# A Tool to Help Develop Cost-Effective M&V Plans

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## ABSTRACT

A necessary but seldom performed exercise in measurement and verification (M&V) of energy savings associated with energy efficiency projects is assessing the accuracy of the predicted savings. Because M&V activities can be costly, the value of information they provide should play an integral role in designing cost-effective M&V plans. Determining an M&V plan's cost-effectiveness, however, involves uncertainty and risk analyses, which practitioners are loath to perform due to the time and effort required. To overcome these obstacles, a database-based planning tool has been developed. This "M&V Value Tool" is a prototype software-based tool that allows the user to evaluate different M&V scenarios according to M&V costs and savings uncertainty for specific measures associated with lighting and motor efficiency projects. The tool identifies sources of uncertainty and considers their propagation through mathematical models, sampling strategies, and savings equations, in order to estimate the overall savings uncertainty for a measure. In addition, it estimates a project's data collection costs and overall energy savings. It generates reports that implementers can use to identify where to most appropriately apply limited M&V budgets and reports to remind planners of the assumptions used and criteria to be adhered to throughout the M&V process. Initial tests of the tool revealed reasonable comparisons of M&V costs and savings uncertainty with cases studies drawn from a utility performance contracting program, as well as revealed areas for tool improvement.

## Introduction

A recurring problem in energy savings projects is the determination of the appropriate level of measurement and verification (M&V). M&V is the inspection, data collection and analysis, and reporting activities by which a project's energy (and cost) savings are quantified.

Several factors influence the level of M&V activities for a particular project, among them are: the magnitude of energy savings, the risks that the savings will (or will not) be realized, the owner's risk tolerance, and the costs of performing M&V. In performance contracts, payments are based on the M&V results, and in such cases the parties must be reasonably certain that the payments are appropriate. However, the more rigorous the M&V plan, the more costly it is, and a point is quickly attained beyond which increasing the rigor of M&V activities is no longer cost-effective (Figure 1).

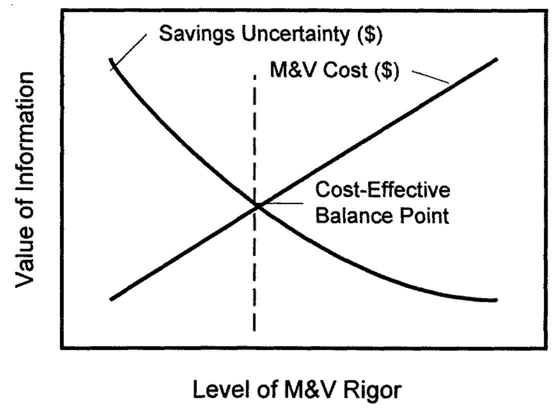


**Figure 1. Comparison of M&V cost and savings uncertainty (Schiller, 1997)**

There exist several guidelines to assist planners in the development of M&V plans for their projects (for instance, IPMVP 1997, FEMP 1996). Although the scope and role of these protocols are to help project planners develop M&V plans, they fall short of providing techniques for evaluating the cost-effectiveness of one M&V plan versus another.

Techniques that exist for evaluating the economic return on investments in energy efficiency projects may be adapted for the evaluation of M&V plans. Benefit-to-cost ratio, or net present value calculations can help establish the value of different M&V methods. These techniques involve uncertainty and risk analyses, which planners believe to be cumbersome and time-consuming. Computer-based tools can help reduce the cost and time involved in these analyses.

The M&V Value Tool (the "Tool") is a database-driven program that allows the user to evaluate different M&V scenarios by estimating M&V costs and savings uncertainty. An M&V plan's cost-effectiveness, together with consideration of a project's risk, are major elements in selecting the best M&V plan for a project. The Tool is a prototype and is intended for planning purposes only. It addresses only lighting and motors projects in which savings are determined from measurements performed on the individual devices. The M&V methods for each project type are programmed as individual modules in the Tool. This feature allows for the future development of modules for other project types and M&V methods. This paper first presents a framework for evaluating different M&V plans and describes how the Tool assists this process. It identifies and discusses error in M&V before describing how the Tool estimates energy and cost savings, savings uncertainty, and M&V costs. Discussion of key elements of the Tool is presented and an example calculation and scenario is shown.

## M&V Evaluation Framework

The methodology presented here follows that from Brakken and Bowen in a report prepared for Boston Edison Company (Brakken, 1993). When two or more M&V methods are under consideration for estimation of energy savings of a retrofit project, how does the project planner determine which of the two is the most cost-effective method?

