Uncertainty Modeling in Multiple Dimensions for Value Methodology

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Introduction

Traditional VM has focused on the relationship between function and cost in assessing value. Today, many VM practitioners are basing value comparisons on trade-offs between outputs (i.e., performance) and inputs (i.e., cost and time) relative to the performance of functions. In both cases, these expressions of value are generally deterministic in nature and do not factor in the inherent uncertainties of performance, cost and time. In a world where uncertainty is prevalent and the ideal conditions are often only statistically the most likely to materialize, it is important to acknowledge the multiple sets of outcomes that may occur. By introducing uncertainty into facets of performance (which seeks to quantify how well a function is being performed), cost (how much a function costs), and time (how long it takes to deliver the function) within the context of the value equation, one can acknowledge the inherent uncertainty present within the dimensions of the value equation.

What is uncertainty?

Uncertainty is defined as the quality or state of being uncertain. That is to say, it is a state of not knowing. Within the context of this paper, the term "uncertainty" refers to a lack of knowledge about current and future information and circumstances. Uncertainty poses a special set of problems to the management of projects as it can potentially affect outcomes for both the good and the bad. In the context of Value Methodology this acknowledges that uncertainty can be addressed by exploring creative alternatives to maximizing positive event frequency and/or minimizing or buffering the effects of negative event and assumption exposure.

What is risk?

It is often assumed that the word "risk" implies a negative outcome. For example, if someone said "that is a very risky assumption" one would take it to mean that they think that my assumption is likely to be wrong and, consequently, something bad will happen as a result. The fact of the matter is that "risk" represents an uncertain outcome. Risks may have either positive or negative outcomes. A negative risk is defined as a "threat" while a positive risk is defined as an "opportunity." Therefore, something that is properly defined as "risky" does not necessarily mean that it is a bad thing, only that it is an uncertain thing.

This bias toward "risks" as being bad things often causes us to overlook potential opportunities. Just as threats can result in a catastrophic disaster, opportunities can result in spectacular windfalls.

Why people are bad at dealing with uncertainty and risk

People are generally not well equipped to deal with uncertainty for a number of important reasons. These include the way in which humans perceive time; the physiological shortcomings that all humans possess that create perceptual roadblocks; and a host of cognitive biases related to emotional and psychological phenomenon.

Firstly, humans begin life from a certain time bound perspective. To use the terminology of noted American psychologist Phillip Zimbardo, this perspective on time is known as "present hedonistic.[1]" All infants begin in this time frame, and many of us end up staying there. This time frame predisposes us to consider things from the viewpoint of how decisions will affect us in the moment or in the short term. People today, and especially children, are generally gravitating toward a present hedonistic perspective due to the ever present nature of technology and its ability to provide us with instant gratification and a sense of control (i.e., video games, hundreds of cable television channels, internet browsing, smart phones, text messaging, e-mail, etc.). This has very important implications for us when considering the role of uncertainty in our decision making because it diminishes our awareness while increasing our vulnerability to future uncertainties.

Secondly, everyone essentially possesses the same physiology, which is fraught with the numerous shortcomings of our six senses. It is important to remember that, to a large degree, the brain functions by interpreting the world around us through the senses. Perhaps the most important of these is vision. Most people depend greatly upon their eyes every single day. With respect to our ability to perceive the future, most optical illusions are caused by a neural lag. When light hits the retina, about one-tenth of a second goes by before the brain translates the signal into a visual perception of the world. Scientists have known of the lag, yet they have debated over how humans compensate, with some proposing that our motor system somehow modifies our movements to offset the delay.

The human visual system has evolved to compensate for neural delays, generating images of what will occur one-tenth of a second into the future. This foresight enables humans to react to events in the present. This allows humans to perform reflexive acts like catching a fly ball and to maneuver smoothly through a crowd. Illusions occur when our brains attempt to perceive the future, and those perceptions don't match reality. For example, one illusion called

[1] Zimbardo, Phillip, "The Time Paradox: The New Psychology of Time That Will Change Your Life," Simon & Schuster, New York, 2008

the Hering illusion (Figure 1) looks like bike spokes around a central point, with vertical lines on either side of this central, so-called vanishing point. The illusion tricks us into thinking we are moving forward, and thus, switches on our future-seeing abilities. Since we aren't actually moving and the figure is static, we misperceive the straight red lines as curved ones.[2]

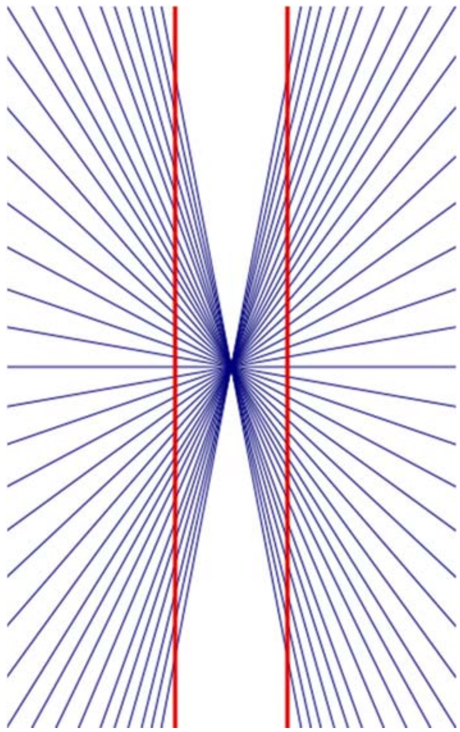

Figure 1 - Hering illusion

Finally, people are subject to a bewildering number of cognitive biases that inhibit our ability to deal with uncertainty. These include, but are not limited to the following:

