A GRAPHICAL METHOD TO CALCULATE THE OPTIMUM REPLACEMENT PERIOD OF WATER METERS

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Abstract:

Calculating the optimum replacement period of meters has always been a major concern for water utility managers. Its determination is time consuming and requires multiple calculations. This paper presents a graphical method to obtain, in a simple but accurate manner, the optimum replacement period of installed meters. For this purpose it has been produced a chart, in which the most influencing variables are considered. These variables include the degradation rate of the weighted error of the meters, the selling price of water, the acquisition and installation cost of the meters, the volume consumed by the users and the discount rate. The chart also allows for a quick sensitivity analysis of different options. For example, by plotting straight lines it is possible to determine by how much the optimum replacement frequency of a meter would change if it degrades at a different rate than expected or the selling price of water increases.

Keywords: Water meter management; meter replacement

INTRODUCTION

As water meters become older, unregistered water volumes have a tendency to rise, increasing revenue losses for the water utility. Although degraded meters could still work for a long time, the resulting economic losses would eventually make their replacement by new accurate meters unavoidable. A double key decision has to be faced by utility managers when a number of working old meters need to be replaced: selecting the most adequate meter type, and quantifying its most profitable working lifespan. Both questions need to be solved simultaneously.

The difficulty of such decision lies in the complexity behind the degradation rate of meters error. Frequently, meter types are chosen based on their initial error performance and their price. Furthermore, meters replacement policies are too often set with simple rules and regulations that limit the maximum meter age or total registered volume.

These simplistic policies based on the accumulated volume or the age of the water meter and recurrently outlined in local and national regulations, although aimed in the right direction, neglect significant factors such as the actual working conditions of the meters, or the characteristics of household appliances and the habits of final consumers. These are key factors, for it is possible that meters of the same type, age and total metered volume, but serving different consumers, produce differing metering errors, and therefore, different unregistered volumes.

The substantial revenue losses that can derive from underregistration surely deserve an accurate analysis that goes beyond the approaches mentioned above.

Factors involved in the optimum replacement policies of water meters

Before the calculation procedure is presented it is necessary to review all factors involved in the economic model used to find the optimum replacement frequency of a meter.

Initial costs

The acquisition price of a new meter is not the only cost to consider when managing meters. Other costs, such as installation and administrative costs related to meter replacement should also be considered. Unlike the costs caused by unregistered water (which are distributed in time), initial costs are paid when meters are bought and installed. At the end of the working life of the meter its salvage value is insignificant.

Distributed costs

Unregistered water due to meter inaccuracies must be considered a real cost for the water company. The monetary losses suffered by the utility are proportional to the unregistered volume and the selling price of water. Metering inaccuracies are present right from the moment meters are first installed (the starting flow rate of a meter is not zero and the error is neither constant nor equal to zero throughout the measuring range). Therefore, the costs of unregistered water volumes should be considered throughout the meter's working life, bearing in mind that as it becomes older, the mechanical parts degrade and measuring errors increase significantly.

The calculation of the so-called distributed costs is more complex than the initial costs, since they depend on numerous factors (Arregui et al., 2007):

- **Error curve of the meter**

  Metering errors depend on the operating flow rate following a very characteristic curve path –the error curve of the meter. The shape of this curve strongly depends on the working principle and design characteristics of the meter. As shown in Figure 1, the shape of the error curve of a typical oscillating piston meter has a much different profile than the curve of a typical single jet velocity meter (the curves presented are the average of 35 new meters, of these two types, tested at the laboratory of the Polytechnic University of Valencia).

Since errors vary throughout the measuring range, the amount of water not registered by a water meter depends not only on the shape of the curve but also on the consumption flow rates of the users. In order to estimate how much consumed water is not measured, both parameters need to be combined to calculate the weighted error of a meter.

The shape of the curve of a new meter affects its initial weighted error and, obviously, the distributed costs of unregistered water. However, the rate at which the error curve evolves with time has a much greater impact on the distributed costs than the initial shape of the curve. A meter that degrades at a faster rate will generate larger distributed costs than a meter with a larger initial error that maintains its error curve more stable with time.