Consider two hypothetical M&V methods—MV1 and MV2; each results in a different precision level for the same project. Assume that the cost of the first method is low, but that its estimated savings precision level is poor compared to that of the second. The second method provides greater precision, but at a higher cost. A graph showing the two methods' estimated savings and precision boundaries is presented in Figure 2. In this example, the expected value of energy savings for both methods is assumed to be the same (E1 = E2). This is a useful assumption for planning purposes, where the energy savings are not known prior to performing the M&V.

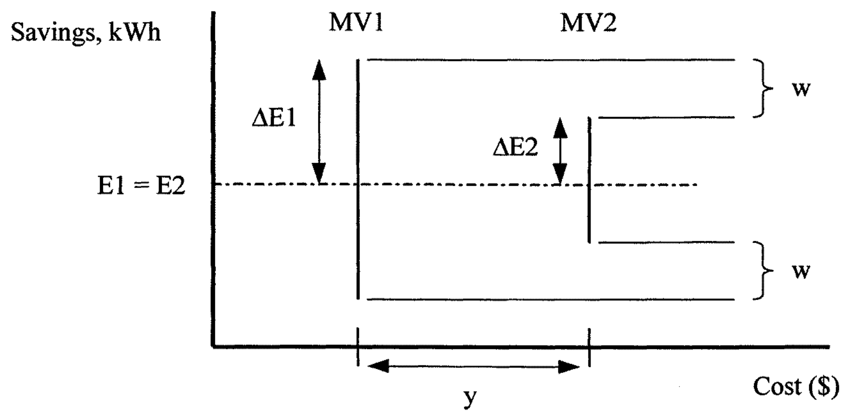


**Figure 2. Estimated kWh savings for two different M&V methods**

In Figure 2, M&V plan MV1 is predicted to estimate the savings E1 with an uncertainty level of $\pm\Delta E1$, while plan MV2 estimates savings E2 with an uncertainty of $\pm\Delta E2$. The uncertainty of MV2 is lower than that of MV1 by 2w, however, plan MV2 is more costly than MV1 by amount y.

The differences in both uncertainty and cost between two M&V plans provide necessary information to evaluate the cost-effectiveness of one method compared to the other. The benefits associated with reducing uncertainty do not, however, directly increase the actual savings. They do reduce the possible worst-case scenario impacts that could result from the use of a less-precise M&V methodology.

Consider an energy savings project in which three different M&V methods are under consideration, as shown in Table 1. In a performance contract, the facility owner and an ESCO are negotiating the specifics of an M&V plan. The project's energy savings have been estimated and the contract duration (in years) has been established. The contract specifies that the ESCO will be paid based on the annual verified savings each year, up to a maximum amount. The savings estimate will have an uncertainty associated with it, and the negotiations are centering on how large this uncertainty can be. From the owner's perspective, if M&V method #1 is chosen, then the potential downside is that the actual savings per year after installation will be 40% less than expected, or a savings of only $6,000 will be realized.

The owner may at this point decide that the risk of achieving less savings is tolerable, and accept M&V method #1. It would be prudent, however, for the owner to investigate further. M&V method #2 has less than half the uncertainty of method #1, but costs $1,000. If this method were employed, the owner could expect $8,500 of savings in the worst case. The benefit-to-cost ratio of selecting method #2 over that of #1 would be: ($8,500 -

$6,000)/$1,000 = 2.5. This would be a more attractive alternative because the B/C ratio is greater than one. The benefits of the more robust M&V method are that the owner will have spent $1,000 to ensure that, in the worst case, the savings will be at least $2,500 greater than what they would have been had a less precise M&V method been employed. The owner should also investigate the third M&V option. By doing so, it would be discovered that the B/C ratio is ($9,000 - $6,000)/$6,000 = 0.5. This option should be rejected as not cost-effective.

