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Research Article

Strategic water loss management: Current status and new model for future perspectives

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ABSTRACT

The methods for water loss management should be selected based on the needs, economy, applicability and current condition. Therefore, it is very important to develop a model that considers all components, actors, analyzes and offers the most appropriate alternatives. The aim of this study is to carry out a detailed evaluations for effective, efficient, sustainable and strategic water loss management, to present a new strategic model and to create a literature discussion that will set a reference for future studies. It is thought that the proposed model will provide significant advantages to studies such as making the current condition analysis in detail, determining the performance indicators that can be calculated, defining the goals, and determining the most appropriate methods. Thus, it will be possible to calculate more accurate indicators according to the data situation, to set realistic goals according to the current situation and to suggest the most appropriate methods.

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INTRODUCTION

Leakages are occurred depending on physical, operational, environmental and hydraulic factors in water distribution systems (WDSs). According to the leakage rate, the operating conditions of system deteriorate and important problems arise for customers and the utilities. Seago et al. [1] emphasized that leaks in WDS continue to be an important problem especially in developing countries. Non-Revenue Water (NRW) consists of two

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basic components: "apparent losses (AL)" and "physical losses" [2–4]. Since the AL include the water that is consumed but not paid, the utility directly loses income over the unit m3. Physical losses include leaks in network, transmission, water tanks and service connections [2–4]. Managing physical losses, which have a high rate in total loss, contributes significantly to delivering less water to the system, delaying the new resource requirement, reducing energy costs, efficient use of energy and water, and reducing the number of maintenance and repairs/costs. In the literature, different methods and tools have been used in water loss management (WLM) such as; active leak control (ALC) [5–13], Minimum Night Flow (MNF) analysis [14–17], pressure management (PM) [18–19], AL management [20-24], strategic model planning [25–32], performance evaluation (PE) [33–36]. These methods could cause significant costs and require technical, technological and personnel condition. For example, in order to provide WLM with approaches such as MNF or PM, the area should be isolated and its boundaries must be defined. Therefore, the current condition analysis should be made in order to develop strategic WLM plans, the method specific to the system and a road map should be created based on the current condition analysis (CCA).

The aim of this study is to making detailed evaluations for effective, efficient, sustainable and strategic WLM, presenting a new strategic model and creating a discussion that will set a reference for future studies. The difference of this study from other studies is that it includes a new strategic model structure for water loss management. This model considers water loss management components, evaluates performance and recommends the most appropriate method. The structure of the strategic WLM model, the current situation analysis, and the modules proposed in collecting data and evaluating the current performance, determining the weaknesses and strengths and choosing the most appropriate methods were evaluated by considering the studies in the literature and discussed. The most important advantage of this study is (i) to create a discussion in terms of WLM based on the advantages and benefits of the proposed strategic WLM model and the studies in the literature, (ii) to develop a model that makes a detailed analysis of the current situation, creates the data matrix according to the current situation analysis, determines the performance indicators that can be calculated, allows the goal to be defined, and determines the most appropriate method. Thus, it will be possible to calculate indicators with accurate, continuous and reliable data, determine the data required for the calculation of other indicators and set the target for the utilities. The main target audience of the model proposed in this study are Municipalities and Water Administrations and technical personnel and decision makers working in the field of water management.

MATERIAL AND METHODS

STRATEGIC WLM MODEL

In literature, a lot of studies are carried out to recognize, detect, reduce, prevent and control losses and to use water and energy resources efficiently. However, the characteristics, network and customer features of each system, environmental, operational and hydraulic behaviors, requirements and most importantly, the goals of the Utility could be varied. Hence, it is not possible to apply a general approach to manage leakages and to achieve success from the methods, and in many cases uneconomic and time-consuming results. Liemberger and Farley [25] stated that understanding and realizing water losses and defining a roadmap is the first step in strategy development. It was emphasized that the sub-components of WB should be filled according to the field data, and physical properties such as the network length and the number of service connections should be taken into account in monitoring performance, calculating background leaks and applying the ALC. In addition, it was stated that strategic planning is very important in WLM, infrastructure leakage index (ILI) should be used in monitoring the leakage performance, MNF plays a crucial role for monitoring and management of leaks. Mutikanga et al. [5] analyzed the asset and meter management, performance benchmarking, leak detection and repair, PM and district metered area (DMA) sustainability to keep efficiency in WLM at the highest level due to the continuous increase in water demand and the cost of new water resources in region. As a result, an increase in income was achieved with the reduction of NRW, a reduction in pumping cost and energy savings were achieved. Mutikanga et al. [21] developed an integrated multi-criteria DSS for WLM planning. For this, meter replacement, illegal consumption control, improvement of failure repair speed and quality, renewal of network and service connections, DMA, PM and ALC strategies were evaluated on the basis of expert opinions, financial, economic, environmental, technical and social. The results showed that the most preferred options are those that improve water supply reliability, public health and water conservation measures. Neamtu [37] determined a WLM strategy to reduce the NRW rate and cost in the improvement and management of water supply, sewage and wastewater treatment systems. The strategy developed aims to determine the technical and economic performance of the system and reduce the losses to 39% for 2013 and 25% for 2018. Mutikanga et al. [7] aimed to review the current tools and methods applied for the evaluation, monitoring and control of the losses in WDSs. In the study, recommendations were made for improving the quality of WB data, assessing AL, improving performance and PM in order to close knowledge gaps and ensure sustainable reduction. Dighade et al. [38] aimed to ensure the most appropriate operation of the system by considering the operating conditions in WDSs. The problems encountered by developing countries in WLM were examined within the framework of intermittent water transmission, poor infrastructure, water metering policy and system pressure. It was emphasized that in WLM firstly, it is necessary to seek answers to the questions of why, how and from where water is lost, and it is important to evaluate the physical and operational characteristics of the network. Kanakoudis et al. [30] developed a user-friendly decision support system to help decide on the methods used to reduce the NRW, evaluate system performance and to propose a list of priority reduction measures. Tsitsifli et al. [39] proposed a DSS in WDS that offers priority strategic steps to reduce the NRW and eliminate the impact of factors, and applied it to WDS with high pressure and MNF and insufficient records in meters.