The evolution of the error curve with time will depend on factors such as meter technology, water quality, consumption profile of the user, installation conditions and meter parts composition. Typically, meter errors at low flows will become more negative with time and accumulated volume (Bowen et al., 1991; Arregui et al., 2006) while at medium and high flows they will be more stable.

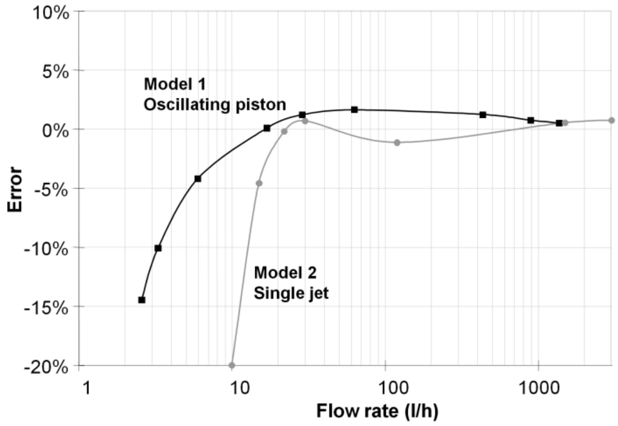

Figure 1. Initial error curves of two residential meters

- **Consumption profile of the user**

The second parameter to calculate unregistered water is the consumption characteristics of the users. Water consumption, expressed as a percentage of the total volume, is plotted against the flow rate at which it is consumed. This is usually called water consumption profile of a user and provides information on the percentage of water consumed within each flow rate range. In statistical terms it can be defined as the density function of water consumption with respect the consumption flow rate. A comprehensive research was carried out by the AWWARF (Bowen et al., 1993).

The importance of the meter error at a given flow rate –as defined by the error curve of the meter– will depend on how much water is consumed at that specific flow rate. If small volumes of water are consumed at a certain flow rate, its importance will be less than if larger volumes are consumed. To account for this, the weighted error of a meter is defined as the combined error at different flows considering the percentage of water that it is consumed at each flow rate. This parameter provides, for a specific consumption profile, the amount of water, in percentage, that is not measured (or measured in excess) for every liter consumed.

Several authors have proposed different methods to calculate the weighted error of a meter (Male et al., 1985; Allender, 1996; Yee, 1999; Johnson, 2001; Ferreol, 2005; Arregui et al., 2006). However the selected methodology will have a great impact on the final results (Arregui et al., 2009). A specific software package, *Woltmann*, has been developed by the authors to calculate the weighted error of a meter (the downloadable free demo version allows to perform this calculation). The use of this software prevents many of the frequent mistakes that are made while performing the weighted error calculation of a meter.

For simplification purposes, the evolution of the weighted error of a meter with time is usually assumed linear (Male et al., 1985; Ferreol 2005; Arregui et al., 2006). Its slope, a, represents how much the weighted error increases per year.

- **Water tariff**

To transform unregistered water volumes into distributed costs, information about the tariff structure is needed. Water volumes can be converted into monetary figures multiplying them by the appropriate water-selling price. In case of a tier-structured tariff, the profit loss caused by meter inaccuracy will be the cost of the last cubic meter consumed and not billed.

- **Discount rate**

To properly evaluate the total cost of unregistered water, future economic losses must be converted to their present value. For that conversion, the nominal discount rate, r, is used. Its value is directly linked to the applicable interest rates and the risk of the investment (Bierman and Smidt, 1993). In this paper, to correct the effect of inflation, s, the real discount rate, r’, will be considered instead of the nominal discount rate (Equation 1).

$$r' = \frac{(1+r)}{(1+s)} - 1 \quad (1)$$

As a final remark, large volumes of water consumed at low flow rates and high prices of water will increase the need for accurate and expensive meters, especially with low discount rates. In this case, meters will have a short scheduled lifespan. Conversely, in a utility billing cheap water and supplying consumers with no leaks in their facilities (less consumption at low flow rates) the chosen meter would not need to be so accurate or expensive, and could be replaced after a longer period of use.