- *Anchoring Heuristic* – The tendency for people to bias their decisions to the first piece of evidence encountered or their initial preconceptions.
- *Availability Heuristic* – The tendency for people to biased toward images that are more vivid and readily available to the mind's eye.
- *Representativeness Heuristic* – The tendency for people to associate outcomes from the events that created them (i.e., a random lottery should produce a random sequence of numbers).
- *Framing Effect* – The tendency for people's decisions to be biased based on how a prospect is articulated within the domain of losses or gains.

[2] Bryner, Jeanna, "Key to all Optical Illusions Discovered," Live Science, June 2, 2008

- *Overconfidence Effect* – The tendency for people to overestimate their ability to control or manage events in which they are involved.
- *Motivational Bias* – The tendency for people to influence decisions for personal gain whether it is to avoid embarrassment, appear knowledgeable or advance one's agenda.
- *Optimism Bias* – The tendency for people to overestimate good outcomes and underestimate the probability of bad outcomes.[3]

Why deterministic assumptions can be misleading

Value Methodology traditionally has focused on improving value through the reduction of cost in delivering functions. Typically, cost savings are expressed in deterministic terms, meaning, it is assumed that the savings will be realized and there is generally no real elaboration on the true likelihood of the stated cost benefits being realized. Generally speaking, most VM studies occur within a relatively short time frame and the alternative concepts developed will require additional technical analysis in order to validate the potential benefits. Further, seldom are the various costs associated with full implementation completely considered (i.e., the cost for redesign, logistics impacts, etc.) The result is that there is generally a great deal of uncertainty with respect to the true cost benefits that will actually be realized. The result, oftentimes, is that promising concepts are rejected or ignored due to these uncertainties.

The potential impact to time and schedules is also quantifiable in terms similar to cost. The schedule savings of a construction related alternative can be calculated using modern scheduling techniques and stated deterministically. Again, however, there are the problems facing a decision maker with respect to the certainty with which the suggested changes can be made within the predicted time frames, especially when untested approaches are recommended. Change, in and of itself, is often more time consuming then we think it will be.

Finally, there is usually some degree of uncertainty when considering how an alternative concept will perform in the present or in the future, especially if it is innovative or untested. For example, we cannot be certain how a change to the design of a highway interchange will affect traffic operations until has been constructed and has been operational for a sufficient time to measure traffic characteristics. Similarly, we cannot know what traffic volumes will be 10 or 20 years into the future. Nonetheless, different interchange concepts will offer different performance characteristics at different points in the future depending upon a set of conditions.

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[3] Cretu, Ovidiu; Stewart, Robert; Berends, Terry, "Risk Management for Design & Construction," John Wiley & Sons, Hoboken, 2011

In summary, the reason why most alternative concepts are rejected is due to uncertainty and risk associated with assumptions that are ultimately driving the deterministic outcomes. We simply cannot know with 100% certainty what will happen. Moreover, we are generally less confident when it comes to new ideas and concepts that are untested or are relatively novel in nature.

Incorporating Risk into Equations for Value

In making value comparisons, four essential elements must be factored. These include cost, performance, time and risk. The Value Metrics approach to value measurement relies upon a fundamental mathematical algorithm for modeling value.[4] There are two types of algorithms that can be considered. These algorithms vary depending on whether a "dynamic" or a "discrete" model best reflects actual conditions.

The dynamic model considers value as the interrelationship between inputs and outputs (or, alternatively, the costs and benefits) of a system. This type of model is non-linear in nature and considers tradeoffs between cost, time, and performance while considering how risk influences each of these elements. The outcomes realized are dependent upon the resources input into the system. This is why it can be said that it is a "dynamic" model of value. The algorithm for this model can be stated as follows:

$$V_f(P,C,t)_{total} = \frac{\sum_{n=1}^{N} P_n \cdot \alpha}{\sum_{n=1}^{N}[(C_n \cdot \alpha) + (t_n \cdot \alpha)]}$$

Where ***V*** = Value, ***f*** = Function, ***P*** = Performance, ***C*** = Cost, ***t*** = Time, ***α*** = Uncertainty, and ***N*** = the number of developed value alternatives.

The discrete model considers value as the sum of the elements of value of a system. This type of model is linear and considers cost, time, performance and risk independently. The outcomes realized are dependent on the net aggregation of the individual components of the system. This is why it can be said that it is a "discrete" model of value. The algorithm for this model can be stated as follows:

$$V_f(P,C,t)_{total} = \sum_{n=1}^{N}\left[W_P \cdot (P_n \cdot \alpha) + W_C \cdot \left(\frac{1}{C_n} \cdot \alpha\right) + W_t \cdot (t_n \cdot \alpha)\right]$$

Where ***V*** = Value, ***f*** = Function, ***P*** = Performance, ***C*** = Cost, ***t*** = Time, ***W*** = weight, ***α*** = Uncertainty, and ***N*** = the number of developed value alternatives.