As can be seen from the literature, the methods should be selected with the needs, economy, applicability by considering current situation. Hence, it is very important to develop a model that consider all components, actors, analyzes and offers the most appropriate option. For this aim, the main components of the "strategic WLM model"

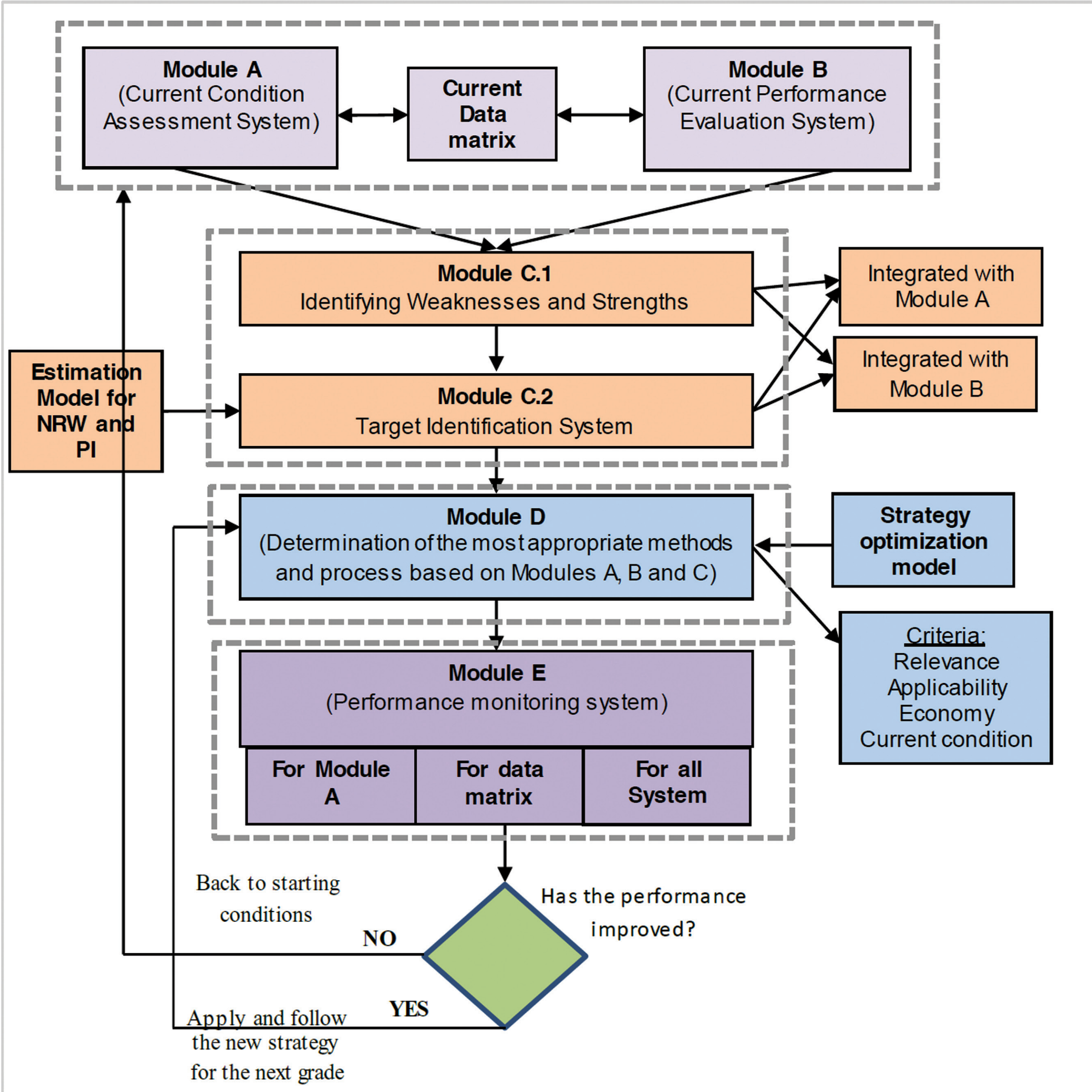

Figure 1. Main components of the strategy model developed in WLM.

proposed in this study for effective and sustainable WLM are given in Figure 1. In the development of this strategy model, the most important step in increasing efficiency and effectiveness can be shown to analyze the current situation in detail. In the following sections of the study, each module of this model is evaluated and discussed on the basis of the literature.

