

ENHANCING THE VALUE ENGINEERING PROCESS BY INCORPORATING UNCERTAINTY ANALYSIS

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ABSTRACT

This paper is to help managers recognize uncertainty in their VE proposals and appropriately adjust their VE studies to reflect this uncertainty during the VE process and in their final report on projected savings. This paper is organized to first review the VE process results for a given proposal on a hypothetical environmental restoration project and then to show an example of how uncertainty analysis, using computer simulation, can be added to improve the usefulness of the VE process. Lastly, brief discussions are provided on: interpreting uncertainty analysis results; applying the technique using a graded approach; using off-the-shelf software tools; and the advantages and disadvantages of the uncertainty analysis technique.

contract reform initiative, all contractors are needing a disciplined and proven methodology for reducing costs and maximizing value for the customer. VE is an excellent tool to meet this challenge.

A VE study is an important tool that can help to optimize resources to eliminate unnecessary functions and their associated unwanted costs. Often the mission of such a study is to come up with a series of proposals to save as much money as possible by eliminating unnecessary functions, without compromising important requirements, such as those of performance, health, safety, and the environment.

Many studies are based on input data, such as cost data, rate/production data, contamination data, etc., that is typically of "best-guess" quality.

Hypothetical ER Project Example

For example, consider an environmental restoration project involving the removal of a large contaminated wooden structure. To keep this example simple, no details on the type of contamination or applicable state or federal regulations will be provided. Assume that the project team estimates that: 1) there are 9,000 contaminated boards in the structure; and 2) the boards have surface contamination on one side only.

INTRODUCTION

Martin Marietta Energy Systems, Inc. is a management and operations contractor for the DOE and is working to further DOE's commitment to perform environmental restoration (ER) work better, faster, and at lower cost. As a part of DOE's

Fig. 1. shows the typical dimensions of a contaminated board. As shown in the figure, the depth of contamination is not fully known. A

statistical survey conducted by the project team estimates that the average depth of contamination is 0.25 inches, with a standard deviation (a measure of the spread or dispersment about its average value) of 0.0625 inches.

The original project (before the VE study) called for complete disposal of all contaminated boards (Refer to Table 1). Disposal costs are estimated at \$65 per ft³. The rough project cost estimate is thus calculated to be \$520,000. For simplicity sake, this estimate should be interpreted to include all relevant costs.

Table 1. Original Project Estimate.

Number of contaminated boards	9,000
Volume of contaminated board ¹	0.8889 ft ³
Total contamination volume ²	8,000 ft ³
Disposal cost	\$65 per ft ³
Project cost ³	

VE Proposal Result (No uncertainty analysis)

Assume further that a VE study is performed on this project. As their primary proposal, the VE team recommends that rather than dispose of the 9,000 contaminated wooden boards, the contaminated surfaces simply be shaved off and disposed of and the boards reused or sold. The team estimates the average cost of shaving a board to be \$45 (this number accounts for the salvage value of the boards). The rough savings generated by this proposal is \$50,000. The VE proposal estimates are shown in Table 2.

Table 2. VE Proposal Estimate.

Number of contaminated boards	9,000
Volume of contaminated board ⁴	0.1111 ft ³
Total contamination volume ⁵	1,000 ft ³
Shaving cost	\$45 per board
Total shaving cost ⁶	\$405,000
Disposal cost	\$65 per ft ³
Total disposal cost ⁷	\$65,000
Project cost ⁸	\$470,000

¹Length = 8 ft.; width = 8 in. (0.6667 ft);
depth = 2 in. (0.1667 ft.)