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[4] Stewart, Robert, "Value Optimization for Project and Performance Management," John Wiley & Sons, Hoboken, 2010

The dynamic and discrete models have different applications and consider the interrelationship of cost, time, performance and risk differently. Generally speaking, the dynamic model is generally a more accurate representation of value in its purest form. It acknowledges the interplay between inputs and outputs and allows stakeholders to evaluate alternatives based on trade-offs between them. The dynamic model is therefore most appropriate in the following applications:

- The evaluation of projects located in the public domain.
- The evaluation of potential solutions for complex problems, especially those involving subjective expressions of performance.
- The evaluation of new technologies in product development.
- The evaluation and development of new projects or processes.
- The comparison of mutually exclusive investment alternatives.

In contrast, there are certain applications where a discrete model is more representative of actual conditions:

- The evaluation of products that have reached a technological plateau and have essentially been "commoditized." Such products essentially have little differentiation in terms of outputs (i.e., performance) and offer a very narrow range of variability. Typically, under these conditions, performance is generally prescriptive (i.e., binary requirements) and cost and/or time are the predominate elements.
- The evaluation of alternatives where the decision criteria has been dictated or pre-conceived. It must be acknowledged that such situations are commonplace; however, they are generally a result of a flawed understanding of priorities. These situations usually occur as a result of decision criteria being imposed artificially and/or by entities external to a decision process.
- The evaluation of a network system with a defined pathway. Examples of a network system include pipeline infrastructure networks, computer system networks, traffic system origin-destination pairing for route management, or any other system with a defined and limited number of pathway alternatives.

Using a mathematical framework such as the ones presented above for the assessment of value, risk can be factored into any or all of the quantities for cost, time and performance. This allows for a more robust consideration of value such that the inherent variability of the system can be acknowledged and factored in to making value minded decisions.

Considering Cost and Schedule Risk

The components of cost and schedule are major elements of value that are often key to making decisions of allocation and ultimately determining which products, processes, or projects move beyond the planning phases. The focus on cost and time to delivery also tends to be increasingly important in situations in which capital constraints limit the domain of real options or in situations in which a solution must be rolled out relatively quickly. The modeling of cost and schedule risk helps to better inform decision makers about the nature and uncertainties associated with cost and duration profiles and can be performed in two distinct manners. The two methodologies of quantitative risk assessment are simple range estimation or complex quantitative modeling; both of which provide information on the exposure of risk, or uncertainty, in the system.

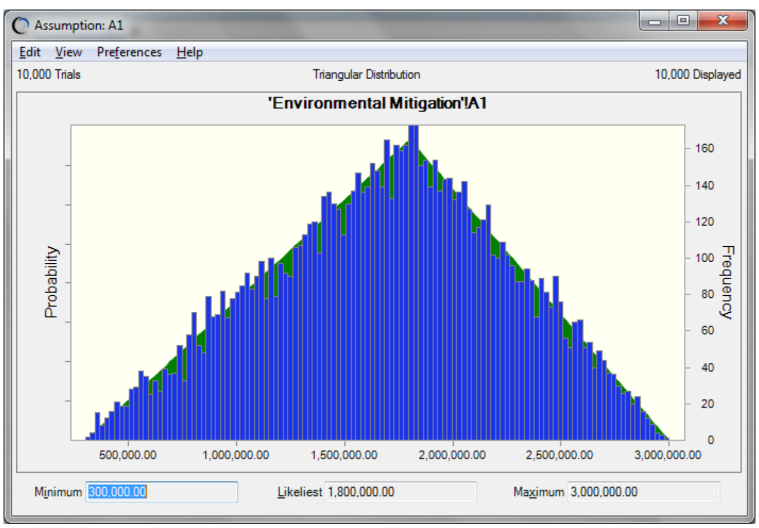
Both types of risk assessment are quantitative in nature and seek to answer the questions of "How long will it take?" and "How much will it cost?". While these questions seem relatively easy in a general sense to answer, it is often much more difficult to answer with any real sense of precision. That is why it is important to depart from deterministic modeling that arrives at simple conclusions and a point estimate answer and move towards answering these two questions in more of a range bound approach. We can acknowledge that the world is dynamic and is constantly changing around us, so why would we settle on a single point estimate? The modeling of cost and schedule risk allows us to explore the range of possibilities that may occur in terms of the dollars and time associated. The simple approach, which is quantitative range estimation, will be explored first. Then the complex quantitative modeling approach will be explored. Note that both of these approaches will be covered in the context of cost and schedule modeling through the use of Monte Carlo simulation, which is an algorithm that allows us to simulate the outcomes.

Simple Range Risk Assessment

In range estimation the act of risk assessment involves developing simple distributions that are relatively representative of the situations that are trying to be modeled. That is, we are trying to understand the variation in the system. When moving to understand the actual range of something there is a need for data to support the assumptions being made. Often, when modeling cost and schedule risk the ranges are elicited from subject matter experts or those individuals with intimate knowledge of the system being analyzed. The other approach is to use mathematical distributions based on available statistical data to develop a range of probable outcomes. For the purposes of this paper and speaking in relation to Value Methodology, we will speak more to the use of subject matter experts, just as would be the case in a value study.

