Case Studies Demonstrate the Implications of Metering Errors

Edgar H Johnson

Email: edgar.johnson@ghd.com

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Abstract

General anomalies that occur in the management of apparent losses are identified and include determination of apparent loss indicators that fail to take into account both the random and bias errors inherent in metering. Estimating the volume of water losses that could be attributed to meter errors is also incorrectly assumed to be equivalent to the error limits (i.e. envelope) stipulated in standards. Performance indicators that are reliant on flow meter data must be expressed as a range and not as a single value which is common practice. It is shown that the measurement error range decreases as the number of meters increase when combining both their bias and random errors. A default value for reference annual apparent losses (RAAL) is quoted as 5% of the authorised consumption unless historic records can demonstrate otherwise. This 5% value relates to water meter errors that are only one component of apparent loss contributing to a volumetric imbalance and still requires inclusion of random errors in its calculation and therefore should be reported in the form of a range. Meter measurement errors include those of the meter fleet (e.g. revenue meters) as well as large (bulk supply) meters.

An Australian case history describes how an Apparent Loss Minimisation Model considers the influence that sequencing of the meter replacements has on determining the optimal meter replacement interval for a cohort of meters as well as how the model facilitates the defining of related metering components of apparent loss indicators. The model considers the justification for the replacement of water meters that compares the savings (e.g. benefits) achieved from an improvement in the measured volumes of water due to the installation of new meters (e.g. savings in apparent losses) with that of the costs of the associated meter replacement program. The availability of the Apparent Loss Minimisation Model in a user friendly software format together with a comprehensive manual tailor-made to a specific water utility's organisational and operating conditions facilitates the analysis of various meter replacement scenarios for planning purposes and the preparation of budgets.

A logic diagram provides a useful illustration that assists with understanding how the model allows for the meter replacement sequence. Sensitivity analysis shows that the apparent loss volume is generally more sensitive to variations in input parameters that have a direct influence on the volumetric amounts registered by the old meters and the optimal replacement period has greater sensitivity to variances in inputs that influence the total cost of apparent losses.

Another case history describes the application of a Metering Lifecycle Model that assists with comparison of various types of metering technologies to determine which technology would provide the best "value for money". The model also quantifies the apparent losses associated with errors occurring during the collection and transmission of data. Application of the Metering Lifecycle Model facilitates both the establishment of apparent losses for the initial part of the data pathway as well as the costs for potential failures in particular technologies. Failure of some meter reading technologies can potentially result in a 'surrogate' apparent loss of 13 L/connection/d if it is assumed that non-defaulting customers are required to pay for these costs through full cost tariffs.

Introduction

Apparent losses can result from metering errors, data acquisition errors, estimating errors and estimates of unauthorised consumption (e.g illegal) as illustrated by the Apparent Loss Four Pillars Diagram in Figure 1.1. The establishment of the Economic Level of Apparent Losses and Reference Annual Apparent Loss have been facilitated through the development and application of two models for recent metering projects.

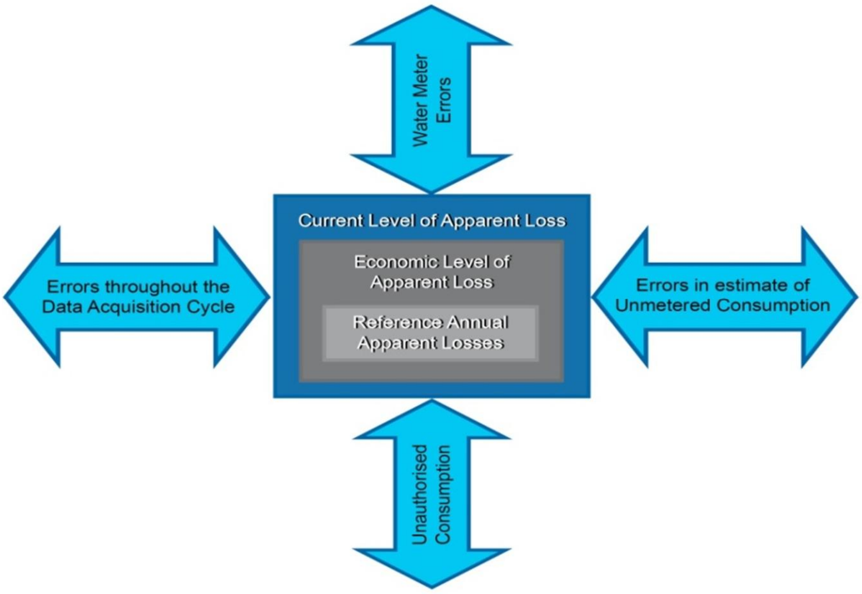

Figure 1.1 Apparent Loss Four Pillars Diagram

These Australian case histories describe how the development of Metering Lifecycle and Apparent Loss Minimisation Models has generally helped to define the related metering components of the apparent loss indicators as well as specifically addressing the following key issues and challenges:

- Calculations and statements of water imbalances and associated apparent loss benchmarks generally fail to take into account both the random and bias errors inherent in metering;
- The incorrect assigning of the meter's error limits defined in standards when establishing the volume of water losses;
- The influence that the sequencing of the meter replacements has on determining their optimal replacement interval has generally been ignored which has introduced inaccurate results generated by some models adopted by utilities; and
- Comparing various types of metering technologies to determine which technology would provide the best "value for money" for a complete metering system requires consideration of other factors related to data acquisition and not just the purchase price of the meter.

This paper focuses on the apparent losses associated with the measurement errors of a water meter fleet and meter reading errors associated with the initial part of the data pathway (e.g. data acquisition cycle).

Metered Water Volume Errors

Types of Meter Errors

The Reference Annual Apparent Losses (RAAL) represent the minimum level of losses that are technically achievable and derivation of this indicator must also take into account the various types of meter measurement errors. All measurements are estimates of the true value being measured and the true value can never be known without some level of uncertainty. All process measurements are adversely influenced by errors during measurement, processing and transmission of the measurement signal. The total error in the measurement is the difference between the measured value and the true value. Generally this is the sum of two contributing types of error, random and systematic errors.

Random errors are associated with inherent random (e.g. stochastic) fluctuation associated with any measurement device resulting from signal noise, ambient conditions etc. Systematic (e.g. bias) errors are caused by non-random events such as miscalibration, degradation of performance, degradation of internal pipe conditions etc.

Meter measurement errors include those associated with the large supply meters monitoring water into and out of the system as well as those smaller revenue meters comprising the meter fleet.

Statistical Uncertainty of Metered Water Volumes

The uncertainty of measurement gives an indication of the quality of a measurement or a result that is derived from a number of measurements. It is necessary to estimate the size of the margin and to qualify the level of confidence in the estimate of the error measurement. Uncertainty calculations identify the reliance that can be placed upon results that are derived from either measurements or estimates. They can also be used to determine the effort required to improve the overall uncertainty of measurement.

Imbalance associated with mass (or volume) balances into and out of a water system has an uncertainty associated with it. This is calculated by combining the uncertainties from each of the constituent in and out-flows (Johnson, 2009).

Weighted Error of Measurement

Although metrological guidelines provide the requirements for meter accuracy, these accuracy statements are only part of the overall definition of an operating water meter's accuracy or rather measurement error as it is correctly known. A particular type of water meter has a generic signature (error) curve that covers the flow rate ranges over which the water meter operates. The water demand measured by the meter generally varies throughout the monitoring period whether this period is an hour, day, week, month or year. Hence the meter operates at various points along its signature (error) curve and the meter's overall error requires weighting to reflect the volumes of water measured at the various flows and errors. Derivation of both the signature curve and the demand pattern have inherent random errors that also require considering.

Estimating the volume of water losses that could be attributed to meter errors is generally incorrectly assumed to be equivalent to the error limits (i.e. envelope) stipulated in standards. When water volumes are derived as part of a water balance or imbalance a water meter's accuracy is correctly determined from its weighted error of measurement. The weighted error of measurement is a function of the meter's error (signature) curve and the usage (demand) pattern for that particular installation.

Reference Annual Apparent Losses

Reference Annual Apparent Losses (RAAL) are the minimum volume of apparent losses that is technically achievable. A default value for RAAL is 5% of the authorised consumption unless historic records can demonstrate otherwise (Johnson & Vermersch, 2011). This 5% value relates to water meter errors that are only one component of apparent loss contributing to a volumetric imbalance. Total apparent loss volume consists of the sum of the systematic errors associated with the meters (i.e. large supply and smaller revenue meters), data acquisition cycle, and estimate in unmeasured consumption and estimates of illegal usage. The meters therefore contribute to a portion of the bias error which will generally be negative for mechanical meters and a single value. The random error is influenced by the size of the meter fleet and must also be accounted for in the calculations and reported statements of RAAL as a range.