**Table 1. Example M&V Scenarios**

| M&V Method | Estimated Savings, E ($) | Uncertainty, ΔE/E (%) | Worst Case, E -ΔE ($) | M&V Cost, y ($) | B/C Ratio (-) |
|---|---|---|---|---|---|
| 1 | 10,000 | 40 | 6,000 | 0 | NA |
| 2 | 10,000 | 15 | 8,500 | 1,000 | 2.5 |
| 3 | 10,000 | 10 | 9,000 | 6,000 | 0.5 |

In reality, assuming the worst-case scenario is a bit extreme. A better method would be to assign a probability distribution between the worst case and best case scenarios, which could be centered about the estimated savings value, and to determine the most likely worst case scenario which stands a 50%, or other desired percentage, chance of occurring. This may be done with the aid of statistical simulation techniques, such as Monte-Carlo methods

After a year has elapsed, and the owner has reviewed the savings and M&V method results, the actual savings estimates and uncertainties will be better known. At this point the owner may check whether the M&V method costs justified the benefits and revise M&V requirements accordingly.

The preceding analysis relies on credible estimates of a project's savings and the associated uncertainties and costs of the M&V method. The M&V Value Tool has been developed to provide reasonable estimations of these values.

## Tool Design

The Tool is designed to allow the user to define the project, select specific M&V methods, define measurement techniques, and estimate costs associated with the selected M&V activities. In order for the user to define the project, the number, capacity and operating schedule of both pre- and post-retrofit equipment must be known. M&V methods are selected from a list built into the Tool. Measurement techniques and equipment are also selected from predefined lists. The user must also enter information related to the cost of the measurement activities, such as travel cost and labor rate. The Tool contains an "Equipment Table" which contains sensor costs and measurement uncertainties, and estimates of measurement labor hours. Cost and accuracy information was taken from manufacturer's specifications and price lists, and estimates of measurement labor times were based on those found in ASHRAE 14P. The user may also enter this information into the equipment table. The Tool develops estimates of energy savings, savings uncertainty, and costs based on user input and data from the equipment table.

The Tool is currently set up to analyze methods related to Option A and Option B of the IPMVP; these methods are based on measurements of the individual devices in the retrofit project.

## M&V Value Tool Modules

The tool includes detailed process-driven modules for each of the following three energy-efficient measures (EEMs):

- Lighting efficiency upgrade (constant load);
- Motor efficiency upgrade (constant load); and
- Variable speed-drive installation (variable load or usage).

These EEMs were selected because they are commonly implemented under standard performance contract programs funded by California utility customers and administered by the state's investor owned utilities (SPC, 1999). In these programs, the most common measure types claimed are ballast and lamp change-outs and the installation of variable speed drives on existing and new fan or pump motors.

The choice of an M&V method depends on many factors, including the measure (the equipment being installed) and the installed equipment's operating schedule. The tool analyzes each EEM individually; it does not account for interaction effects of two or more different EEMs.

The main variables for the proposed M&V methods listed in the tool are electric demand (expressed as kW), electric energy usage (expressed as kWh) and time-of-use (expressed as TOU and measured in hours). These are common, measurable quantities for both lighting and motor efficiency projects. As M&V methods become more complex, more variables are required. The techniques to measure and monitor these variables are assumed known and will not be described in detail.

## Tool Development

The Tool was developed using a relational database program with Basic programming language functions and visual interface capability. A relational database was selected as the platform because it allows investigation and tracking of multiple M&V scenarios. It also allows for a less complicated interface. For example, the list of menu items available to users on one screen is filtered by selections of menu items on a previous screen, allowing the user to see only the appropriate information needed in developing M&V scenarios. To further the example, each EEM has different M&V methods available to it. The M&V methods have unique energy savings equations that identify the variables to be used in the analysis. Once an M&V method has been selected, the user is allowed to make selections based only on the variables used in the energy savings equation.

Basic code was written to perform the energy calculations, develop error propagation equations, determine the uncertainty and develop the M&V costs for each scenario. The code inspects the savings equation and develops the corresponding uncertainty propagation equation dynamically. This eliminates the need to separately define the uncertainty equation and helps maintain the Tool's modular design. Testing and debugging of the energy savings, uncertainty and cost equations was exhaustive, and the Tool's computational engine was found to be robust.

A logical procedure was developed to guide the user through defining the project, and choosing the M&V method, data collection methods, and measurement equipment. This procedure was broken into the five main user interface screens of the Tool. These screens allow users to develop M&V scenarios for specific projects, analyze and track them to determine the best M&V plan for the project.

The first screen is the User Info. screen, where the user can develop M&V scenarios and associate them to specific user names. For each user name, a list of previously defined projects appears. The user can select one of these projects to modify, or define a completely new project.