When developing a simple range estimate, a triangular distribution can be employed to approximate the system. The ranges are established by identifying what the best case, worst case, and most likely situations are. For risks that are threats the best case is the low end of the range, the worst case is the high end of the range, and the most likely is the median of the range. For risks that are opportunities the best case is the high end of the range, the worst case is the low end of the range, and again, the most likely scenario is the median of the range. From these data points a simple triangular distribution can be constructed in order to model the range of probable outcomes in a simplified manner.

Suppose that a cost threat of environmental mitigation on a highway interchange project has been identified that has a best case scenario of costing $500,000 if it is realized, a worst case scenario of $3,000,000 if it is realized, and a most likely value of $1,800,000. From this data we could construct a simple range estimate to understand what the probabilistic outcomes could be. If we run this simple triangular distribution in a Monte Carlo simulation by assuming that the low end of the range has a confidence interval of 10% (i.e., the risk has only a 10% chance of being equal to or less than $500,000) and the high end of the range has a confidence interval of 90% (i.e., the risk has a 90% chance of being equal to or less than $3,000,000) and the median or 50% confidence interval (i.e., it is equally likely that the value could be higher or lower than the median), we would find the following situation depicted in the Figure 2 below.



Statistic	Forecast values
Trials	10,000
Base Case	0.00
Mean	1,698,293.26
Median	1,719,589.34
Mode	---
Standard Deviation	552,390.20
Variance	305,134,928,132.3
Skewness	-0.1019
Kurtosis	2.38
Coeff. of Variability	0.3253
Minimum	316,655.70
Maximum	2,987,675.40
Mean Std. Error	5,523.90

Figure 2 - Example range estimate

You can see how the model is attempting to assess the risk by modeling the distribution approximately according to the parameters input. The minimum exposure in this case is $316,655.70 while the maximum exposure is $2,987,675.40, while the median, or most likely, value is $1,719,589.34. Instead of saying “This risk could cost us $1.8 million” the range tells you that it is most likely to be roughly $1.72 million, but in reality it could be as low as $316,655 all the way up to $2,987,675. It could be better or worse and there is no guarantee that the risk will be exactly $1.8 million. That is exactly the point of range estimating. It is to acknowledge that there is a *range* of outcomes that may transpire if and when the risk is realized. Just as this example illustrates the cost impacts of a risk, the schedule side of the equation can be addressed in the same manner by assessing the low, median and high ends of duration parameters.

Complex Quantitative Risk Assessment

Moving into complex quantitative risk assessment involves taking the analysis of the nature of the risk much further. In complex quantitative analysis several more layers of the nature of the risk must be captured. It must be understood how likely the cost or schedule risk is to materialize. It must be noted if there is a situation that the cost or schedule risk is dependent upon and how it affects other activities in the system both in terms of cost and time. Complex quantitative risk assessment looks to provide an assessment of the expected value exposure, and in order to arrive at what the anticipated or expected impacts of a risk event are, each of these issues must be explored. The idea of being able to understand what the expected range of impacts truly is involves going through a series of steps to more thoroughly define the system in terms each of these domains.

Answering the questions relating the nature of the risk gets into exploring issues of correlations and dependencies. Risks may be dependent on other risks or events transpiring. Risks may also have a realistic nature in which they correlate to other events in a defined relationship. In risk modeling, dependencies are defined as the reliance of a risk event on another event. It is an if-then logic scenario. For example, if we run into contaminated soils, then we will have to clean up the mess and we may have another risk associated that if we have to do environmental mitigation, then we must bring a clean-up expert in to continuously monitor the site for an indefinite period of time. In our example let's say that we don't know of any environmental monitoring companies and none are available. This could create a schedule delay on the project until we can locate another contractor to continue work progression. The risk of schedule delay is now dependent upon having to perform environmental clean-up. Let's say that our risk event is triggered and we have to clean up contaminated soils. The very nature of the dependency here is not whether or not the contaminated soils exist, but the relationship of if we have to clean it up, we end up with a schedule delay. There is an independent risk of schedule delay that exists as a result of having to locate an environmental contractor if we don't already have one on-call or as a part of our contracting team (note that in this case, a dual mitigation could be having the environmental monitoring company locate possible contaminated areas that we could avoid in order to not realize either the cost or schedule risk!).

There are also correlations amongst risks. In cost and schedule risk assessment correlations tell us about the nature of relationships and how they interact. For example, cost and time are often correlated, or have a relationship to one another. If we were to have to clean up the mess of the contaminated soils and perform environmental mitigation, we may be able to do it quite quickly but it will be expensive. This is a negative correlation of cost and time. In other words, when cost is high, the duration is low and vice versa. The point of all of this is that in complex quantitative risk modeling it is important to capture the nature of the risk by explicitly defining the dependencies and correlations of the actual event in order to make the modeling of the event as realistic as possible.