In the strategic WLM model, "Module A: Current Situation Assessment" aims to form a basis for "analyzing the current situation and the methods currently applied" within the scope of WLM. In Module A, it was planned to create a computer-based expert system for entering data in WLM and organized to work integrated with data and PE matrices. A data matrix is created depending on the information collected and the data obtained in Module A. According to the data collected in utility, it is revealed which CCs can be calculated and accordingly and the performance of the system is evaluated according to the data status with Module B. Module C determines the strengths and weaknesses of the system based on Modules A and B, and examines the risks and difficulties that may arise for WLM. Module D is the most appropriate method and process determination system and includes the list of strategies that may be most suitable for the study area in line with the evaluation / scoring / PE / goal definition and the data obtained in the previous modules. Module E is a performance monitoring system and includes monitoring the effects of identified strategies WLM. Here, a systematic literature review including the importance and steps of strategic plan proposed based on characteristics of the regions in this study for WLM was presented. In addition, the importance of CCA in WLM was discussed and supported by literature studies and the details and advantages of the strategic model proposed were focused. This model will provide significant advantages for making the CCA and performance analysis correctly and systematically.

In the proposed model, the relationship between modules (module D, module B, module A and data matrix) needs to be defined. Basically, the road map for this can be given as follows; (i) identifying the relationship of each component in module A with the components in the data matrix, (ii) determining the relationship between each component in module A, (iii) determining the relationship between each component in data matrix, (iv) defining the relationship between the components in module A and data matrix and the indicators in module B, (v) determining the relationship between the components in module A and data matrix and the indicators in Module D, (vi) (i) identifying the relationship of each component in module B with the components in module D.

CURRENT CONDITION ANALYSIS

WLM can be compared to a "patient doctor" relationship. In order to treat the patient in a shorter and effective time, the disease and its degree should be diagnosed and the most appropriate treatment method must be applied. Similarly, it is very important to develop a model for effective and sustainable WLM. This model should consist of; (i) determining the problem based on the CCA, (ii) identifying the priority areas that need improvement, (iii) considering the risks, requirements and goals, (iv) ensuring the development of an appropriate, feasible and long-term strategy. Farley and Liemberger [26] emphasized that detailed analysis of the current physical and operating conditions and other components of the system is the first and critical step in the development of WLM strategy. It was emphasized that the following questions should be sought in the first basic step of planning and implementation of WLM; "How much water loss? Where does water loss occur? How does it occur? Is there a strategy to improve system performance? " It was also stated that methods and tools should be used according to the characteristics of the system and that the appropriate, applicable, accessible and most appropriate process should be determined.

However, making detailed analyzes for system components especially in developing countries is not possible in most cases due to the lack of data, information, financial and technical personnel and the administration's inability to provide the necessary importance and support. This situation causes some problems such as unrealistic golas in WLM, failing to achieve the defined golas, revision of goals, development and implementation of daily policies and not developing long term solutions. The reasons for these problems in WLM could be explained as; (i) lack of roadmap that can serve as a reference for data collection, monitoring and analysis, (ii) lack of a strategy based on the CCA, identifying weaknesses / strengths and defining risks, (iii) lack of processes, methods and tools that allow defining areas of priority focus, not defining realistic goals, (iv) lack of sufficient technical infrastructure, personnel, economic situation to reach the goal, (v) lack of sufficient information and strategy for using the most appropriate method and a "PE model". Choosing the most appropriate method in line with the needs of the administration and applying in the field is very important in terms of efficient use of resources and time. Therefore, in order to choice the priority method in reducing the NRW, the following analyzes should be carry out [25,26]; (i) knowing the operating components such as customer, water management, technical, personnel, economic, analyzing water and energy efficiency in current and advanced projections, (ii) analyzing the current water resources, population growth, middle and long term water demand, (iii) examining the currently applied WLM activities and data, (iv) examining the economic, technical, social and environmental effects of NRW components.

In the strategic WLM model given Figure 1, Module A was defined to form a basis for analyzing the current situation and the methods and processes currently applied in utility (Figure 2). This module constitutes the basis for the activities of making gap analysis, setting realistic goals, and suggesting the most appropriate method for process improvement. With Module A, it was planned to create a computer-based expert system for entering data in WLM and organized to work integrated with data and PE matrices. A data matrix is created depending on the information collected and the data obtained in Module A.

It is thought that Module A will constitute a reference especially for analyzing the CCA of the utility, identification of components with missing data, performing gap analysis, determining the components that need to be improved and focused, defining the strengths and weaknesses of system and determining the most appropriate method. Since this module will work integrated with the Module B, it will make a significant contribution to the definition of current performance. Therefore, in next section, the details of Module B, its connection with Module A and data matrix and its differences from the literature are discussed.