²9,000 boards x 0.8889 ft³

³8,000 ft³ x \$65 per ft³

⁴8 ft x 8 inches x 0.25 inches

⁵9,000 boards x 0.1111 ft³

⁷1,000 ft³ x \$65 per ft³

⁸\$405,000 + \$65,000

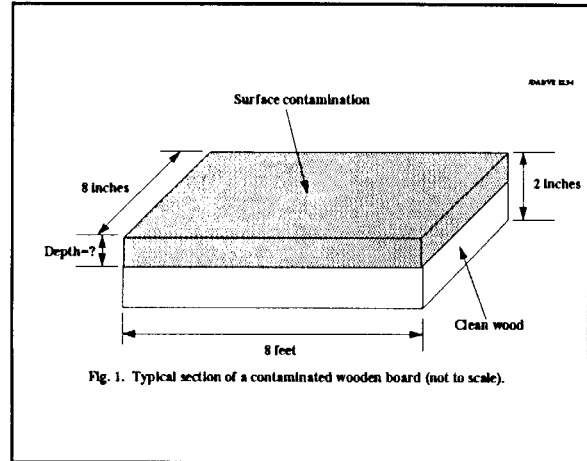


Fig. 1. Typical section of a contaminated wooden board (not to scale).

This VE proposal estimates a savings of \$520,000 - \$470,000, or \$50,000, which looks attractive at first glance.

VE Proposal Incorporating Uncertainty Analysis

In the preceding example there was no attempt to quantify the uncertainty in the VE proposal; estimates were reflected as our best guess. All would probably agree, though, that at project completion there will not be *exactly* \$50,000 in savings. The question is, how certain is that estimate? What are the possible savings amounts and what is the respective probability of each of them occurring? Is there a significant possibility that we may save more than \$50,000? Is there a significant possibility that we may save a lot less than \$50,000 (or perhaps have a negative savings!)? Management or the customer may permanently lose faith in VE if we promise \$50,000 and then deliver a cost overrun. Thus, we next need to assess our confidence in this number.

Uncertainty analysis will help us understand the inherit uncertainty in our proposal inputs and the impact on the projected savings. For example, let's examine three significant and uncertain inputs in the above VE proposal: the total number of contaminated boards; the depth of contamination on each board; and the net shaving cost per board. Each of these inputs can significantly drive the savings up or down. The following sensitivity tables, that were generated by loading the estimate data into a Microsoft® Excel electronic spreadsheet, show this.

Table 3. Savings Sensitivity due to Number of Boards.

Number of Contaminated Boards	Original Project Cost (\$)	VE Proposal Cost (\$)	Savings (\$)
6,000	346,667	313,333	33,333
7,000	404,444	365,556	38,889
8,000	462,222	417,778	44,444
9,000	520,000	470,000	50,000
10,000	577,778	522,222	55,556
11,000	635,556	574,444	61,111
12,000	693,333	626,667	66,667

From Table 3 we see that if we have underestimated the number of contaminated boards (i.e., we estimated 9,000 but found 10,000), it will result in a higher VE proposal savings. The converse of this is also true. Table 4 below is a sensitivity analysis of the effect of the depth of contamination on the projected savings.

Table 4. Savings Sensitivity due to Contamination Depth.

Depth (inches)	Original Project Cost (\$)	VE Proposal Cost (\$)	Savings (\$)
0.05	520,000	418,000	102,000
0.10	520,000	431,000	89,000
0.20	520,000	457,000	63,000
0.25	520,000	470,000	50,000
0.30	520,000	483,000	37,000
0.40	520,000	509,000	11,000
0.50	520,000	535,000	-15,000

From Table 4 several points are noteworthy. The original project cost estimate does not change with a change in the depth of contamination, which should make sense since in

the original project we planned to dispose of all the contaminated boards, regardless of the amount of contamination. Also note from the VE Proposal Cost column that the cost of adopting the proposal rises with an increase in the depth of contamination, which should also make sense as there would be a need to dispose of more shaving waste. The resultant fourth column shows the savings, which for large depths of contamination approaches zero savings. In fact, a half inch depth of contamination results in a cost *overrun* of \$15,000.

Now consider the sensitivity of projected savings due to the shaving cost per board, shown in Table 5.

Table 5. Savings Sensitivity due to Shaving Cost per Board.

