Management strategies for optimum meter selection and replacement

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Abstract There are two main decisions faced by utility managers regarding meters in an undertaking: which meter to instal and when to replace it. Traditionally the criteria used to make these decisions have been arbitrary and often imposed by third parties regardless of the situation of the individual undertakings. This paper presents “Comparative billing analysis”, a methodology to analyse meter performance within the undertaking, as a means to support decision making in water meter management.

The main difference between the comparative billing analysis and previous methodologies resides in the use of the commercial billing database that most undertakings have these days. By analysing existing data with a systematic approach, it is possible to determine which kind of domestic meter is most appropriate for the utility. This method turns out to be as reliable as previous ones, but much more efficient in the use of economic and human resources.

Keywords Management; meter; replacement of meters; selection of meters

Introduction

Water management is becoming more reliant everyday on accurate customer metering. Most strategies, from demand management to detailed water balances, depend on reliable metered consumption figures. This information is strongly dependent on the working conditions of the existing meters and consequently on the meter management plans previously adopted. However, meter management within the undertaking is often done without specific preparation or a detailed analysis of the situation. Frequently, the staff are responsible for several other areas and cannot focus on deciding which meter to instal, or when to replace it. And more shockingly, there is not even information on the utility’s current meters’ characteristics. An optimised metering system in a utility will considerably reduce the operational metering costs (which include both the meters’ cost and the unaccounted-for water).

There are two main decisions faced by utility managers regarding meters in an undertaking: on the one hand selecting the optimum commercial meter from the ones available in the market. Regardless of other criteria, such as commercial agreements and company policies, there is an optimum technical solution to the problem of selecting the best meter for the existing conditions within the utility. The price of water, water consumption patterns and water quality are some of the factors affecting this decision. On the other hand, managers need to decide for how long those meters should remain installed without being replaced. An early replacement will result in a higher average cost due to the influence of the initial fixed costs. If the meter is replaced too late, a significant loss of revenue caused by metering inaccuracies will also increase the average cost.

To solve both questions it is necessary to consider that water meters are mechanical devices that wear out during the time they are installed. However, not all metering technologies deteriorate in the same way and hence experience the time past in different ways. Consequently, economic losses due to the non-metered water do not share the same trend for different meter technologies or constructions.
Furthermore, and added to the complexity that this last variable poses, it is necessary
also to consider some others, such us the cost of the meter unit itself. This cost is usually
related to the meter accuracy or its reliability under certain working circumstances.

So far, there have been several methodologies proposed in the literature, allowing deter-
mination of the optimum meter type and the most adequate replacement frequency
(Allender, 1996; Arregui, 1998; Male et al., 1985; Planells et al., 1987; Yee, 1999). These
techniques require intense lab testing of used meters and field measurements of real con-
sumption patterns (consuming a great deal of human and economic resources).

The alternative solution presented in this paper makes use of the company’s billing
information system to solve these questions, reducing considerably the costs identified in
previous methodologies.

**The traditional approach**

Traditional methodologies are based on the calculation of the total cost of the meter for its
entire life, to determine the most appropriate type of meter. Such costs can be divided into
those strictly related to the acquisition, installation and maintenance of the meter, and the
water that the meter will not register due to mechanical deterioration (often, in small diam-
eter meters, there are no maintenance costs involved, and the problem can be simplified by
only considering acquisition and installation costs in the first category).

The non-metered water increases with time at a rate that depends on the utility context,
the meters themselves and the evolution of the accuracy vs. rate characteristic. This, how-
ever, is not always the case, and under some circumstances it can be demonstrated that the
amount of water not registered does not change with time, and sometimes even decreases
(owing to overmetering in some models at medium and high flow rates).

![Figure 1](https://iwaponline.com/ws/article-pdf/3/1-2/143/477619/143.pdf)

To adequately estimate the cost of the non-metered water, it is necessary to know the
weighted accuracy of the meter with time. The problem lies in the fact that meter accuracy
depends on both the flow rate and its age, as shown in Figure 1. Consequently, the dis-
crepancies between the metered volume and the actually consumed one do not depend
exclusively on the accuracy vs rate characteristic, but also on the consumption rates of the
users (water consumption patterns).

To correctly establish the total volume of water not metered within the undertaking, it
would be necessary to know every meter’s individual accuracy vs. rate characteristic as
well as the consumption patterns of the associated user.