To put the previous default value for the meter fleet error component of RAAL into perspective, a Spanish research project which involved the testing of a 2,000 meter sample, with diameters from 13 to 40 mm, found that the volume of water not registered, or under-registered, by domestic meters was -14%. The weighted metering error value was -8.4% of the total volume of water supplied to Madrid in 2006 (Díaz & Flores, 2010).

A simplified example of the meter error component of RAAL that takes into account a bias error of -2.5% and a random error of ±2% is illustrated in Figure 1.2 for various numbers of meters and indicates that the measurement error range decreases as the number of meters increase. The assumptions used are that all the meters are the same type, size, have the same volumetric amounts registered and are monitoring the demands for same type of homogeneous users (e.g. a cohort of meters). Figure 1.2 shows that the combined bias and random error for a cohort of ten meters is -2.5%±0.32%. The resultant bias and random errors for a whole meter fleet would be a combination of the differing bias and random errors for the various cohorts of meters that constitute the meter fleet.

The measurement errors of the large (bulk) meters monitoring water flowing into and out of the system must also be considered when establishing the RAAL as these errors can be misinterpreted as real losses due to interactions in the determination of water imbalances (Johnson, 2011).

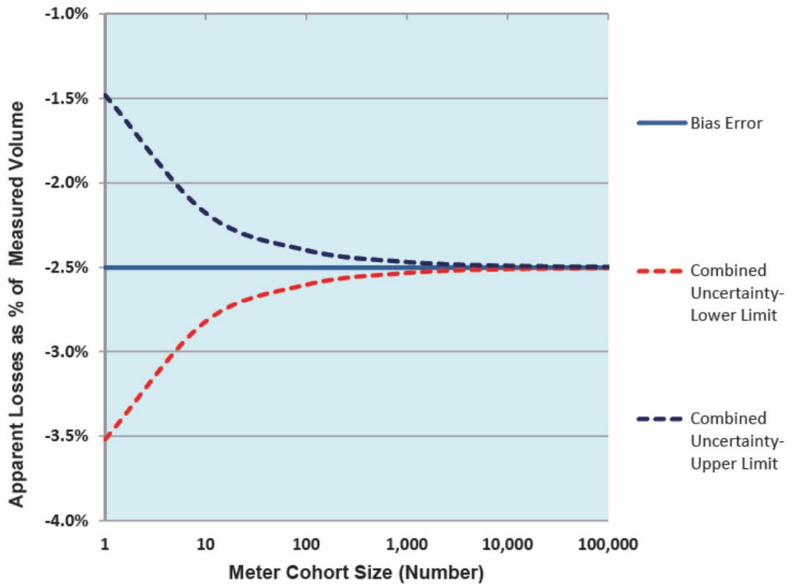

Figure 1.2 Combined Errors for a Cohort of Meters

Apparent Loss Minimisation Model

Purpose of the Model

The Apparent Loss Minimisation Model facilitates the determination of the impacts that a particular meter replacement policy would have on the level of apparent losses and considers the justification for the replacement of water meters. It compares the savings (e.g. benefits) achieved from an improvement in the volumes of water measured due to the installation of new meters (e.g. savings in apparent losses) with the costs of the associated meter replacement program. The model also takes into consideration the time value of money and the sequencing of the meter replacements.

Application of the model requires input of the average age (as a proxy variable for cumulative volume) of the existing meter fleet, weighted error of measurement of the existing meters, the decay in error of measurement for both old and new meters and the duration of the meter replacement cycle, to establish the volume of water saved. The influence that the sequencing of the meter replacements has on determining the optimal meter replacement period has generally been ignored in the past. This has introduced inaccurate results generated by some models previously adopted by utilities.

An example of how an improvement in meter replacement policy would result in reduction of the replacement period from 12 to 9 years with a commensurate reduction in apparent losses from -6.9 % to an optimal -4.4% (equivalent to a reduction from approximately 20 L/connection/d to 13.4 L/connection/d), is illustrated in Figure 1.3.