Shaving Cost (\$)	Original Project Cost (\$)	VE Proposal Cost (\$)	Savings (\$)
15	520,000	200,000	320,000
25	520,000	290,000	230,000
35	520,000	380,000	140,000
45	520,000	470,000	50,000
55	520,000	560,000	-40,000
65	520,000	650,000	-130,000
75	520,000	740,000	-220,000

As with the prior sensitivity table, the original project cost estimate would not change since there was no plan to shave boards. The VE Proposal Cost, however, does change, since by adopting the proposal we would commit to shaving boards. Note that with an increase in shaving cost, the attractiveness of the VE proposal diminishes. If the shaving cost per board were to be \$75, by adopting this proposal the project team may expect a cost *overrun* of \$220,000. Conversely, if we could apply experience curve effects to reduce the shaving cost per board to \$15, we could expect to save \$320,000—more than six times previous savings

estimate of \$50,000.

At this point in our analysis the uncertainty in our estimates could result in management or the customer getting a significant “surprise”—either less savings or more savings. Such surprises can be a problem, even when the savings are greater than expected since project managers may end with a significant amount of unused funds — funds that could have been deployed elsewhere.

Although sensitivity tables using conventional spreadsheets are one way to ferret-out the uncertainty in an analysis, there are other tools that both speed the process and produce much better results. For example, in the tables above we considered the impact on savings by changing *only one* variable at a time (e.g., we varied the number of boards *or* the expected depth of contamination *or* the shaving cost per board). But what about the *combined* simultaneous effect of changes in all three? And what about all the intermediate values for our three variables, such as 8,756 boards, \$32.58 shaving cost per board, or a 0.275 inch depth of contamination? Furthermore, we considered only a few values in our tables and gave no weight to those values that are more likely to occur than others (e.g., perhaps the extreme values are less likely to occur than the average values).

This problem is remedied by modifying our Excel spreadsheet with a product called @RISK, by Palisade Corporation. @RISK obviates the need for sensitivity tables; allows us to replace static input variables with probability distributions (a set of probabilities associated with all possible outcomes of an uncertain event, such as the number of contaminated boards in our wooden structure) that represent those variables; and allows us to assess the combined effects of changes in those variables on data of interest, in our case the expected savings of the VE proposal.

For example, using @RISK we can replace our static estimate of 9,000 boards in our electronic spreadsheet with a representative

uniform distribution. Likewise, we can replace our static estimates for the depth of contamination and our estimate for the cost of shaving the boards with suitable distributions. Based on statistical sampling, we previously estimated that the depth of contamination was normally distributed (the “bell curve”) with an average value of 0.25 inches and a standard deviation (a measure of the spread or dispersement about its average value of 0.25 inches) of 0.0625 inches.

Those not familiar with terms such as “normally distributed” and “standard deviation” may want to consult an introductory statistics book. Similarly, by statistical sampling we can determine that the shaving cost per board is uniformly distributed with a minimum cost of \$30, an average cost of \$45, and a maximum of \$60 per board.

Our other input variable, the number of contaminated boards, was estimated by the project team to be uniformly distributed with a minimum number of boards of 6,000, an average of 9,000, and a maximum of 12,000. Table 6 summarizes this statistical information.

Table 6. Input Variables Statistical Summary.

Variable	Distribution	Parameters
Number of Boards	Uniform	Minimum of 6,000 Average of 9,000 Maximum of 12,000
Depth of Contamination	Normal	Average of 1/4 inch Standard dev. of 1/16 inch
Shaving Cost per Board	Uniform	Minimum of \$15 Average of \$45 Maximum of \$75

The functions in @RISK allow us to easily modify our spreadsheet with these distributions. For example, in Excel we can replace our static estimate of 9,000 boards with the following spreadsheet cell entry:

=Risk Uniform(6000,12000)." The cell content shows the average of this distribution, which is of course 9,000. Also, @RISK has a normal probability distribution function that we can use for the depth of contamination:

=RiskNormal(0.25,0.0625). Lastly, we can replace our shaving cost per board estimate cell entry with:

=RiskUniform(15,75). Once these modifications to the spreadsheet have been made (it takes about 60 seconds to make these changes) we select the spreadsheet cell(s) that we want to see results (output) for; in our case the spreadsheet cell of interest is savings.

At this point we instruct @RISK to electronically simulate the calculations for a given number of iterations. This amounts to the software simultaneously taking a sample number from each of these distributions and recalculating the spreadsheet based on these samples. The combined results of each of these iterations are saved in both tabular and graphic format. The greater the number of iterations, the more representative the results.