Once it is understood how cost and time risks are related to the world around us in terms of dependencies and correlations, we need to understand how likely it is that a risk will transpire. Answering the question of how likely a risk is to materialize is basically asking a very discrete question pertaining to the probability, or frequency, of an event occurrence. What is meant by discrete is that the event either happens or it does not. It can be likened to a light switch either being on or off. Understanding the probability of a risk event is not just a relative measure of frequency. It is a measure of the frequency in which one could anticipate a risk event to materialize. If you were to say that the same environmental mitigation risk explored above has a likelihood of occurring of 35%, you are also saying that there is a 65% likelihood that it will not occur. What this illustrates is that the system is not continuous. In other words it happens 35% of the time and 65% of the time it does not. This is important to understand, because it helps in determining what the expected value impacts of a cost or schedule risk may be.

When assessing the expected value impact of a risk it is a matter of taking the simple range estimate and applying probabilistic assumptions of frequency to it. In deterministic form, an expected value impact calculation is as follows:

$$Expected\ Value = Probability \times \left(\frac{(a + (4 * b) + c)}{6}\right)$$

Where *a* is equal to the low end of the range, *b* is equal to the median value, and *c* is equivalent to the high end of the range.

Plugging in the numbers from our environmental mitigation example above with our sample 35% probability, we arrive at a deterministic estimate of the expected value of exposure of $612,500. However, if we run the Monte Carlo simulation for this situation, we again see a departure from a simple deterministic answer to gaining a better understanding of the system. It is discovered that the expected value impact has a minimum of $0 (because the risk may not even happen!), a maximum of $2,985,823, and a most likely outcome of $581,020. This information tells us much more about the nature of the risk and how to plan for it versus the simple deterministic approach that does not even acknowledge that the risk may not even happen. It is the “one sided” approach that sometimes biases decision makers from realizing they can pursue mitigation strategies to minimize risk exposure to 0 and leads them to plan for an impact of $612,500. How foolish does that seem if you could simply avoid the situation rather than plan for paying for it?

That is the point of moving from deterministic results to range bound results and the modeling of cost and schedule risk. It opens up our thinking to exploring options for managing cost and schedule uncertainties, which provides yet another area wherein Value Methodology can improve value. Using cost and schedule risk assessment as a means of defining the cost and time parameters of the value equation allows us to better model the reality around us and to open up our thinking to understand the range of outcomes of cost and time that could transpire. This also means that we can measure the effects of possible VM alternatives and determine which of them offers the best cost and time relationship relative to the performance of the system under the influences of uncertainty.

Let us explore these concepts further using an example. Assume that a VM study has developed three alternative interchange concepts to a baseline design concept. The cost and schedule of each has been estimated according to Table 1 below. Note that the cost and schedule ratings were derived by dividing each strategy by the sum of the total to convert it into a ratio scale. Cost and schedule were determined to hold equal importance, thus 50% of each score was added together to provide an aggregate cost and schedule score.

Priorities:	**Cost**	**0.50**	**Schedule**	**0.50**	
Alternatives	**Costs**	**Rating**	**Schedule (Months)**	**Rating**	**Total Score**
Baseline	$30,300,000	0.1345	24	0.1714	0.3060
Strategy 1	$29,128,000	0.1293	18	0.1286	0.2579
Strategy 2	$26,495,000	0.1176	14	0.1000	0.2176
Strategy 3	$26,693,000	0.1185	14	0.1000	0.2185
Total	$112,616,000		70		1.0000

Table 1 - Deterministic values for cost and schedule

From this table, we can see that VM Strategies 2 and 3 offer similar cost and schedule advantages over the baseline concept and VM Strategy 1. Note that the ratings columns for cost and schedule represent the normalized values expressed as a ratio measurement. Let us assume now that simple range risk assessment is performed for each of these four options for cost and schedule. Looking at Figures 3 and 4, when we consider the level of risk inherent in each of the options, the advantages posed by VM Strategy 3 begins to lose a bit of its luster. Clearly, judging by the much wider distribution of VM Strategy 3, there is a lot less confidence in the deterministic values for both cost and schedule as compared to the other options. In fact, overall, VM Strategy 2 appears to be a much safer bet. This example demonstrates how considering risk can provide much greater insight in considering value.