In practice, obtaining this information is not possible. As a consequence, a statistical

$$\text{Total costs} = \text{Installation cost } + \text{Meter cost } + \sum_{\text{year}=0}^{\text{year}=n} \text{Non-metered water}$$ (1)

![Figure 1](https://iwaponline.com/ws/article-pdf/3/1-2/143/477619/143.pdf)

**Figure 1** Domestic meter accuracy vs. rate characteristic by age
sampling of the meter population is needed, stratified by brand and age, to estimate an average accuracy vs. rate characteristic for each model with age. Simultaneously, flow trace analyses are done to establish typical consumption patterns for each type of household within the undertaking.

By adequately combining the results of the sampling, it is possible to obtain the evolution with time of the weighted accuracy (accuracy degradation profile (Yee, 1999)) of every brand or type of meter, and consequently the cost of the water not metered through time (second term in equations 1 and 2).

The most appropriate meter would be the one with a lower average yearly cost (Eq. (2)). Details on this methodology can be found in Allender (1996), Arregui (1998), Male et al. (1985) and Yee (1999).

\[
\text{Average yearly cost} = \frac{\text{installation cost} + \text{meter cost} + \sum_{\text{year}=0}^{\text{year}=n} \text{Non-metered water cost}}{n}
\]  

\text{(2)}

**Comparative billing analysis**

As an alternative to the traditional approach, the comparative billing analysis relies on existing data, and not on costly statistical studies. This method is based on the analysis of the commercial billing information system used by the undertaking to produce the periodical bills to the users. Basically, the method tries to determine how well a meter behaves comparing the user’s monthly (yearly) billing with the rest.

To compare the performance of several makes and models of meters, a few conditions are required.

- The studied models of meters are homogeneously installed within the undertaking, to ensure that the influence of variables such as the plumbing characteristics, the socio-economical background of the users, the quality of water and the number of repairs in the network affect equally all brands, and do not influence the conclusions.
- There are no differences in the consumption characteristics of the users between models.
- The reference period is the same for all models.

To apply the methodology, the billing database should contain fields with the following information:

<table>
<thead>
<tr>
<th><strong>Meter</strong></th>
<th><strong>Model</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diameter</strong></td>
<td><strong>Installation date</strong></td>
</tr>
<tr>
<td><strong>Installation characteristics</strong></td>
<td><strong>Meter characteristics</strong></td>
</tr>
<tr>
<td><strong>Water consumption</strong></td>
<td><strong>Meter reading 1</strong></td>
</tr>
<tr>
<td><strong>Reading 2 date</strong></td>
<td><strong>Reading 2 date</strong></td>
</tr>
<tr>
<td><strong>Additional information</strong></td>
<td><strong>Household characteristics</strong></td>
</tr>
<tr>
<td><strong>City area</strong></td>
<td><strong>City area</strong></td>
</tr>
</tbody>
</table>

* This information is not strictly necessary, but may be of great help when trying to explain the sources of significant differences in registered water consumption.

The methodology relies basically in grouping the meters by model and age and, in general, by any other variable that might make the consumption characteristics of the group more homogeneous.

With regards to age, many authors believe that the deterioration in the meter is more closely related to the total volume of water that has circulated through it than to the time it...
has been in service. For this reason, the stratification in ages may be done either by installation date or by meter reading (total accumulated volume).

Out of each group of similar meters (same model and age range) the average metered volume for a certain period is calculated. Since the time lapsed between the last two readings of the meters is not necessarily the same for all of them, the obtained volume is divided by time to calculate the water consumption per unit of time.

The final objective is to determine for each meter model an evolution of the average yearly metered volume versus age or the total metered volume. The comparison between models should be quite simple, because there will be different tendencies for each one of them. These tendencies will account for the rate of decay of each model. Hence, the older meters within a certain model with a flatter accuracy vs. rate characteristic will average more volume per year than the meters of a model deteriorating faster.

To validate the decrease in accuracy of a certain group of meters, corresponding to a certain model and age group, the metered volume of different periods can be tracked. Obviously, this rate of decay will be biased by the changing trends in consumption patterns (due for instance, to water saving campaigns). Nevertheless, it is possible to correct this effect by compensating the evolution in a single meter’s registered volume with the overall evolution of consumption in the undertaking.

The method presents further advantages if the information system is detailed enough. When this is the case, it is possible to identify additional variables that could negatively affect the weighted accuracy of the meters.

Traditional methodologies, on the other hand, do not allow us to easily identify the causes of a decrease in performance of a certain meter. This is because the status of the meter is determined through laboratory tests. The number of meters to be tested, and hence the cost of the study, is directly related to the number of variables observed. For instance, if the number of repairs in the network, the quality of water, the installation conditions or the users characteristics are to be analysed for their influence in the meter’s accuracy, each one of the meters tested in the laboratory should be characterised according to these variables. Consequently the number of subgroups to consider would increase considerably, and so would the number of meters of the total sample.