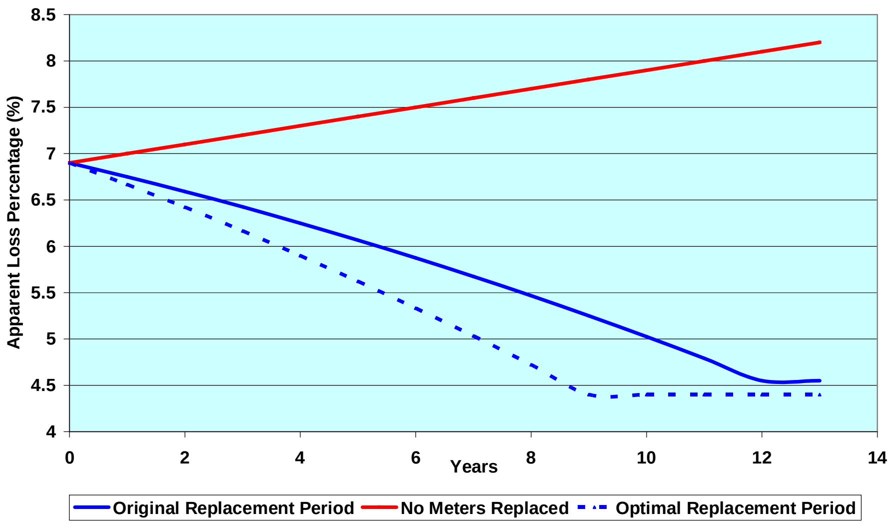

Figure 1.3 Decay in Error of Measurement of a Meter Fleet (Johnson, 2011)

The availability of the Apparent Loss Minimisation Model in a user friendly software format together with a comprehensive manual tailor-made to a specific water utility's organisational and operating conditions facilitates the analysis of various meter replacement scenarios for planning purposes and the preparation of budgets.

Apparent Loss Volumes

The formula used to find the initial apparent losses is as follows:

$$AL = Size * Dem * ((\frac{OE}{100}) + (\frac{ED * Age}{100}))$$ ....**Eqn (i)**

Where AL is the apparent losses, Size is the size of the meter fleet, Dem is the average annual demand, OE is the original weighted error of measurement of old meters, ED is the measurement error decay rate and Age is the average meter age since the original weighted error of measurement was established.

The formula used to find the apparent losses of the old meters at year x is:

$$AL = Size * Dem * ((year - x) / year) * ((\frac{OE}{100}) + (\frac{ED * (Age + x)}{100}))$$ ………….…**Eqn (ii)**

Where year represents the number of years in the meter replacement cycle, x is the current year being calculated and all of the other variables are as indicated in equation (i).

Sequence of Meter Replacements

Understanding how the model allows for the sequence that the meter replacements occur provides an insight into the logic of the model. The logic diagram of the sequence that meter replacements occur is illustrated by the example given in Figure 1.4 where a meter fleet is completely replaced over an 8 year period (e.g. one eighth of the fleet is replaced every year).

The sequence of the meter replacement is such that:

1. In the first year, $1/8^{th}$ of the fleet is replaced with new meters (red boxes) while $7/8^{th}$ of the fleet consisting of old meters (blue boxes) continues to experience decay in their error of measurement for an additional year;
2. In the second year, $1/8^{th}$ of the fleet's new meters experiences one year decay in their error of measurement, $1/8^{th}$ of the fleet's old meters are replaced with new meters while $6/8^{th}$ of the fleet consisting of old meters continues to experience decay in their error of measurement for an additional year;
3. In the third year, $1/8^{th}$ of the fleet's new meters experiences two year's decay in their error of measurement, $1/8^{th}$ of the fleet's new meters experiences one year decay in their error of measurement, $1/8^{th}$ of the fleet's old meters are replaced with new meters while $5/8^{th}$ of the fleet consisting of old meters continues to experience decay in their error of measurement for an additional year;
4. This replacement sequence will continue until equilibrium is reached whereby the oldest decay that $1/8^{th}$ of the fleet will experience will be equivalent to the previous seven years plus the portion of the decay in its eighth year of the scheduled replacement. Hence the plateau in apparent losses previously illustrated Figure 1.3.

Sensitivity Analysis

Analysis was undertaken to determine the degree of sensitivity that the key outputs of the model have to variations in the nine input parameters. The key outputs were the volume of apparent losses and the optimal meter replacement period. The variance in output was relevant to the optimal benchmarks previously established at the 9 year meter replacement period (Johnson, 2011).