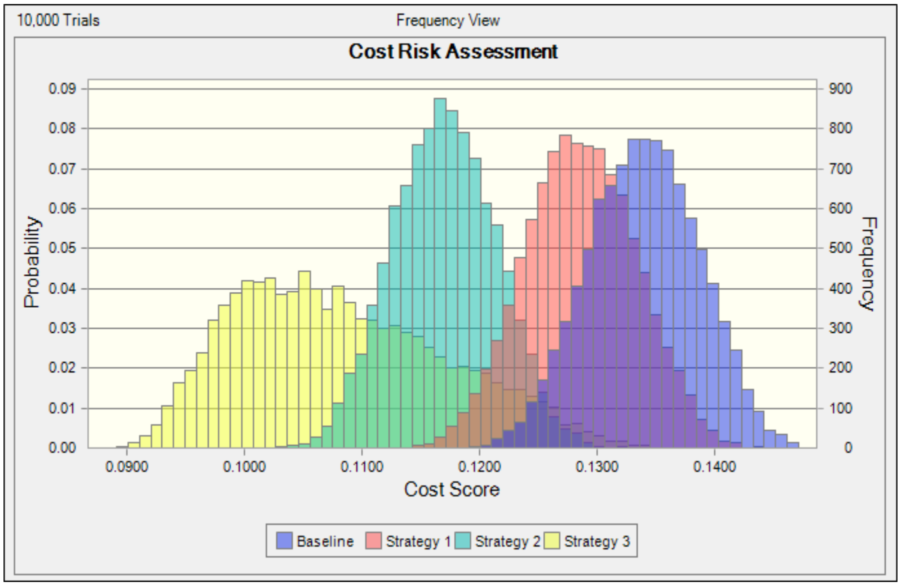


Figure 3- Probabilistic cost distributions for four options

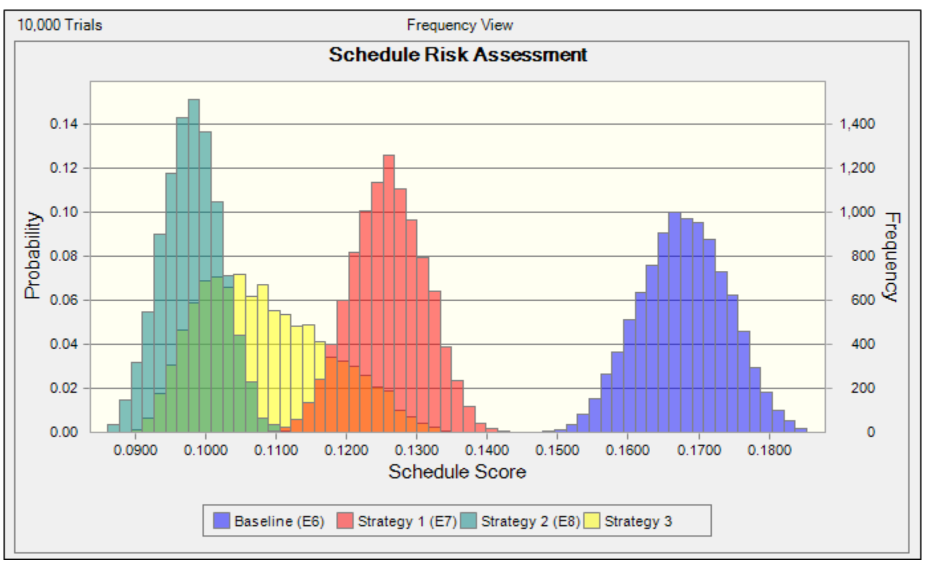


Figure 4 – Probabilistic schedule distributions for four options

Considering Performance Risk

Assessing performance risk is not quite as clear cut as it is for cost and schedule and poses a number of unique challenges. Firstly, performance encompasses a nearly infinite set of potential manifestations and cannot be so easily narrowed down to cost and time, which are understood, accepted and measurable quantities. Secondly, performance can be expressed as either a quantitative or qualitative using a variety of potential measurements.

The recommended method for measuring performance, and subsequently value, relies upon the framework of the Analytic Hierarchy and Analytic Network Processes (AHP and ANP) developed by Dr. Thomas Saaty.[5][6] The process essentially allows a variety of diverse performance attributes to be converted into ratio measurements using scaled, pair-wise comparisons. The process essentially consists of five basic steps: 1) Identify the decision goal, alternatives and evaluation criteria, 2) establish the priorities of the selection criteria (i.e., performance, 3) rate the performance of the alternatives, 4) synthesize the judgments to yield the overall priorities (scores), 5) Verify the consistency of the judgments.

With respect to modeling the uncertainty of performance using this method, one can consider how it affects performance priorities (step 2 above) as well as the performance ratings of individual alternatives (step 3 above).

Performance prioritization, if it is to reflect the minds of the decision makers, should obviously actively engage them in the prioritization process. This is the best way to ensure that the priorities are aligned with the actual decision makers (i.e., those that are in a position to approve or reject the alternatives emanating from a VM study). Assuming they have been involved in the process, it is not uncommon during the elicitation process to see significant differences in the priorities of the individual decision makers that are involved. Oftentimes, decision makers have different agendas, represent different groups of stakeholders that have divergent interests, and may even disagree on fundamental aspects of a project. This is oftentimes a reality, especially within the context of public projects, and it must be acknowledged. Simply forcing consensus and glossing over dissenting views on what is important is not reflective of the actual conditions and risks compromising the validity of the analysis.

One way to handle the uncertainties related to priorities related to performance is to evaluate the range of the intensities of priorities of the participants. In the following example, special AHP software known as Decision Lens was utilized to perform the pair-wise comparisons. Participants were given hand held remote control units to enter in their individual preferences and priorities. Figure 5 below shows a screenshot from the software where participants were asked to express the intensity of their preference between mainline and local operational performance for a highway project relative to the project's purpose and need. As can be seen

[5] Saaty, Thomas "Decision Making for Leaders," RWS Publications, Pittsburgh, 2008

[6] Saaty, Thomas and Peniwati, Kirti, "Group Decision Making: Drawing out and Reconciling Difference," RWS Publications, Pittsburgh, 2008

in this figure, the majority of participants have indicated that mainline operations are more important than local operations, and by a significant degree.