PERFORMANCE EVALUATION

It is essential to improve the operating conditions, regularly monitor the system, reduce the failure rate and monitor the system performance to increase customer satisfaction and service quality. Therefore, it is necessary to develop evaluation systems that have a certain systematic, based on the characteristics of the system, offer a holistic approach rather than just calculate indicators, and produce results that will set a reference for the utilities. In simplest form, the NRW rate is obtained as the ratio of the NRW volume to the input volume. The WB proposed by IWA is applied to determine the NRW and sub-components to define the component that constitutes the biggest problem in terms of water and economy at a certain standard [2, 26, 40].

In literature, there are many studies based on "calculation of PIs" within the scope of "Water and Wastewater Management" of the utilities by using different terminologies to express their specific conditions and requirements. In the IWA PE system, a total of 170 indicators in 6 components such as; water resources, personnel, service quality, operation, physical, economic and financial are available [41]. In IBNET system, a total of 80 indicators under 12 main-components were proposed. In the AWWA system, a total of 31 indicators are proposed under the headings of administrative development, customer relations, business operations and water operations. Liemberger et al. [33]

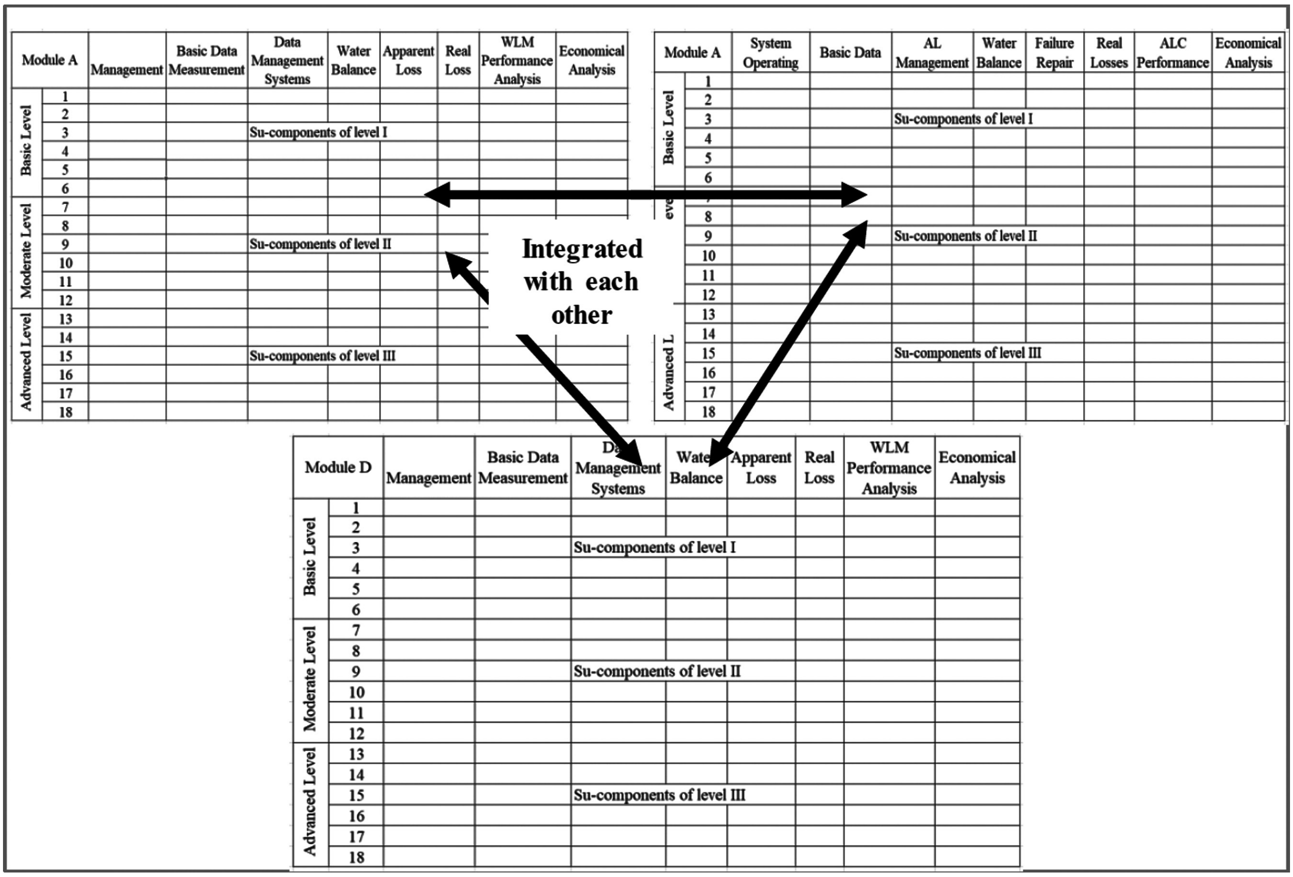

Figure 2. Module A, Data Matrix and Module D define in WLM strategy model.

