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An asset management approach to optimize water meter replacement

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A R T I C L E I N F O

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A B S T R A C T

Despite existence of many developed approaches for identifying optimal time of Water Meters (WMs) replacement, less attention has been paid to the impact of WM failure risk on utilities revenues and the proper time of replacement. Here, the Asset Management (AM) approach is introduced as a holistic managing framework optimizing Life Cycle Costs (LCC), especially incorporating WM failure risk in asset replacement decisions. The proposed AM framework is based on four core steps. The application of the proposed framework for a real case study has shown confidence in finding the economical time of WM replacement. It was further shown that the risk costs associated with WM failure have higher impacts on optimal time of WM replacement than the revenue lost due to its inaccuracy. The sensitivity analyses of input data values show that water price, initial investment and accuracy degradation rate have the highest impacts on LCCs amongst other parameters.

1. Introduction

International experience has shown that water as the social and economic commodity served by utilities, must be better appreciated and compensated through customers' water bills (Barraqué, 2011; Biswas and Tortajada, 2010). Calculations of these bills are based on two important factors: 1) water tariffs allocated to the amount of water consumptions 2) the amount of water measured by the Water Meters (WMs). Since the utility policy makers, usually revisit the first factor annually, the second factor can play a more effective role in loosing revenues through issuing inaccurate bills. WMs are the only practical tools for the utilities to measure their revenues and from this perspective; they are the most important assets of water distribution networks around the world. Despite progressive developments in the metering industry and water measurement, most of the existing WMs in many water distribution networks have been inherited from the past decades. Water measurement accuracy of these meters is degraded over the years and most of them reach to the end of their useful life while still operating inefficiently. This accuracy degradation of WMs during their operational lifespan can pose severe challenges for the utilities, more often than not, in the form of increase in non-revenue water supply.

To help utilities to face the above mentioned challenges (ensuring the accuracy and precision of the measurement), the developed official standards and regulations present some recommendations about time of testing and replacing of the WMs. For example, based on American Water Work Association the WM size of 5/8″-1″, 1″-4″, 4″ and larger, should be tested every 10, 5 and 1 year respectively (American Water Works Association, 1999). Since the accuracy degradation of WMs is dependent on different factors under varying operational conditions, these proposed recommendations have not been fully constructive. Consequently, many researchers have tried to go beyond these suggestions. Therefore, many different guidelines or models for predicting WMs' timely replacement have been proposed. The majority of these models are sensitive to their inherent assumptions, complexity, involved uncertainties and influencing factors (such as condition of WMs' installation and operation, age, water quality, pressure head of water distribution network and …). Thus, finding a holistic approach for managing WMs services with fewer challenges is very much encouraged.

For the sake of simplicity, many utilities around the world have used simple criteria to judge the time of WMs replacement. For example, some of the utilities use cumulative registered volume passed through meters and some others use the age of WMs from its installation date as the criteria for replacement (Davis, 2005; Thornton et al., 2008). In this type of decision-making, some thresholds for the criteria (like 10 years of operation or 5000 m^3 as the total cumulative volume of water measured by one WM) are

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Data availability

Data used in this study are available, in Persian, in spreadsheet format and may be obtained from the authors on request

List of Acronyms and Abbreviations

WM	is the water meter
AM	is the asset management
LCC	is the life cycle cost
CRI	is the composite replacement indicator
NRW	is the non-revenue water
OA	is the operational age
TWM	is the total water measurement
AAWM	is the annual average water measurement
NT	is the number of available consumption data
BR	is the annual breakage rate
P	is the probability of the failure
t	is the time step
HCI	is the hydraulic criticality index
R	is the risk measurement of failure
NPV	is the net present value
WP	is the water price
ε	is the meter error (accuracy degradation)
n	is the number of year
r'	is the real discount rate
C_{in}	is the capital cost
C_{INST}	is the installation cost
C_{Admin}	is the administrative cost
C_{Lab}	is the labor cost
C_{sv}	is the salvage value
S	is the inflation rate
r	is the discount rate
T	is the meter reading frequency
N	is the number of zero reading of meter
D	is the conscious delay time of meter replacement