The use of the billing information system reduces considerably the workload during the analysis stage, because the procedure is limited to making the appropriate queries to the database, and to analyse statistically the resulting data to determine the significant variables.

Figure 2 is an example of the results that may be obtained in this type of analyses. In the figure, two brands of meters (oscillating piston) homogeneously installed in an undertaking, are compared. Initially, up to 2,000 m$^3$ of accumulated volume, model 1 appears to be more accurate. However, as a higher volume flows through both meters, these brand of meters tend to register a lower annual amount of water, which indicates a higher rate of decay. Consequently, depending on the replacement policy of the undertaking one of the models will be more appropriate. If the undertaking wishes to replace meters more frequently, model 1 will provide a better performance. However, for longer replacement periods, model 2 should be chosen.

These results are quite significant, especially as both meters share construction characteristics and are virtually identical. More surprisingly, both models are uniformly installed throughout the undertaking, in connections corresponding to similar types of users.

A deeper analysis of the (in this case) complete database provided an explanation for the differences. The problem was not so much a matter of wear in the parts, but rather the obstruction of the filter. The determining factor was in fact the length of the meters. The 115 mm meter’s filter clogged much easily than the one corresponding to the 190 mm...
meter. Model 2 meters were mainly (between 80 and 95%) 115 mm, and hence the number of meters that did not work, or registered lower volumes was higher than for model 1.

Advantages and disadvantages of the proposed methodology

The comparative billing analysis allows us to reduce considerably the fieldwork and, through systemisation, to track the performance of meters through time more frequently and in a consistent way. The advantages of the method can be summarised as follows.

- Allows easy comparison of the weighted accuracy of different meter models without the need to perform laboratory and field tests. Implementing the method does not require to purchase additional instrumentation or equipment, such as those needed to determine consumption patterns or to test the water meters.
- Allows identification of other variables affecting the meter’s accuracy (e.g. number of repairs in the sector, length of the meter, installation location and position, accuracy class, measuring technology, etc.).
- The current trend towards management information systems (such as the Geographic Information systems many undertakings have already implemented) provides the perfect grounds for implementing the system. In most cases the information is already available. Furthermore, and as a side effect, data handling allows to identify meters wrongly sized, abnormal consumption due to leakage, non-working meters, illegal connections, etc.
- The analysis may be carried out for each billing period, allowing the results to be periodically validated and hence, checking their reliability.
- If a complete billing database is not available, the methodology can still be applied to several reference users.

As useful and convenient as the methodology is, it still presents certain disadvantages:

- To precisely assess the meter’s rate of decay, a vital variable to determine its working life, the precise date of installation must be known.
- The method’s reliability depends on the number of meters considered. The higher the number, the greater the reliability of the results.
- In undertakings with several types of household, it is essential to carry out a second grouping, including not only model and age, but also type of household.
- The information on the meters, their installation and the users’ consumptions needs to be available in a relational database accessible through queries.
- The method is sensitive to estimations and errors in meter readings.
- All variables with influence on the decay must be considered, and hence appropriate sub-grouping must be carried out.
Comparison of methodologies – case study

To determine the real applicability of the comparative billing analysis, a case study was done in a South American city. The objective of the project was to determine the accuracy characteristics of two different measuring technologies (multijet meters vs. oscillating piston meters). Meters were grouped by technology and total registered volume (meter reading) (Figure 3).

The evolution of the annual billed volume versus the meter reading (total volume registered by the meter during its life) might seem odd at first. It could be logical to think that meters with a higher meter reading are more deteriorated and hence should present lower annual readings (as a consequence of a lower accuracy). However, the analysis demonstrated that meters with a higher overall reading, did register more volume during the last year (Figure 3). The reason for this is that, in average, those meters actually correspond to users with a higher consumption.

To prove this last assumption, for each range of accumulated volume, the average yearly volume for the entire life of each meter was calculated (meter reading/meter age). Figure 4 shows that meters with a higher total reading have a higher yearly registered volume throughout their life (which means that the user consumption has been greater in average).

The study also showed (as can be seen in Figure 3) that the multiple jet meters did register a higher volume per year than the oscillating piston meters. As the meters accumulate more volume (higher reading) these differences become greater.

\[ y = 0.0269x + 161.33 \]
\[ y = 0.0145x + 166.08 \]

**Figure 3** Annual registered water vs meter reading

**Figure 4** Annual water consumption vs meter reading
To confirm the differences between the two meter technologies, a series of laboratory tests were performed. A total of 248 oscillating piston and 349 multiple jet meters were tested. Figures 5 and 6 show these results. Although the accuracy of the oscillating piston meters (Figure 5) is always on the side of a negative error (measuring less volume than the actual flow passing through the meter), the multijet meters present positive errors (measuring more water than the one that is consumed) for medium and high flow rates (Figure 6).