stated that determining the goals and constraints of the system would be useful in the selection and definition of PIs. Important messages were highlighted that; (i) the components of the PE system should be clearly defined; (ii) the data should be accessible, auditable, universal, simple and understandable. It was stated that the practitioners generally did not have detailed information in terms of accuracy, quality and reliability during data collection and measurement, and this could not provide sufficient reliability in the calculation of indicators. Kanakoudis et al. [42] proposed that WLM methods should be prioritized according to cost and benefit indicators and proposed a PE system which enables the selection, calculation, comparison and determination of performance index. [28] developed a methodology that combines the indicators to be used in PE in small WDSs. It was stated that the current PIs have a very complex structure and are suitable for the system where the technical and economic infrastructure is sufficient, but it is not applicable for WDS with limited technical, personnel and economic conditions [43]. Haider [35] developed a multi-level PE consisting of five modules for small and medium-sized water management in Canada and selected the most appropriate PIs for water management for performance comparison using as few data as possible. The authors stated that PE system cannot be directly applied to small and medium sized WDS due to special requirements. Mutikanga et al. [44] expressed that the applicability of the PE systems suggested in the literature in evaluating the performance of WDS in developing countries is quite difficult and the appropriate PIs for developing countries should be determined.

As a result, in evaluating the system performance, it was emphasized that the indicators should be suitable for the requirements, goals, the strategy and the methods and the data used to calculate the indicators should be measurable, accurate and reliable. As a result, it is very important to use a "PE system" that can meet the needs of the utility based on comparable appropriate indicators. The WLM strategy model proposed in this study, "Module B: PE Module" which works in integration with the module "Data Matrix" and "Module A", was developed (Figure 2). In the PI selection and implementation, "Module A" and "Data Matrix" created according to the CCA are taken as basis and the indicators that will represent the system are determined. Thus, it is possible to calculate indicators with accurate, continuous and reliable data, to determine the data required for the calculation of PIs, and to set targets for the utility. The "PE system" in the WLM model makes significant contributions to the determination of realistic and current situation-based targets to reveal the weaknesses and strengths of the system and identify potential risks areas and improve weaknesses. Thus, by using Module B, information that will constitute the basis for determining the most appropriate method for improving the performance of components will be produced by presenting the current performance. Therefore, in next section, details of Module D, its advantages and the relationship with other modules are shared and discussed.

METHODS AND TOOLS FOR WLM

In WDSs, a certain part of the water supplied to the system leaks to the ground due to various reasons in the transmission lines, water tanks, mains and service connections. The amount of leakage varies according to the pipe material and diameter of the burst, system pressure, form of leakage (background, reported and unreported). Particularly, unreported leaks have a high rate in the total leakage volume since the time of detection and location increases because they do not surface. Therefore, the most important step in leakage management can be shown to be leak awareness [3, 25]. The methods and tools used in WLM can be basically given as; defining the NRW rate [24, 45], DMA design [31, 46-49], PM [19, 50-51], determining the priority regions in rehabilitation [52-54], development of failure prediction models [55-58], MNF analysis and automation systems [14, 16-17, 59], AL management [20-23]. However, most of these methods create significant costs in terms of equipment, workmanship, monitoring and analysis systems. Hence, it is important that the methods to be applied in WLM should be appropriate and applicable.

In this section, "Module D" developed to determine the most suitable method by integrating with other modules, was detailed. It was proposed to select the most appropriate method based on the CCA, data available, the current performance and to create a road map. Thus, it is thought that it will generate important information for decision makers and technical personnel within the scope of the necessity and applicability of methods in the system according to the CCA, data and PE modules. Considering that the methods applied in WLM are time consuming and costly, it is thought that the strategic model proposed in this study will provide significant contributions to the utilities. In the following sections, the constraints, requirements, potential benefits, difficulties of the methods applied in WLM (Figure 3), and the importance of the proposed strategy model are evaluated and discussed by considering the literature studies. It is thought that these discussions and evaluations are very important in terms of determining the issues and requirements to be taken into consideration in the selection of methods in WLM and forming a basis for future studies.

There are methods and processes that follow one another and are interdependent in water loss management. In addition to the basic methods such as active leakage control, isolated zone creation, failure management, improvement of failure rate and repair quality, pressure management in the managing the leaks, advanced methods given in Module D are also applied depending on the technical-economical and personnel background of the system. However, some other basic methods should be applied first