ANALYTICAL SOLUTION TO THE PROBLEM

Some authors (Male et al., 1985; Allender, 1996; Yee, 1999; Johnson, 2001; Ferreol, 2005) do not consider the opportunity value of time and do not include the discount rate in their economic models. Using this incomplete approach, the optimum is found by calculating the minimum of the average annual costs of the meters.

However, when considering that money has a different value today than it will in the future, such approach is no longer valid (Seitz et al., 1999). In these cases, a method based on the NPV approach (Arregui et al., 2006) can be used to compare options with different lifespan (the NPV of the costs of infinite replacements, carried out at fixed intervals of time, is calculated). The present value of the cost of those infinite replacements is typically called NPVC (net present value of the replacement chain):

$$NPVC_n = \left[C_{acq} + C_{inst} + C_{adm} + \sum_{i=1}^{n} \forall_i \cdot \varepsilon_i \frac{C_W}{(1+r')^{(i-1)}} \right] \cdot \frac{(1+r')^n}{(1+r')^n - 1} \quad (2)$$

where C_{acq}, C_{inst} and C_{adm} are the acquisition, installation and administrative initial costs, C_W is the selling price of water (considered constant throughout the calculation period), $\forall_i$ is the average volume consumed by a user on the year i, ε_i is the weighted error of the meter for year i, r' is the real discount rate and n is the number of years of the replacement period.

In order to obtain the optimum replacement period, the $NPVC_n$ for several values of n should be calculated. For a given meter, the value of n that gives the minimum $NPVC_n$ will be the replacement option that generates the minimum cost for the water utility. In other words, n will be the optimum replacement period of the meter. The meter featuring the lowest $NPVC_n$ for its optimum replacement period will be the meter to install. A complete numerical example of this methodology is developed in Arregui et al. (2006).

With this approach, all the factors involved in the problem are correctly considered and there are no inconsistencies in cost or time figures. This procedure therefore provides the best theoretical solution in terms of economic optimization.

However, uncertainties often prevent obtaining a fully reliable and exact result (e.g. those related to the real degradation rate of the weighted error of the meter). In these cases, a sensitivity analysis for the uncertain variables can be used to assess different scenarios.

GRAPHICAL METHOD TO CALCULATE THE OPTIMUM LIFESPAN OF A METER

The presented method poses certain difficulties in its practical application. Even with the help of a spreadsheet, performing all the calculations involved in Equation 2 for different meter types and different lifespans could become a tedious task.

By simulating and analyzing a high number of cases, the authors have developed a simple tool that quickly deems the optimal lifespan of a given meter type under specific working conditions. This approach is possible by gathering in a single variable, V, the main initial conditions related with costs, as Equation 3 shows. Basically, this parameter represents the payback period of the initial costs of the meter by taking into account the annual income expected from billed measured volumes.

$$V(\text{years}) = \frac{\text{Initial costs of the meter (€)}}{\text{Avg. consumption per user (m}^3\text{/year)} \cdot \text{Price of water (€/m}^3\text{)}} \quad (3)$$

Hence, keeping the degradation rate of the weighted error and the real discount rate as independent parameters, the optimal lifespan of any meter can be plotted on a vertical axis against the variable V on the horizontal axis. Taking a range between 0 and 2 years for the V variable; the values 1, 2, 3 and 4% for the real discount rate, r'; and the values 0.1, 0.3, 0.5, 0.7 and 0.9%/year for the degradation rate of the weighted error, a; the resulting chart is obtained (Figure 2).

The presented chart (Figure 2) can be used for any water meter independently of its type and size. To obtain the optimal lifespan of a meter, once the V value is calculated and both the discount rate and error degradation rate are set, the optimal replacement period can be obtained on the vertical axis of Figure 2. Only then, Equation 2 is solved just once to get the exact NPVCn of the costs for that optimal lifespan. Finally, Figure 2 displays all possible combinations for the variables involved, and therefore the sensitivity of the results can be quickly checked. For example, drawing a vertical line in the chart will allow checking different lifespans for a meter having different degradation rates of the weighted error.