VE Proposal Uncertainty Analysis Results

Our spreadsheet was modified and @RISK instructed to perform 1,000 iterations. This modification took approximately two minutes. Using an Intel 486 personal computer, the simulation analysis took approximately five minutes. On faster, Intel Pentium-based computers the processing time would decrease significantly. The figure below shows the uncertainty analysis results for the projected savings. In addition to a graph, @RISK also generates a summary statistics table. For our simulation the following data were generated (summarized for simplicity):

Table 7. Simulation Statistical Summary.

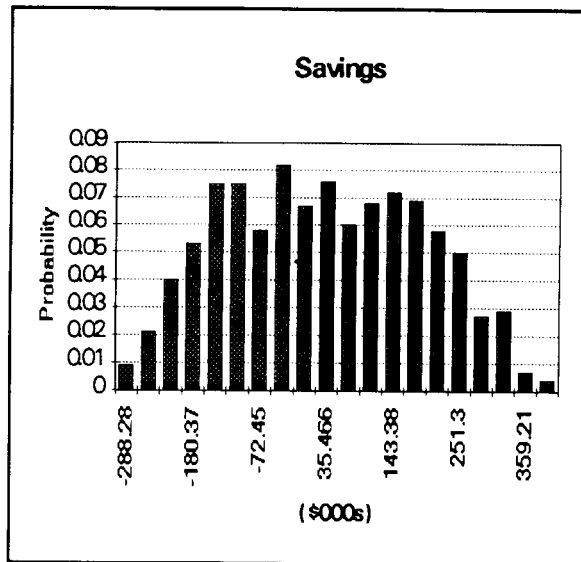
Variable	Simulation Results
Savings	Minimum Savings - \$286,081 Average Savings \$50,698 Maximum Savings \$422,042

This tells us that on average we should realize approximately \$50,698 worth of savings, and have the potential to overrun by \$286,081 or save up to \$422,042, which is a wide distribution in savings. Another feature of @RISK is its ability to determine the probability of getting a target value or less. For example, we can determine the probability of realizing a negative savings by entering zero as a target value in @RISK. This was done, and the result was 41%, which means that there is a 41% chance that our proposal could generate negative savings. The converse of this is that there is a 59% chance that there will be positive savings. The VE team and management need to know this before adopting a proposal so that the uncertainty that is causing this wide distribution in expected savings can be managed.

INTERPRETING ANALYSIS RESULTS

Interpreting and Communicating Results

Care should be taken when interpreting and communicating the results of an uncertainty-adjusted VE study. Personnel who understand statistics should be consulted for help in preparing study results and



in interpreting the results. Presenting reams of tables and graphics to management or the customer is not a prudent approach.

Presentations to management should limit the statistical emphasis and highlight a very limited set of graphics, such as an expected savings distribution. If management has no understanding of statistics, even greater consideration should be given to explaining in

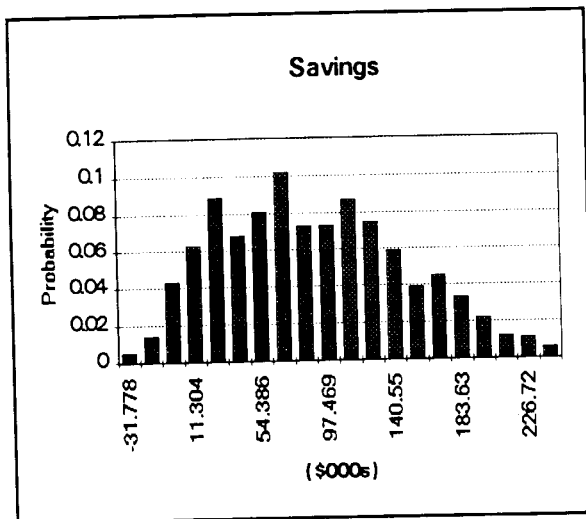
simple terms what the output is communicating. Presentations should also recommend unequivocally the actions that management should take to manage the uncertainty.