required to be established. The idea of WMs replacement based on these criteria has been presented through finding the relationship between WMs accuracy and their age or the cumulative water registered by any meter. Most of these relationships were presented in a linear form (Arregui et al., 2006; Davis, 2005; Mutikanga, 2012; Noss et al., 1987). In 1987, Noss et al. stated that WM accuracy must be measured in three different ranges of flow including high, medium (intermediate) and low flow. His results showed that the less the available flow rate is, the less the WMs' accuracy will be. Moreover, it was found that the accuracy degradation rate in low flow versus WM age is more severe than high flow. Furthermore, the optimal testing period of WMs is most sensitive to the rate of deterioration of meter accuracy with its age (Noss et al., 1987). Some of Noss's results were confirmed later by Allender (1996). Later, Fontanazza et al. (2012) stated that, knowing WMs age and cumulative water registered are not sufficient criteria for replacement decisions. Therefore, they presented a new criterion called Composite Replacement Indicator (CRI) based on OECD recommendations (2008). It was found that the use of this criterion may result in better replacement decisions.

Another set of research with different points of view has focused on the impact of considering the economic issues (such as water and WMs prices) in WMs replacement time. Noss et al. (1987) and Yee (1999) can be cited as the pioneer researchers in this field. In this viewpoint, the right time of replacement is detected when the annual average costs of replacement become minimum. In later studies, it was found that the proper time of replacement not only depends on the rate of accuracy degradation and economic issues, but also strongly sensitive to the opportunity value of time such as discount rate and consequently minimizing cost during entire life of the WMs (Arregui et al., 2010; Mutikanga, 2012). In these life cycle cost (LCC) analyses, several costs of installations, replacement policy, water lost, testing and maintenance, salvage, water and WM price, along with several rates of discount, inflation, interest and so on were considered. These efforts are sometimes presented in the forms of handy tools such as I-WAMRM in order to determine the optimum time of WMs replacement (Mutikanga, 2012), WOLTMAN in order to assess weighted error of a meter (Arregui et al., 2010) and ECONANAL in order to define optimum testing periods of WMs (Noss et al., 1987). Despite all the advantages of these developed tools, some points of concern are evident: requiring rich databases (such as meters accuracy and their degradation rates over the years, customer water demand patterns and flows, WMs accuracy curves), limitation of meter types (Mutikanga, 2012), posing difficulties in real practices (Arregui et al., 2010) and performing calculations in the black boxes involving many uncertainties. As a result, applications of these tools are faced with several fundamental questions.

Comprehensive review of the literature about identifying WMs and finding their optimal time of replacement shows that what has been rarely discussed, is the costs that water utilities may accept in order to burden the risk of WMs failure during their LCCs. When the meter fails, the utility may lose some its revenue due to the unrecorded customer water consumption. Therefore, WM failure can impose risks on the utility's revenue. It therefore becomes necessary to investigate whether this risk cost may be considered as one of the effective elements of the WM LCC and its corresponding optimal time of replacement. To respond to this necessity, a holistic management framework is proposed here, as the main contribution of this work, which can take economic risk of WM failure into account while maintaining the required level of meter services with the lowest LCC.

An asset Management (AM) approach, switching the required annual assets rehabilitation as part of the operation and maintenance program, can ideally set the appropriate management framework for making decisions on timely replacement of WMs. Extensive use of this management approach in many disciplines and applied sciences such as business and financial planning, transmission and distribution of energy and power, smart telecommunication, management of infrastructures (such as transportation and water distribution), short and long term planning, and risk based decision making has posed AM as an effective integration of engineering and management approaches. Interestingly, the majority of these fields of work are somehow related to the subject of optimizing the replacement of meters and further addressing the increasing interests in smart metering and monitoring.

In addition to other existing WM optimal replacement options, AM can help in various ways: identify where the utilities have any assets of any given type, anticipate risky aging meters by location, identify potentials for risk cost reduction, assess replacement of which meter is profitable, minimize life cost of each meter with regards to the risk cost and identify priority of each meter for optimal replacement. The proposed AM approach is presented based on a four-step framework comprising: identifying current state of assets, identifying critical assets and their corresponding risks, minimizing LCC of each asset, and presenting long-term