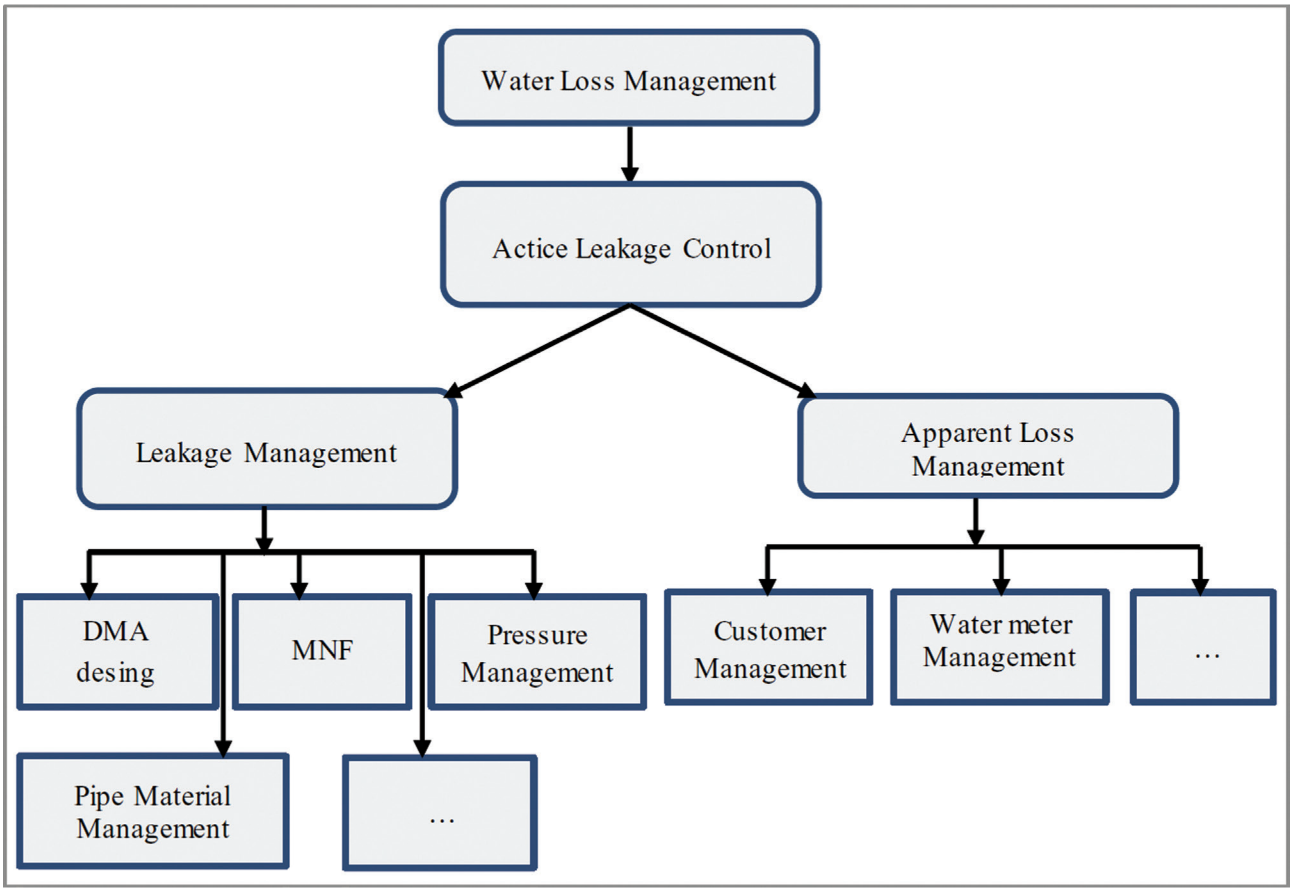

Figure 3. ALC flow chart for WLM.

in order to apply these methods, besides having sufficient data in the system. For example, let's assume that the "Real Loss rate" indicator calculated in a system is at a high level. The main process to be followed in the improvement of this indicator is to recognize, locate and repair the unreported leakages. The methods that are the minimum night flow analysis and active leakage control should be applied in order to recognize, locate and repair the leakages in a DMA. However, in order to apply these methods, the following conditions should be fulfilled: (i) testing the application status of the processes and methods related to this component in module A, (ii) the status or measurement of the basic data (databases of the network plan and customers, devices, GIS integration), (iii) checking the method matrix and testing the methods required to be applied before (planning the isolated zone, flow / pressure meter status, (iv) SCADA integration for systematic monitoring of hydraulic data, etc.). As can be seen, leakage management includes certain processes, and the necessary conditions should be tested and fulfilled in order to reach the final goal. Therefore, in the proposed water loss management model, the processes and methods that should be applied to improve each performance component and reduce the loss rates (and its subcomponents) are determined in hierarchical order and a roadmap is proposed.

LEAKAGE MANAGEMENT

The ALC approach including many tools and methods was used in management of unreported leakages [3, 60]. In order to decide on the methods in Module D, the CCA, PE, gap analysis and target setting and economic criteria should be considered. The WLM should be system unique, and the road map and method should be determined based on the system's requirements and characteristics. In other words, the appropriate method should be applied according to the characteristics and progress of the disease, such as the "patient-doctor" relationship. It is possible to detect and monitor leaks by using DMA and MNF methods, to locate with acoustic devices and regional recorders, to prevent new leaks with PM to monitor hydraulic behavior of the system with SCADA and GIS [61-62]. Gupta and Kulat [11] evaluated the importance of smart technologies for detection of leakage location, control, and effective leakage management. For this purpose, top-down, bottom-up approach, BABE, ILI methods were used.

In the next sections, an evaluation and discussion has been established by taking into account the studies in the literature about the requirements, expected benefits, road map and process order in the application of the methods given in Figure 2. These discussions and evaluations are considered to be very important, especially in terms of determining the issues and requirements to be considered in the selection of methods in WLM and forming a basis for future studies.