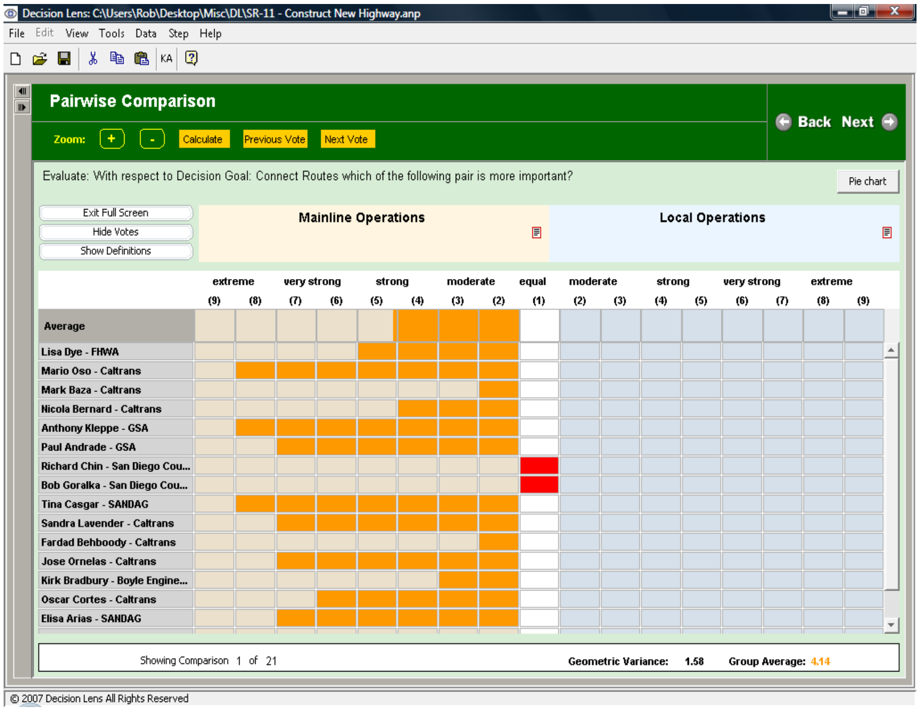


Figure 5 - Distribution of individual intensities for a pair-wise comparison using Decision Lens

The intensities range from 1 (which indicates both attributes are of equal importance) to an 8, whereby mainline operations is extremely more important than local operations. The median value is 4.1 in favor of mainline operations. The use of the data series also allows us to derive a representative distribution that can then be used to consider performance priorities in a probabilistic manner.

Using this data, we can test the relative level of confidence displayed in considering performance priorities. This information can be helpful in evaluating the group's assumptions about the relative importance of key performance criteria. Furthermore, the Decision Lens software allows the priorities of the evaluation criteria to be adjusted in order to test the sensitivity of the judgments as illustrated in Figure 6. This provides powerful feedback on how future changes in priorities could affect the outcome of decisions.

Another way to consider uncertainty relative to performance is by considering performance as a range of potential values rather than as a deterministic value. For example, assume we are considering a number of interchange alternatives for a highway project, each of which has different potential impacts to traffic operations. Using risk modeling software such as Oracle's Crystal Ball, one can derive probabilistic distributions of performance by identifying the minimum, median and maximum anticipated values for the performance attributes. Similarly, this could be performed for any or all of the performance attributes.

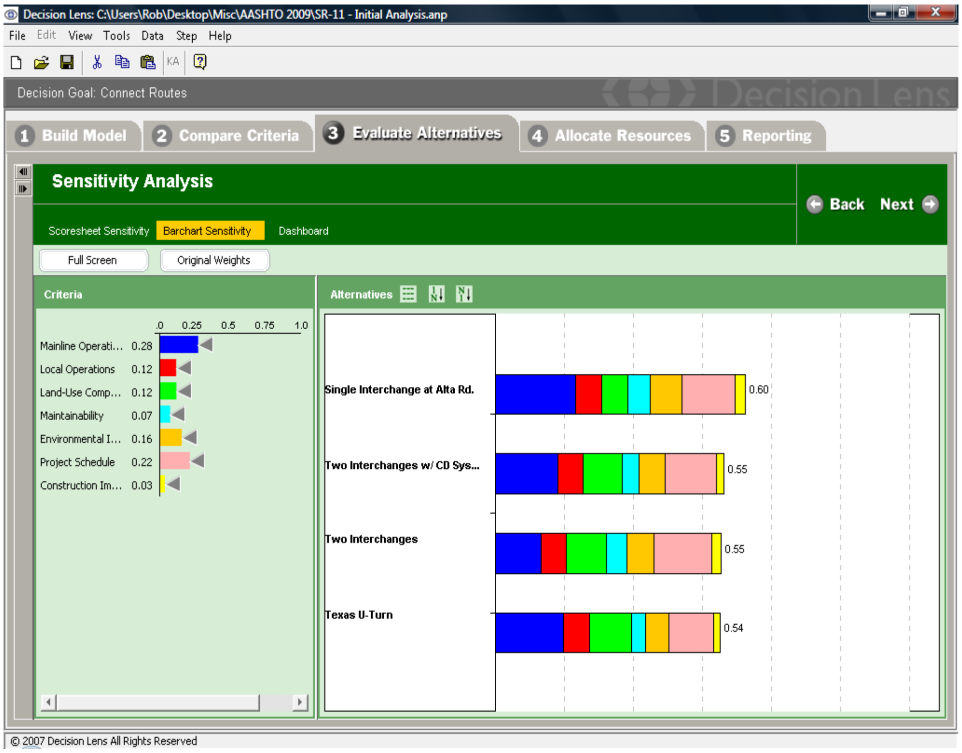


Figure 6 - Sensitivity analysis allows priorities to be evaluated relative to uncertainty