Knowing the rate of decay of the accuracy characteristics does not allow an estimate of the weighted accuracy of the meters, the consumption patterns remaining unknown. To account for this, measurements were carried out in 305 households of different social strata. The details on the fieldwork can be found in Arregui (2000). The final result, out of weighting the evolution of the accuracy characteristics for both technologies (Figures 5 and 6) and the domestic consumption pattern, is shown in Figures 7 and 8, representing the weighted meter accuracy.

The change in accuracy with age is the determining parameter in the selection of the meter, because the costs generated by the non-metered water are proportional to this variable (Eqs (1) and (2)). Using the comparative billing analysis, it is quite complicated to calculate the rate of decay in accuracy. However, it is possible to compare the performance of two types of meter, reaching similar conclusions to the ones obtained by traditional methods.

![Figure 5](https://iwaponline.com/ws/article-pdf/3/1-2/143/477619/143.pdf)  
**Figure 5** Meter accuracy at different flow rates vs meter reading

![Figure 6](https://iwaponline.com/ws/article-pdf/3/1-2/143/477619/143.pdf)  
**Figure 6** Meter accuracy at different flow rates vs meter reading
To validate the new methodology, the results obtained by both procedures were compared for the meters tested (oscillating piston and multijet).

Using comparative billing analysis, the evolution of the annual billing with the total accumulated volume was calculated (Figure 3) and a linear adjustement of the represented trends was carried out. Taking as a reference the registered volume by the multiple jet meters, the additional volume registered (in comparison with the oscillating piston meters) was determined. This percentage of additional volume, was called A\textit{valt} (%) (see Figure 9). For instance, oscillating piston meters with readings between 1,750 and 2,000 m\textsuperscript{3} will register annually (according to Figure 3) around 195 m\textsuperscript{3}, whereas the multijet meters will reach, on average, 215 m\textsuperscript{3}. So according to the comparative bill analysis, the difference in water registered will be a \(\left[\frac{215-195}{195}\times100\right] = 9.3\%\) more water.

By performing a similar operation with the evolution of the weighted accuracy for each type of meter (Figures 7 and 8), the difference in water registered for each 100 litres of consumed water can be obtained. This percentage was defined as A\textit{vtrad} (%) (see Figure 9). For instance, the average measurement error for the oscillating piston type, with a meter reading between 1,750 and 2,000 m\textsuperscript{3} (obtained through laboratory tests and measurements of domestic consumption patterns) was found to be \(-12.5\%\) (negative meaning that the
water registered is less than the water consumed). Consequently, out of 100 litres, only 87.5 are registered. On the other hand, the measurement error found for the multijet meters was of −5.2% (94.8 litres out of 100). Consequently, and according to this method, for the meter reading interval of the example these would register a \[
\frac{(94.8 - 87.5)}{94.8} \times 100 = 7.8\% \]
more water.

Taking into account the high uncertainty associated with a study based on a few samples, discrepancies between both methods can be considered minimum. And in any case, the differences in accuracy between both modes can be clearly identified.

An additional cost analysis is very easy to perform with comparative billing analysis. To determine the additional cost that a type of meter generates with respect to another, it is only necessary to multiply the average price of the cubic meter by the difference in registered volumes by both models and add the differences in the retail price of the meter. This will allow us to determine, for a certain utility, which of the considered meters will turn out to be cheaper in the long run. In the present example, there is no need for additional calculations, because it is quite obvious that multijet meters always register a higher volume, regardless the age.

**Conclusions**

Traditionally, the selection of a meter has been conditioned by variables not related to the pure technical management. Among these commercial interests, legal constraints, and even pure lack of knowledge on the performance of meters can be found. Regardless of other reasons that may condition the selection of a meter over another, one of the main constraints to strictly consider technical and economic reasons has been the difficulties and costs associated with the traditional methodologies of analysis of the undertaking meters.

The use of comparative billing analysis makes good use of the most common and updated of the databases in the average utility, the commercial billing information system. This method allows us to determine which meter is more adequate for a certain utility and replacement period, with similar results to those obtained by traditional methods.

The method is not only easier and more cost effective to perform. Once it has been done successfully, it can be performed periodically (even at every billing period) for an increased reliability and accuracy of the results. Furthermore, if a detailed database is available, it is possible to identify additional variables that could negatively affect the weighted accuracy of the meters.
References