The next screen (Figure 3) is the Project Information screen, which is used to define a project. A project may be a lighting or motor energy efficiency measure. The user defines the measure, assigns a usage group name (in the case that statistical sampling will be used), and the number of devices in the usage group. If previous scenarios have been investigated, the names of these scenarios will appear on this screen. From this screen, the user can also request summary and detailed project reports.

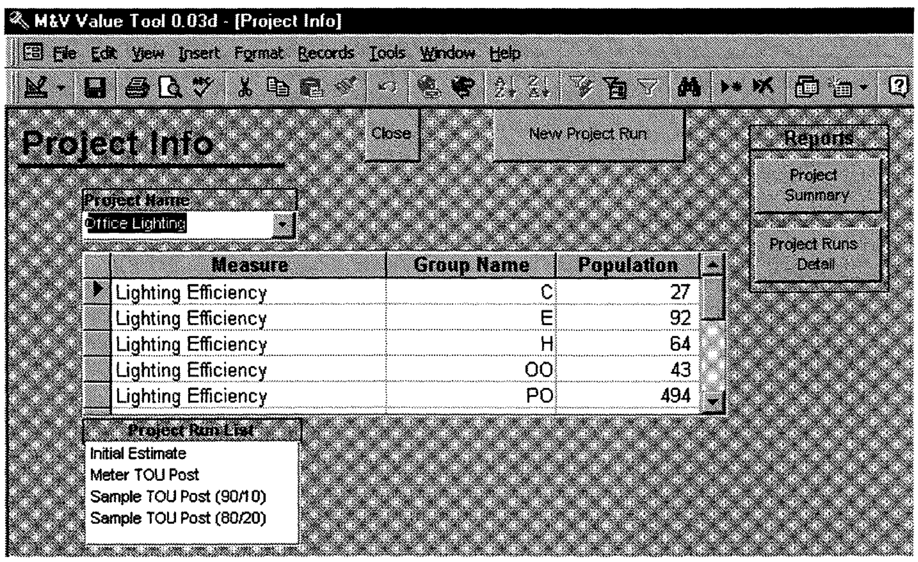


**Figure 3. Project information screen.**

The user may select an existing measure and modify existing M&V scenarios, or develop new scenarios for a measure. The next user interface screen is an administrative screen that shows all scenarios previously developed for each measure (M&V scenarios are referred to as "project runs"). The user may also request reports that summarize the scenarios, provide individual scenario detail, or provide the data and assumptions used to develop the scenario.

M&V scenarios are described using the Project Element Run screen (Figure 4). From this screen, the user selects the M&V method from a drop down menu. The menu list contains only the allowable methods for this measure. The method's variables appear in a table on the screen. The table will be blank except for the variable names if a new scenario is being defined, otherwise it will be populated with data defined from a previous iteration. Two check boxes are also included. One identifies the scenario as a base case. If checked, all other scenarios will be compared to this scenario. The other check box is used to identify the scenario as one to compare against the base case scenario. The base case and selected scenarios will be included in the summary reports. After the variable table has been defined, the savings uncertainty will be determined by clicking the "Calculate Uncertainty" button. This event also calculates the estimated energy savings and M&V cost for the scenario. These algorithms are described in the following sections.

