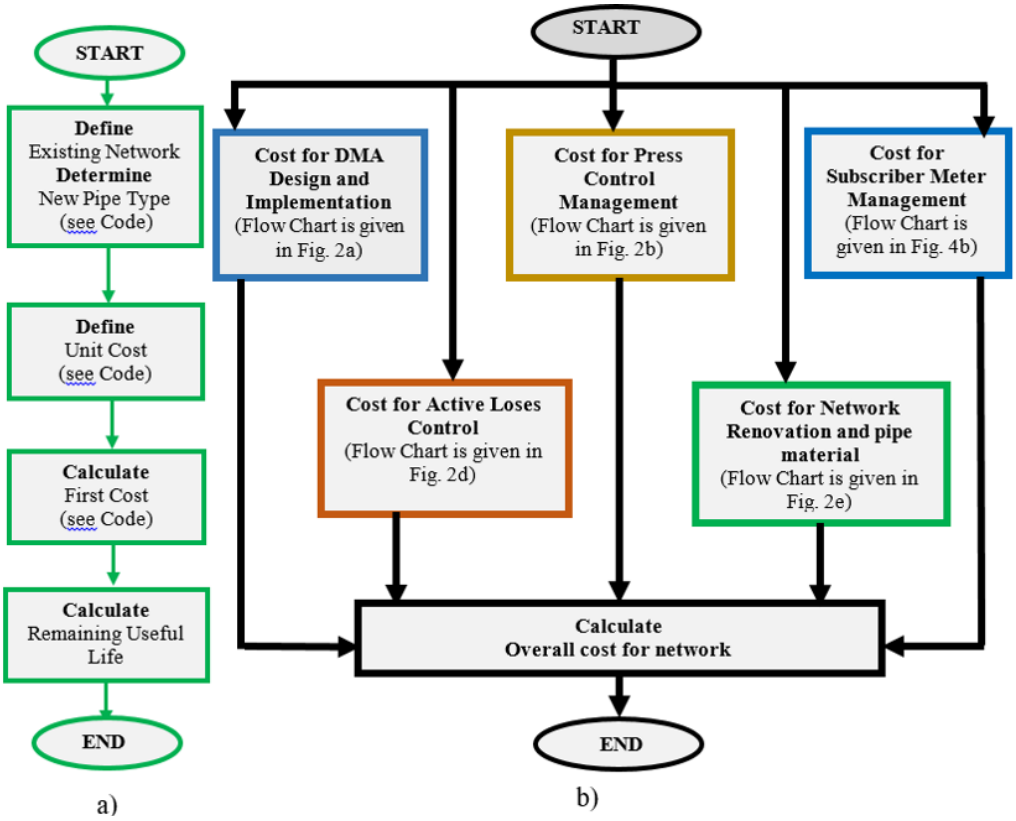

Figure 3. a) Flowchart for Network Renewal cost b) Flow chart of Overall cost calculation for network.

The rehabilitation cost should be calculated for the calculation of the useful life based on mathematical structure. The pipe diameters of the network and the new pipe type used in rehabilitation should be predominantly defined in the program to calculate the total rehabilitation cost of the network and unit failure costs for each diameter and pipe type that will arise during the renewal of the network. The cost items such as rehabilitation, failure and leakage are calculated separately, considering the interest rates for each year. Moreover, the remaining useful life of the network simultaneously is analyzed by eequation (7).

$$Brk_n = \frac{\ln(1+R)}{\ln(\frac{C_{n+1}}{F_n}+\frac{F_{n+1}}{F_n})} \quad (6)$$

$$BRK_n > BRK_{n+1} \; ve \; BRK_n > BRK_{n-1} \quad (7)$$

The point where the calculations meet the conditions in equation (7) at the same time will give the remaining useful life of the network. In other words, the point where the peak of the graph intersects with the year is the remaining useful life (Figure 1c). In this way, the useful remaining life will be calculated, considering the current network and rehabilitation conditions and annual interest rates. If the peak point does not occur at all, that is; if the condition of equation (7) is not met at all, it means that the network has completed its economic life. Another important method in leakage reduction is the optimization of failure repair teams. The annual number of failures, average failure intervention time and the number of existing repair teams should be determined to make this analysis correctly. Average failure intervention time is defined as the time between recording the failure and putting the system back into normal operation after the failure is repaired. Before these calculations, it is necessary to determine the changes in failure rates and the effect of this on the average intervention time. Then, the cost-benefit analysis is performed between the cost of each team whose number is increased and the amount of water lost depending on the length of the intervention period. Each team increase will shorten the solution time to a certain extent (determined by percentage), which will result the reduction in leakages. In addition, a certain monthly fee must be paid for each team increase. It is recommended to increase the number of teams by the specified number in case of the sum of benefits is greater than the sum of costs. If the benefit is not higher than the cost at any point of the algorithm, the result is that the number of teams is optimal or should be reduced. The benefits obtained from PM, ALC and team planning are collected and the new loss rates of the system are calculated based on these analyzes. Thus, the remaining useful lives of the networks are determined in order to assist in the determination of ELL.

Overall cost calculation of the network

Cost analysis terminology is presented for basic methods based on mathematical foundations and algorithmic layouts explained in the previous sections. These basic methods used to reduce water losses can be evaluated independently. However, it would be more appropriate to evaluate them together in a planned fight against leaks. When common variables are defined together for each method in the proposed algorithms structure, common solutions of the system and the proposed algorithms are possible. Figure 3 shows the general flowchart of the cost analysis structure used in the system. In this flowchart, costs for DMA design, PM, ALC and network renewal were run simultaneously and the total cost calculation of the system was calculated by considering of all constraints and requirements. Thus, an algorithmic cost terminology that acts as an expert system that includes all constraints and components for the WDS has been proposed. **I**n the flowchart, five different cost components are operated synchronously and the optimal configuration for the relevant network could be obtained to optimize the system in terms of WLM components. The algorithm is run and the optimal configuration for the relevant network is determined by taking into account the basic methods to find the most appropriate values of the components.

Conclusion

In this study, the economic analysis standards were determined for the methods applied in efficient and sustainable WLM and an algorithmic structure was defined. The flowcharts for cost analysis of components were established for each step. The cost components were defined for pressure management, number of teams, and pipe rehabilitation and active leakage control, in managing leakages. The applicability and economic impact of reduction methods and maintenance costs, expected benefit should be considered. It is thought that the CBA algorithm developed will make a significant contribution to the ELL analysis and serve as a reference for sustainable WLM.

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