Influence on Management Decision Making

One of the most important points for management to seize upon in reviewing an uncertainty-adjusted VE analysis is the root cause of the uncertainty. Often management can take a few decisive, cost-effective steps to reduce the uncertainty and shift the savings distribution to be more favorable. Performing an uncertainty analysis can be a valuable exercise; but management must take action based on those studies. Using our environmental restoration project, management should investigate how to reduce the shaving cost per board and ensure that the experience curve principle is implemented. These simple steps can be re-factored into the simulation. For example, by doing this the shaving cost per board distribution could be changed to: =RiskUniform(30,50); this gives an average shaving cost per board of \$40 and tightens the distribution (instead of 15 to 75; it is 30 to 50). These are realistic uncertainty management techniques.

This change was made to the spreadsheet and rerun. The following savings distribution resulted. Note that the distribution is much more favorable, with only a very small chance of having a small overrun. As in section 2.3, a target value of zero was entered. With these changes the analysis concluded that there is only a 2.8% chance that the savings will be less than zero—a dramatic improvement over a 41% chance. Recall that the converse is also true—there now is a 97.2% chance that our VE Proposal will result in positive savings!

GRADED APPROACH TO UNCERTAINTY ANALYSIS



Uncertainty analysis is a powerful technique and should be implemented using a graded approach, which simply means that for a small, low cost, or otherwise low impact proposal, uncertainty analysis may be unnecessary. For a costly or high visibility project, where the consequences of having a significant savings surprise would be unacceptable, a rigorous amount of uncertainty analysis may be appropriate. Since most proposals have many input variables, the team should focus their uncertainty analysis on the significant few variables instead of the trivial many.

Also note that usually there would not be a need to add a statistician to the VE process; with some basic statistics training (or refresher), most teams can incorporate uncertainty analysis into their proposals using @RISK with minimal additional effort.

SELECTION OF PROBABILITY DISTRIBUTIONS AND PARAMETERS

One of the more difficult aspects of using uncertainty analysis is the proper selection of the applicable probability distributions and their parameters. For example, is the depth of contamination in the boards normally distributed? What is the standard deviation? These decisions are quite important since the entire analysis results will be determined based on them. Often it may be possible to perform statistical sampling as was done in the example to determine these numbers. Otherwise, the project team’s best estimates should be used.

In our example, we used two distributions: the uniform distribution and the normal distribution. The @RISK software offers more than thirty distributions and is accompanied by an interactive distribution graphing program that facilitates selection of the best distribution.

OFF-THE-SHELF UNCERTAINTY ANALYSIS TOOLS

While there are several off-the-shelf products that offer uncertainty analysis, the dominant product by far is @RISK, by Palisade Corporation. This product, along with its companion products, one of which helps users determine the best distribution for a given set of data, is by far the easiest to use, most flexible, and most powerful in terms of speed and features. The examples in this paper were prepared with @RISK for Excel, which works in a Microsoft Windows® environment.

COMPARISON TO TRADITIONAL VE STUDY

The sections below highlight some of the more salient advantages and disadvantages of an uncertainty-adjusted VE study with a non-uncertainty-adjusted VE study. When applied in a graded approach, the advantages exceed the disadvantages.

Advantages

The primary advantages of incorporating uncertainty analysis in a VE study include:

- It quantifies for management the amount, cause, and impact of uncertainty;
- It forces recognition of the sources of uncertainty. Once they are identified, management can decide how best to minimize or even eliminate them in a cost-effective manner; and
- It can prevent clients of VE studies from being “surprised” by the deviation between a savings amount forecasted by a VE study and the actual, realized savings when implemented.

Disadvantages

The primary disadvantages of incorporating uncertainty analysis in a VE study include:

- it takes more time to complete the study and most likely will increase the cost of a given study;
- it requires a basic understanding of probability and statistics; and
- it requires analytical tools and possibly some training on how to use them.

CONCLUSION

Traditional VE studies can be significantly

enhanced through the judicious incorporation of uncertainty analysis. By incorporating such analytical tools as @RISK, the VE practitioner, management, and the customer of the VE study, can better understand the uncertainty in the expected savings and can wisely allocate resources to reduce it. This type of analysis can reduce unwelcome “surprises” and increase the credibility of VE studies.

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FOOTNOTES

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