In the literature, it was emphasized that the DMA, whose boundaries are isolated from other regions, provides significant gains in MNF analysis, leak detection with acoustic methods, customer and failure management [3, 5, 15, 29, 49, 62-63]. However, in systems where there is no up-to-date GIS database, determining the entry point, number and location of isolated valves, defining the boundaries, and performing zero pressure testing are time consuming and costly [3, 48, 64]. DMA size is generally defined by main length, number of customers and service connections [65-67]. With smaller DMAs, it is easier to control and monitor the system, resulting in more equipment and labor costs. However, in large DMAs, initial and operating costs will be low, but the control and management of the system will be difficult [3, 48, 64, 68]. Lipiwattanakarn et al. [13] investigated the effects of leakage prevention and reduction on energy and system operating costs. It was emphasized that after the repair of the leakages in the DMA, the inlet flow rate of the DMA decreased by 9% and the system input energy was reduced by 8% and the efficiency of the system improved with ALC. It is seen that the DMA provides significant contributions in WLM. However, DMA design and implementation requires detailed analysis as it creates significant costs as well as technical, technological, data measurement requirements. For the effective and sustainable application of the DMA, it is very important to fulfill the following conditions; (i) analyzing the necessity and technically applicable of this method to CC, (ii) current of basic data such as network, service connection, customers, valves and adequate knowledge and infrastructure for zero pressure testing in GIS (iii) ensuring the installation and integration of the necessary equipment for measuring and monitoring data. Module D proposed in this study includes the DMA method and tests the constraints, requirements, CC and performance by working integrated with other modules for the necessity and applicability of this method.

In the MNF analysis, the input flow and pressure changes are monitored between 02: 00-04: 00 when the consumption is minimum, and the recoverable leakage is determined by subtracting the authorized consumptions and background leaks from the input flow [25, 69]. MNF analysis has been widely used in the literature [14, 16, 17, 70]. It is very important to apply this method in a DMA in order to use this method effectively, for detection and locating leaks in a short time and to increase efficiency. The most widely used method in calculating the background leakage and authorized consumption is the BABE method based on network and customers characteristics that should be correct [69]. Farley et al. [3] emphasized that MNF occurs between 02.00-04.00 hours, when consumption is minimum and leaks constitute the largest percentage of total night flow. Farah and Shahrour [71] applied the MNF method to a large-scale pilot project to predict leaks and monitored the area with a real-time system. It was emphasized that with the strategy developed, the rate of water loss has decreased from 43% (2015) to 7% (2016). As can be seen, MNF analysis provides important contributions in the management of leakages. However, this method must be applied in DMA, the input flow must be measured and monitored with SCADA, and the customer, network and operating data must be up-to-date in GIS. In a DMA, ground microphone or regional recorders are used for local leak detection and monitoring the sound frequencies and allowing the spatial location of the leaks. However, in the successful implementation of these methods, the type of pipe material, the soil thickness on the pipe and the monitoring time interval have a significant effect. Module D includes the MNF analysis and tests the constraints, requirements, current conditions and performance by working integrated with other modules for the necessity and applicability of this method.

In WDSs, system operating pressure and changing in pressure is very effective on the new faults and the leakage amount in existing faults and background leaks [3, 69, 45]. In the mathematical explanation of the pressure and leakage relationship, the FAVAD equation was proposed by [72]. In the literature, PM has been applied to reduce the effect of pressure and pressure variation on leakage and failure [18, 50, 51]. Fontana et al. [19] emphasized the importance of PM in detecting background leaks in WDS and showed that leaks can be reduced with a real-time PM. In the study, it was observed that by providing the necessary pressure in critical nodes, excess pressure is reduced and pressure levels in all WDS are optimized. The main purpose of PM can be given as;(i) reduction of leakages in existing faults, new failures and leaks and operating costs, (ii) extending the economic life of the system, (iii) supplying less water to the system, ensuring water and energy efficiency. However, in order to apply PM, it should be implemented in a DMA, existing network and customer characteristics, topography, day and night water demand, number of critical points and minimum/maximum pressure requirements should be considered. Module D includes PM and tests the constraints, requirements, CC and performance by working integrated with other modules for the necessity and applicability of this method.

The network rehabilitation should be based on extending the economic life of the existing pipes and deferring the network renewals as much as possible. Kleiner et al. [73] emphasized that the failures that occur as a result of the completion of service life of pipes, the increase in the damage frequency and the decrease in the hydraulic capacities could require network rehabilitation. It was stated that alternative methods should be applied before renewal and the most appropriate renewal strategy should be defined. Tee et al. [54] aimed to operate the system under budget constraints, to make maintenance and renewal plans, and to determine the remaining service life of the pipes. For this, the most appropriate replacement was determined by minimizing the risk of failure and the life cycle cost of the pipe with the genetic algorithm. Moglia et al. [74] aimed analytical analysis of the risks of methods such as NR and pressure reduction with the DSS developed, and planned long-term planning and budget adjustments by ensuring NR prioritization. Rogers and Grigg [52] developed a pipe failure model by taking into account the characteristics of the infrastructure, operation and maintenance conditions, and asset management tools for determining failure-prone pipes in renewal and assessing the current network condition.