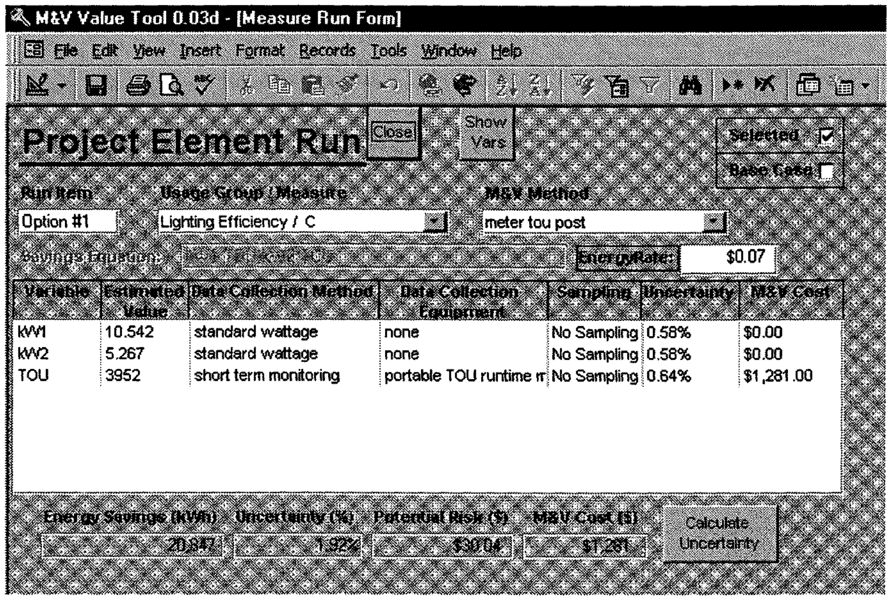


**Figure 4. Project element run screen.**

Double-clicking on a variable name in the variable table will bring up the Variable Data screen, shown in Figure 5. This screen is used to define the variable's data collection method, estimate it's value, define what data collection equipment will be used, and indicate whether a sampling strategy will be employed. The user will see only the relevant sensors and monitoring equipment in the data collection equipment menu for the variable to be monitored. The menu is populated from records in the Equipment Table. The user is also required to enter information useful in estimating M&V costs. This includes the number of measurement devices already owned, the user's labor rate for performing M&V activities, and travel costs. The screen will display labor and equipment M&V costs and metering equipment and sampling uncertainties.

Data for all measurement equipment is included in the Equipment Table. Each record in it consists of a variable name, a sensor and data logger description, the measurement method class, the error, the sensor and logger purchase cost, an estimate of the install and remove time, and an assumed amortization factor. If the variable will be quantified through the use of a proxy variable and statistical or modeled relationship, information about the relationship's precision and bias uncertainties will be included. This relationship is defined prior to its use in the Tool.

Data for sensors and data acquisition system equipment was compiled from internet web sites and catalogs of sensor manufacturers. The time to install and remove the measurement equipment was based on information from ASHRAE 14P, and estimated by the tool developers.

Estimating costs and uncertainties for measurement equipment demonstrated the Tool's dependence on this underlying data; the Tool is not useful if the data in the equipment table is unreliable. Therefore, users are not allowed editable access to the data, but are instead able to make additions to the table and obtain a report of their assumptions.

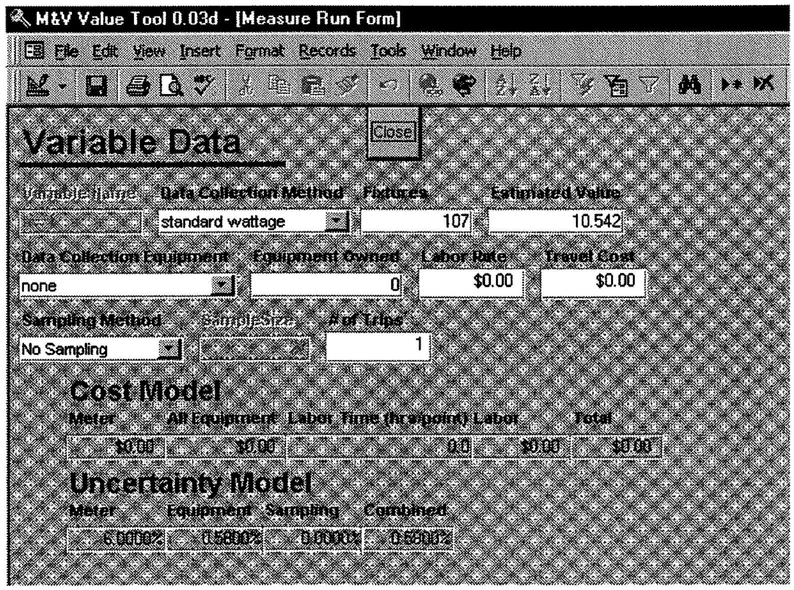


**Figure 5. Variable Data screen**

Energy usage, savings, uncertainty, and M&V costs for the entire population are developed from individual device quantities. While it is straightforward to determine energy usage for a population of devices, how the Tool determines uncertainty in savings and the M&V costs merits further discussion. The next sections discuss the sources of uncertainty, their propagation, and M&V cost development.

## Uncertainty Analysis

### Sources of Uncertainty

The Tool considers five types of uncertainty in the calculation of energy savings: measurement precision and bias, model precision and bias, and sampling uncertainty. Measurement and modeling precision and bias uncertainties are well described in ASHRAE, 1986; ASME, 1998, Reddy et. al., 1999, Zar, 1996 and Dally et. al., 1984.