Results of the sensitivity analysis indicate that the volume of apparent losses at the optimal replacement period is most sensitive to variations in the average annual demand, meter fleet size and weighted error of measurement of the old meters. Apparent loss volumes are least sensitive to variations in the decay in measurement error, weighted error of measurement of new meters and the unit cost of water. The results of the sensitivity analysis are illustrated in Figure 1.5.

Results of the sensitivity analysis of the optimal replacement period found that this optimal period is most sensitive to weighted error of measurement of the old meters, the average annual demand and the unit cost of water. The optimal replacement period is least sensitive to the meter fleet size, discount rate and decay in measurement error.

In summary, the apparent loss volume is generally more sensitive to variations in input parameters that have a direct influence on the volumetric amounts registered by the old meters and the optimal replacement period has greater sensitivity to variances in inputs that influence the total cost of apparent losses.

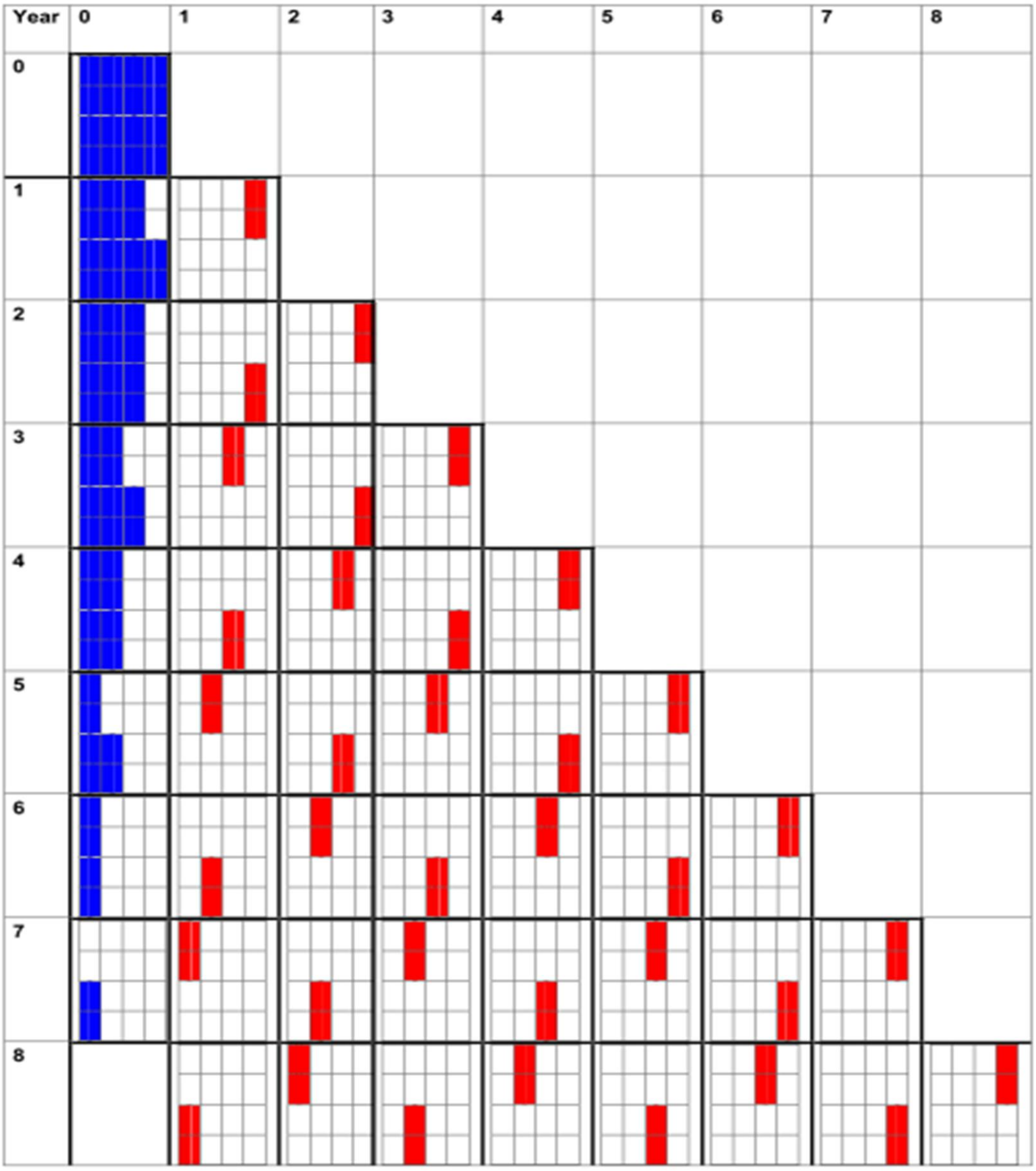

Figure 1.4 Sequencing Logic Diagram for 8 Years Meter Fleet Replacement Cycle

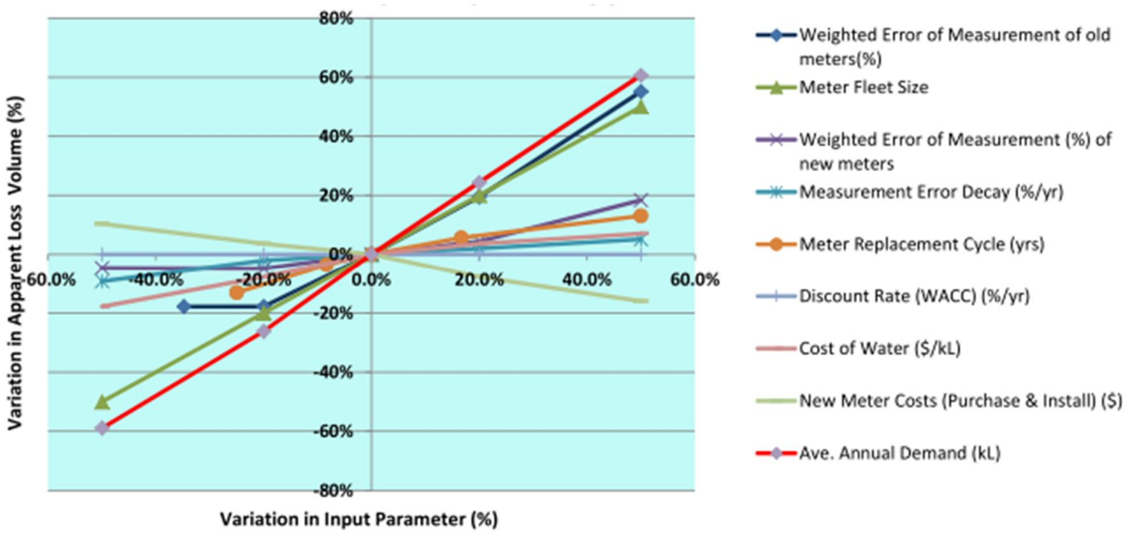

Figure 1.5 Sensitivity of Model

Metering Lifecycle Model

Data Acquisition Cycle

Effective management of water relies on effective measurement, coupled with reliable and accurate information transfer. Water data is required by a water utility for the design, planning, operational and management functions associated with its water supply system. This data follows a cycle of acquisition, evaluation, manipulation and application that result in a response or feedback from the system which influences design, planning, operational, administrative and management policies. These policies/decisions will, therefore, eventually be revealed in the new data collected (Johnson, 2009). Errors are therefore introduced into each part of this cycle that influence the accuracy of the data as it follows the path from its source to its eventual application. These anomalies are especially noticeable at data and organisational systems' interfaces. Analysis of the uncertainties associated with the errors introduced into various stages of the data cycle is required as part of the process to establish the current level of apparent losses.

Establishing the water meter's weighted error of measurement, bias error and random error are relevant to first component of the data pathway (e.g. data capture). The impact that errors associated with collection and transmission of data along the pathway has on establishing apparent losses must also be determined. Although meter reading efficiencies associated with manual systems can be greater than 5% of the total meters read compared to less than 0.5% for electronic meter reading devices, the costs of equipment failures of some electronic based technologies can negate their perceived benefits (Johnson, 2009). Development of a Metering Lifecycle Model provides a tool to undertake a "value for money" analysis for comparison of various meter collection and transmission technologies as well as facilitating the determining of the extent of the potential errors associated with the different technologies.