Therefore, before deciding to renew the network in a region, it is necessary to monitor the number of failure maintenance and repair, analyze the operating costs and to determine the locally changed pipe rates. Moreover the most importantly, a detailed cost benefit analysis should be performed. However, in order to carry out these analyzes, there should be sufficient infrastructure facilities to have a fault management system, to keep data regularly, to analyze the current situation, to monitor the performance according to the most appropriate indicators and to implement and monitor other methods. By making these analyzes, it is very important to determine the priority regions in renewal, make investments according to this order and to manage the initial investment and operating costs. Therefore, Module D includes PM and tests constraints, requirements, CC and performance by working integrated with other modules for the necessity and applicability of this method.

APPARENT LOSS MANAGEMENT

AL consisting of illegal consumptions and losses from customer water meters includes the consumed by customers but not paid for and causes direct loss of revenue for the utilities [2]. As in WLM, in order to determine the most appropriate method in preventing AL, the CCA of the system, data available, PIs, gap analysis and target setting modules should be taken as basis. In the WLM model proposed in this study, the components of the AL, the causative factors and the current methods are evaluated in the Module A. AL management should be system specific, and the road map and method should be determined based on the system's requirements and characteristics [33]. However, in order to obtain the expected benefits from these methods, it is essential to carry out detailed analysis within the framework of the constraints, requirements, costs, technical applicability of each method. Since it is important to increase customer reading efficiency in providing revenue increase, the customer management (CM) system should be matched with the field where the data updates should be made. In an updated CM system with the field, monitoring the customer's consumptions, making monthly regular readings and inquiries according to customer types, ensuring integration with GIS can be shown as the most basic and necessary processes. Criminisi et al. [20] emphasized that meter errors are the most important and the most difficult component to measure. The results showed that AL increased rapidly with the age of the meter, and in private water tanks, 15-40% of users created additional AL due to insufficient measurement records. Mutikanga et al. [21] developed a methodology based on the size of the utility, meter age, management and control procedures in place for data processing and invoicing. The results showed that measurement errors and illegal use were the most important components of AL. Fontanazza et al. [23] examined the effects of AL arising from measurement errors caused by the meter age and special water tanks through experimental and theoretical analyzes. It was determined that measurement errors are affected by the flow velocity through the meter according to the network pressure and the water level in the tank.

Integration of updated customer and meter information with GIS enables spatial and temporal analysis of meters over 10 years old, making inquiries according to meter error rates. For these analyzes, first of all, it is necessary to evaluate the CCA in terms of customer management in the utilities, determine the weaknesses and strengths and the priority components that need improvement. Module D includes the methods that can be applied to prevent the components of the AL. This module allows the selection of the most appropriate method according to the determination of weaknesses and strengths.

CONCLUSIONS

In this study, the structure of WLM model and modules proposed in collecting data and evaluating the current performance, determining the weaknesses and strengths and choosing the most appropriate methods were evaluated and discussed based on literature studies. The reasons for the problems experienced in WLM were highlighted. The lack of roadmap for data collection, monitoring and analysis, a strategy based on the CCA is the one of the most important problems. Moreover, identifying weaknesses/ strengths and defining risks, lack of sufficient technical, personnel, economic situation and lack of sufficient information and strategy to use the most appropriate method are also main problems encountered by utilities. This situation causes unrealistic golas in WLM, failing to achieve the defined golas, revision and postponement of goals, development and implementation of daily policies and not developing long term solutions. The methods recommended in reducing and preventing water losses are high-cost and require important technical, personnel and information systems infrastructure. Therefore, the most appropriate reduction/control methods should be selected and applied, taking into account the existing technical and personnel condition of system, and the technical and economic applicability of the methods. Hence, the strategic WLM model proposed in this study can provide significant gains in reaching the results in a shorter time. In this model, the Module D, which was developed considering the previous modules, can make important contributions to reach the defined targets or certain performance values of the system. Since the measurable variables affecting the system are created in Module A and Module B, and there are many components and methods in these matrices that can affect each other. It is extremely difficult to generate a strategy with basic algorithmic queries in this space of alternatives, as in expert systems. As is known, in water management, each variable and method affects the system performance at different levels. Based on these variables and methods and performance criteria, the CCA of system can be found with optimization algorithms in order to reach the targeted optimum performance value. It is possible to make the CCA, condition assessment, defining performance evaluation by applying this model. For future study proposed module structure will be used in a heuristic optimization algorithms method in order to obtain optimum system performance. Furthermore, unique objective functions will be defined and they are optimized by minimizing and maximizing in algorithm process for optimum system.

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THE LIST OF ABBREVIATION

AL	Apparent losses
ALC	Active leak control
AWWA	American Water Works Association
CCA	Current condition analysis
CM	Customer management
DMA	District metered area
GIS	Geographic Information System
IBNET	The International Benchmarking Network for Water and Sanitation Utilities
ILI	Infrastructure leakage index
IWA	International Water Association
MNF	Minimum Night Flow
NRW	Non-Revenue Water
PE	Performance evaluation
PI	Performance indicator
PM	Pressure management
WDS	Water distribution system
WLM	Water loss management

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