### Analysis

The Tool identifies uncertainties in measurement and modeling of each dependant variable and determines their contribution to the overall uncertainty in the energy savings estimate. The process has three levels: (1) single device uncertainty estimation, (2) accumulation in device populations, and (3) propagation through M&V Method savings equations.

The third level identifies the variables that will be used to determine the savings. If there is more than one device in the project, the uncertainties in each variable must be combined for the entire population of devices. In the second level, the accumulated uncertainties may be determined directly for all the devices in the population, or a sampling strategy may be employed. In the first level, the uncertainty of a measured value for a single device is estimated. This uncertainty is a combination of measurement and modeling uncertainty. Each of these levels is described in more detail below, beginning at the device level.

**Level 1: Single Device Uncertainty Estimation**

In this first level, the uncertainty in the objective variable (usually the device's energy or power consumption) is determined for a single device (e.g., a single lighting circuit or a single motor). Variable quantities may be estimated from tabular values, determined by direct measurements, or may be determined through the use of a proxy variable and a modeled relationship with the objective variable (such as using a motor's current draw as a proxy for power). The total uncertainty of the objective variable has four elements: measurement precision and bias error and model precision and bias error. These uncertainties are combined in quadrature to obtain the overall device uncertainty. All uncertainties are expressed as relative uncertainties. Before combining them, they are first normalized to the same confidence level. This information is included in the Equipment Table.

**Level 2: Accumulation of Uncertainty in Device Populations**

A project may contain numerous devices, and the uncertainty in the energy usage for each device contributes to the resulting uncertainty for the population. For example, the total baseline kW of a group of motors is found from the sum of the kW measurements on each motor. The total uncertainty is determined from a sum-in-quadrature of that for the individual devices. The following describes the equations used in the Tool to determine population uncertainty.

The total relative uncertainty resulting from summing energy consumption from individual devices is:

$$\frac{\Delta a_{total}}{a_{total}} = \frac{\sqrt{\sum_{i=1}^{N} \Delta a_{device,i}^{2}}}{N\overline{a}_{device}} = \frac{\sqrt{\sum_{i=1}^{N} \frac{\Delta a_{device,i}^{2}}{\overline{a}_{device}^{2}}}}{N} = \frac{1}{\sqrt{N}} \frac{\overline{\Delta a_{device}}}{\overline{a}_{device}}$$

where: $\Delta a_{device}$ is the absolute uncertainty in the individual device value, described in the first level above.

The uncertainty in determining average energy consumption for a population of devices is:

$$\frac{\Delta \overline{a}_{device}}{\overline{a}_{device}} = \frac{\sqrt{\sum_{i=1}^{N} \Delta a_{device,i}^{2}}}{N\overline{a}_{device}} = \frac{1}{\sqrt{N}} \frac{\overline{\Delta a_{device}}}{\overline{a}_{device}}$$

Two assumptions are made to facilitate calculations. One is that the relative uncertainties for each individual device are equal; the other is that the relative uncertainties are based on the average device value. These are necessary because there is no way to know the absolute uncertainty of each device value prior to measurement. The assumptions are reasonable if the same measurement instrument and modeling technique are used for each measured device.

**Sampling Uncertainty**

When the population of equipment is large, such as in lighting and motors projects, sampling strategies are employed to reduce measurement costs. Standard practice assumes a normal distribution of values about the mean. Measurements are made on a representative sample of equipment to estimate the population average. The sample size is dependent on the variation of the population, and the desired precision and confidence levels. A correction is applied when the population size is small.

The relative uncertainty due to sampling is given by the standard error of the sample mean, which for a finite population is given by (Zar, 1996):

$$\frac{SE(\bar{a})}{\overline{a}_{device}} = \sqrt{\frac{CV^2}{n}\left(1 - \frac{n}{N}\right)}$$

where s is the standard deviation of the sample, n is the sample size, N is the population size, and CV is the coefficient of variation, $s/\overline{a}_{device}$. Note that as the sample size increases, the standard error of the sample mean decreases.

The total uncertainty of the population is a combination of the accumulated device uncertainties, and the sampling uncertainty. These are combined using the addition-in-quadrature convention:

$$\frac{\Delta a_{total}^2}{a_{total}^2} = \frac{1}{n}\frac{\Delta a_{device}^2}{\overline{a}_{device}^2} + \frac{SE(\bar{a})}{\overline{a}_{device}^2}.$$

In the Variable Data screen, level 2 analysis is activated when the data collection equipment menu item has been selected.