Input Parameters

A "Value for Money" analysis was undertaken for a metering project to estimate of the life cycle (present value) costs for various makes of meters used in an Advanced Metering Infrastructure (AMI) for a drive-by meter reading application. The model employs present cost analysis and does not include a net present value (NPV) analysis where the present costs of the various systems are compared to the value of any benefits received. The lowest present cost for various scenarios indicated the best "present value for money" and compares the total current dollar value of future amounts for the purchase and reading operation of various metering technologies.

The following categories of costs are considered in the analysis:

- Purchase costs;
- Maintenance costs;
- Drive-by meter reading costs for both two-way and one-way types of communications;
- Lost revenue (e.g. apparent losses); and
- Reed switch failure costs for those makes of meters using this type of electronic reading technology.

The flexibility of the model is demonstrated by its ability to accept changes in input values and assumptions as more information becomes available.

Findings

General findings relating to the meter capture and transmission technologies included the following:

- Older data transfer technology required more maintenance than the newer technology;
- Two-way communication systems have a greater potential for meter misreads when compared with that of one-way communication systems that have greater reliability when used in drive-by applications;
- Reed switch meter interface unit (MIU) failures are random in nature and result in potential delays and/or requirements for the application of additional resources by the water utility and hence incur additional costs.

The model also facilitated the identification of a particular break-even point for a set of assumptions and costs associated with the level of maintenance and failures that could occur with a particular technology. These failure costs included both the replacing of faulty equipment plus the cost to undertake manual meter readings that could be more than 20% of the total present cost for some metering technologies. These failures could therefore result in a ‘surrogate’ apparent loss of 13 L/connection/d if it is assumed that non-defaulting customers are required to pay a tariff that recovers the total cost of water.

Discussion

Key issues and challenges associated with the identification and quantification of Apparent Losses include the following:

- Random and bias errors inherent in metering are generally not taken into account when determining and reporting Apparent Loss Indicators;
- The influence that the sequencing of meter replacements has on determining their optimal replacement interval has generally been ignored; and
- The impact that errors associated with collection and transmission of data along the pathway of the Data Acquisition Cycle have on apparent losses.

These issues are emphasised when apparent loss indicators fail to take into account both the random and bias errors inherent in metering as well as when estimates of water losses attributed to meter errors are incorrectly assumed to be equivalent to the error limits (i.e. envelope) stipulated in standards. Apparent loss indicators that are reliant on flow meter data must correctly be expressed as a range and not as a single value. The typical characteristic that combined bias and random errors have is that the measurement error range decreases as the number of meters increases. Although the IWA has defined a default value for reference annual apparent losses (RAAL) as 5% of the authorised consumption, this single value accounts for meter bias errors only and it still requires allowance for random errors in its calculation and reporting as a range. Consideration of meter measurement errors in the determination of water imbalances must include those of the meter fleet (e.g. revenue meters) as well as large (bulk supply) meters.

An Apparent Loss Minimisation Model that considers the influence that sequencing of the meter replacements has on determining the optimal meter replacement interval has also facilitated defining the related metering components of apparent loss indicators based upon nine input values. The model considers the justification for the replacement of water meters that compares the savings (e.g. benefits) achieved from an improvement in the volumes of water measured due to the installation of new meters (e.g. savings in apparent losses) with the costs of the associated meter replacement program. A logic diagram provides a useful illustration that assists with understanding how the model allows for the meter replacement sequence that had generally been excluded from previous models.

Results of the sensitivity analysis indicate that the volume of apparent losses at the optimal replacement period for a cohort of meters (e.g. revenue meters) is most sensitive to variations in the average annual demand, meter fleet size and weighted error of measurement of the old meters. The sensitivity analysis also indicate that the optimal replacement period is most sensitive to weighted error of measurement of the old meters, the average annual demand and the unit cost of water.

The impact of metering errors on apparent loss volumes is generally more sensitive to variations in the volumetric amounts registered by the old meters and the optimal replacement meter period has greater sensitivity to variances in inputs that influence the total cost of apparent losses.

A Metering Lifecycle model assists with comparison of various types of metering technologies to determine which technology would provide the best “value for money”. This model also quantifies the apparent losses associated with errors occurring during the collection and transmission of data. Application of the Metering Lifecycle model facilitates both the establishment of apparent losses for the initial part of the data pathway as well as the costs for potential failures in particular technologies. Failure of some meter reading technologies can potentially result in a ‘surrogate’ apparent loss of 13 L/connection/d if it is assumed that non-defaulting customers are required to pay for these costs.

Acknowledgement

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