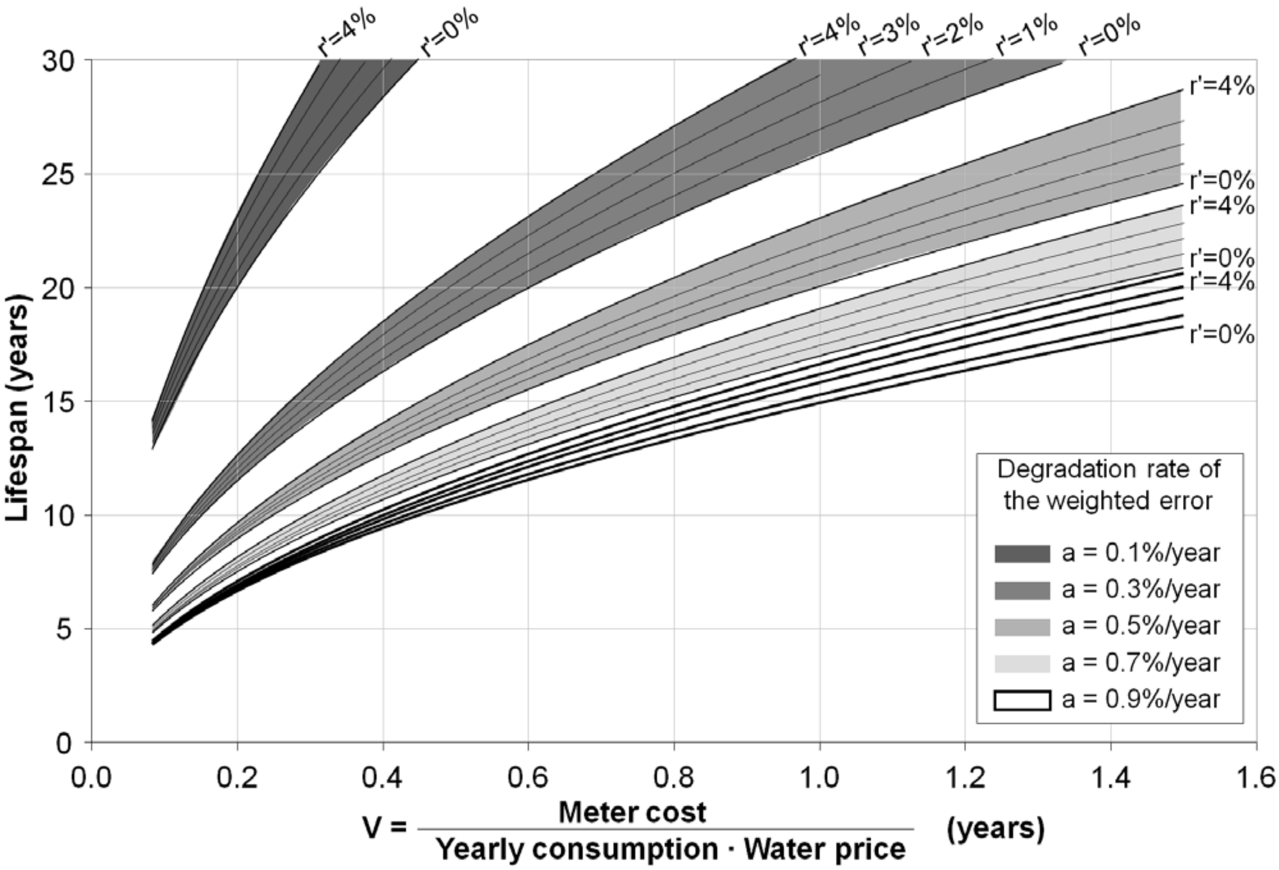

Figure 2. Optimal lifespan of a meter depending on the initial conditions

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FIGURE CAPTIONS

Figure 1. Initial error curves of two residential meters

Figure 2. Optimal lifespan of a meter depending on the initial conditions