**Level 3: Propagation Through M&V Method Equations**

The selected M&V method determines the specific equations and variables that the Tool will use in analyses. The Tool will develop the corresponding error propagation equation from the energy savings equation. Currently, only electric kilowatt-hour savings are included. The functional form of a savings equation is:

$kWh_{save} = f(kW, TOU, etc.)$

Examples include:

$kWh_{save} = kWh_{base} - kWh_{post}$

$kWh_{save} = (kW_{base} - kW_{post}) \times TOU_{post}$

The error propagation equation is developed for each savings equation using the following formulae:

- addition or subtraction: $x = a \pm b$; $\Delta x^2 = \Delta a^2 + \Delta b^2$
- multiplication or division: $x = ab$ (or a/b); $\Delta x/x = \left((\Delta a/a)^2 + (\Delta b/b)^2\right)^{1/2}$

In rare circumstances do the equations associated with Option A and B-type methods involve calculations more complicated than addition, subtraction, multiplication, or division. On the Project Element Run screen, the "Calculate Uncertainty" button initiates the level 3 analysis. It also initiates calculation of energy savings and M&V costs. The M&V cost model is described below.

**Simplified M&V Cost Model**

The Tool calculates the total cost (in present value dollars) for implementing the selected M&V plan for the particular measure using the following simplified cost model:

$$C_{total} = C_{equipment} + C_{setup} + C_{travel}$$

The total equipment cost, $C_{equipment}$, considers the meter cost, amortization rate, sample size, number of meters owned and the anticipated number of trips to the project location. The total equipment cost, $C_{setup}$, accounts for installing and removing the sensors and data acquisition equipment for the measure. This equipment cost is a function of the project-specific labor rate and install/remove times for various equipment types listed in the Equipment Table. The total cost to travel to and from a project site to install and remove the monitoring equipment, $C_{travel}$, is a function of the project-specific labor rate, and the number of site trips needed. The number of site trips is based on whether all points will be monitored at the same time or the monitoring equipment will be rotated across the monitoring points.

Equipment purchase costs are amortized across several projects, because the devices are reusable. The data required to determine the cost of the proposed M&V activities are identified when the user specifies the type of measurements to be made, their duration, and the number of devices in a population of devices to be measured. Costs for measurements on individual devices are summed for the number of devices to be measured.

Several assumptions are made about the labor hours required to install and remove measurement equipment. Other factors which realistically contribute to the cost of a given M&V plan, but which have not been considered in the cost model presented above (for simplicity) include:

- Development of a monitoring plan,
- Time required to download and process data,
- QA/QC of polled or collected data,
- Sensor calibration, and
- Residual amortized costs of currently owned measurement equipment.

The total cost of the above mentioned items might be less significant than the cost of analyzing and reporting the collected data. There are many factors that influence this cost; the level of expertise of the person processing the data, the reporting requirements of the performance contract, and so on. The Tool currently does not include such costs in developing the M&V costs of a project.

## M&V Assessment Technique

The Tool calculates project risk as described in the hypothetical example at the beginning of this paper. The risk is calculated as:

$$\text{Risk} = \Delta E_{savings} \times \text{Rate}_{project}$$

where $\Delta E_{savings}$ is the total uncertainty estimate, in kWh. The relevant cost per energy unit, $Rate_{project}$ can be the owner's utility costs, or a utility's incentive rate for the project. The tool calculates the incremental benefit-to-cost ratio of increasing M&V efforts as follows:

$$BC_{\text{run i}} = \frac{\left(Risk_{\text{total, base case}} - Risk_{\text{total, run i}}\right)}{\left(C_{\text{total, run i}} - C_{\text{total, base case}}\right)}$$

Where $Risk_{\text{total, base case}}$ is the calculated savings risk for the EEM using the base case M&V method, $Risk_{\text{total, run i}}$ is the calculated savings risk for the EEM using the alternate M&V method, $C_{\text{total, base case}}$ is the calculated cost of implementing the base case M&V method (i) for the EEM and $C_{\text{total, run i}}$ is the calculated cost of implementing the user defined M&V method (i) for the EEM.

## Tool Testing

The tool was tested on a number of actual energy efficiency projects to assess the validity of the results, one of which is described here to illustrate typical results. The project tested was a lighting efficiency project in a ten-story office building. An initial estimate of savings was done using standard fixture wattages (obtained from a lighting wattage table used in a utility performance contracting program) for the baseline and post-retrofit kW, and stipulated annual hours of operation. This baseline savings estimate resulted in a 20.5% uncertainty, which is reasonable for this type of project. Three different M&V scenarios were then tested. All of the scenarios used the M&V method for monitoring post-retrofit TOU; however, the sampling method was varied. The runs consisted of one in which all circuits are sampled, one in which a 90/10 confidence/precision level sampling plan was selected, and, finally, one with an 80/20 sampling plan. The 80/20 sampling plan resulted in a higher level of uncertainty than the baseline savings estimate, which is why the benefit is displayed as a negative value (see Figure 6). This higher level of uncertainty in the 80/20 sampling method was a result of the method used to calculate sampling uncertainty. This may have indicated that the assumption used in estimating this uncertainty method should be reassessed. All the other values in this table appeared to be reasonable. As more points were sampled the relative uncertainty decreased. It is important to note, however, that none of the runs resulted in a benefit to cost ratio greater than one, and therefore none of the tested M&V methods were found to be cost effective.

### Project Summary

**Project:** Office Lighting

| Run Name | Savings (kWh) | Uncertainty (%) | Uncertainty Value ($) | M&V Cost ($) | Benefit ($) |
|---|---|---|---|---|---|
| Sample TOU Post (80/20) | 713,340.55 | 50.27% | $26,894.18 | $2,130.00 | ($15,927.33) |
| Initial Estimate | 713,340.55 | 20.50% | $10,966.86 | $0.00 | $0.00 |
| Sample TOU Post (90/10) | 713,340.55 | 15.64% | $8,366.05 | $8,511.33 | $2,600.81 |
| Meter TOU Post | 713,340.55 | 1.87% | $1,002.56 | $29,403.00 | $9,964.30 |

**Figure 6. Office Lighting test results**

## Conclusions and Recommendations

Many elements of the Tool were shown to be very effective. The use of a database platform and the design of the core table structure and relationships appear to be the strong points of the design. Logging the data associated with a single M&V alternative made comparing a later alternative quick and easy through the use of queries and reports. The bulk of the selections made by the user during the definition of a proposed M&V method were stored in the database. A report could be quickly generated to show the assumptions and project requirements for the implementation phase, in order to maintain the specified levels of uncertainty and costs. At any point, the user could go into the tool and redefine one element of a project, measure, or data collection method and recalculate the total project energy savings and uncertainty. This feature is made possible by the storage of the individual elements of the cost and uncertainty models in the records associated with the user's project.

The uncertainty model was shown to be valid under the assumption that the data provided was reasonable. Tests indicated that the sampling uncertainty needs attention. The aggregation of measurement and modeling error at the variable level appeared to have the appropriate affect on the resulting total uncertainty of the variable. This process may be tuned in the future, but the underlying structure proved to be effective.

The use of reports for manual analysis of design alternatives also turned out to be a strong point in the tool's design. This allowed the user to easily compare project alternatives as well as look at the effects of individual measures within a project. In addition, the effects of data collection methods for individual variables within a measure alternative could be reported so that a manual sensitivity analysis could be done.

The cost model turned out to be a weak element of the tool's design. Data analysis and reporting time associated with various data collection methods was not included. We have yet to determine an appropriate account of analysis and reporting time that would be reasonable or that would properly scale with the amount of data collected or level of analysis required. This is a significant portion of the M&V cost for particular projects and should be accounted for in the cost model. In addition, the method for determining equipment cost incurred by a single project was somewhat generalized and should be improved. There were also some significant problems with the way travel cost was included in the total project cost. Additional information was required about the nature of the M&V activities in order to more accurately determine the cost to travel to and from the project sites.

A user input module for adding equipment to the library of measurement equipment should be developed. This module should allow the user to add measurement equipment, sensitivities and costs. It should also allow users to define how well proxy variables model objective variables.

Finally, extensive use and testing by practitioners is in order. Feedback on the usefulness of the energy savings, uncertainty, costs and M&V plan assessment scheme is much needed. Such feedback would be invaluable to determine the appropriate venue for its use, whether it is for negotiations of M&V between private facility owners and energy service professionals, or in regulated utility performance contracting programs. Such information is necessary before undertaking Tool enhancements, such as adding more M&V methods for more complex EEMs, or including capability to assess IPMVP Option C or D – type methods.

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