Table 2 shows the deterministic performance scores for four potential interchange options (the baseline concept and three potential VM strategies). It is important to note that based on the weighted performance scores, the four options have nearly identical performance scores ranging from 5.04 to 5.22 on a scale of 1 (minimum) to 10 (maximum). If were judging these four options strictly on performance, and on a deterministic basis, none of them stand out from the others as being the "best" choice. One could say that Strategy 1 has a slight performance advantage, but not convincingly so.

	Baseline	VM Strategy 1	VM Strategy 2	VM Strategy 3
Nordahl Rd. - Traffic Ops.	0.841452	0.841452	0.841452	0.841452
Pedestrian Circulation	0.461122	0.461122	0.461122	0.461122
Bicycle Circulation	0.520668	0.520668	0.520668	0.520668
Nordahl Rd. - Geometry	0.833331	0.833331	0.833331	0.833331
Visual Impacts	0.603952	0.603952	0.603952	0.671058
Traffic Impacts to Nordahl Rd.	0.495538	0.555603	0.300326	0.300326
Traffic Impacts to SR-78	0.465260	0.474755	0.569706	0.465260
Temp. Environmental Impacts	0.122669	0.122669	0.122669	0.143460
Maintainability	0.802554	0.802554	0.802554	0.802554
TOTAL PERFORMANCE SCORES	5.15	5.22	5.06	5.04

Table 2 - Median performance scores

If we evaluate these same options from a probabilistic standpoint and consider the range of potential performance values for those attributes that we have at least a small degree of uncertainty, the analysis paints a remarkably different picture. The example provided in Figure 7 illustrates the probabilistic performance distributions for the same four options. Notice that from a performance perspective, the Baseline concept demonstrates a much narrower range (denoting less uncertainty) and is shifted farther to the right. Looking at the overlap of the distributions of the three VM strategies, one can clearly see that the baseline concept has a striking advantage considering risk as a large proportion of the distributions for the VM strategies lay to the left of the lower tail of the baseline concept's distribution. In hindsight, this makes good sense as the Baseline concept has been designed to a much higher level than the VM strategies and, therefore, demonstrates an appropriately greater degree of certainty in its anticipated performance. Further, VM Strategies 2 and 3 pose the highest risk of poor performance judging by their relatively broad distributions. Clearly, given this information, a prudent decision maker would opt to stick with Baseline concept if the judgment were based solely on performance.

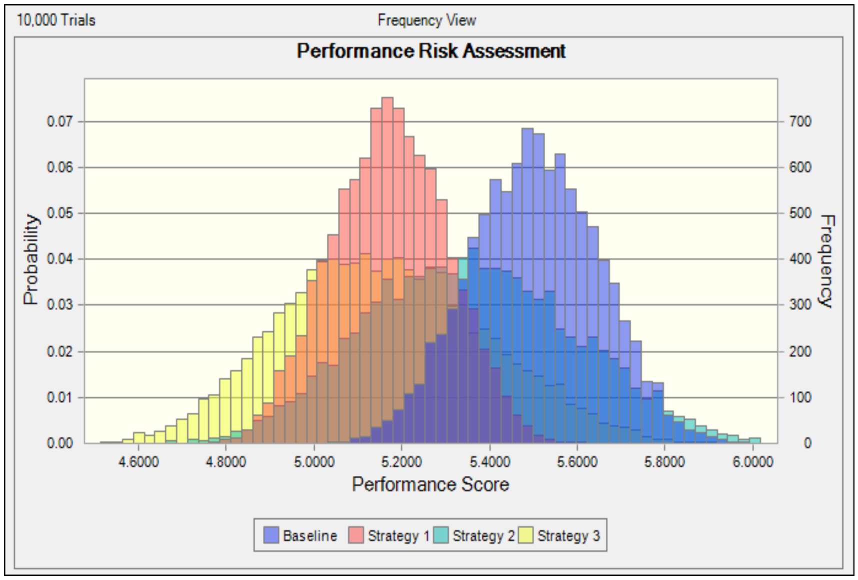


Figure 7 - Probabilistic performance distributions for four options

Tying it all together as an expression of probabilistic value

Assuming we have considered the effect of uncertainty on one or more of the elements of cost, time and performance, the next step is to calculate the value indices using the probabilistic values previously derived for them. In this example, the dynamic model for value was utilized. Building on the data from the previous models, we can now express the variability in the value indices as represented in Figure 8.

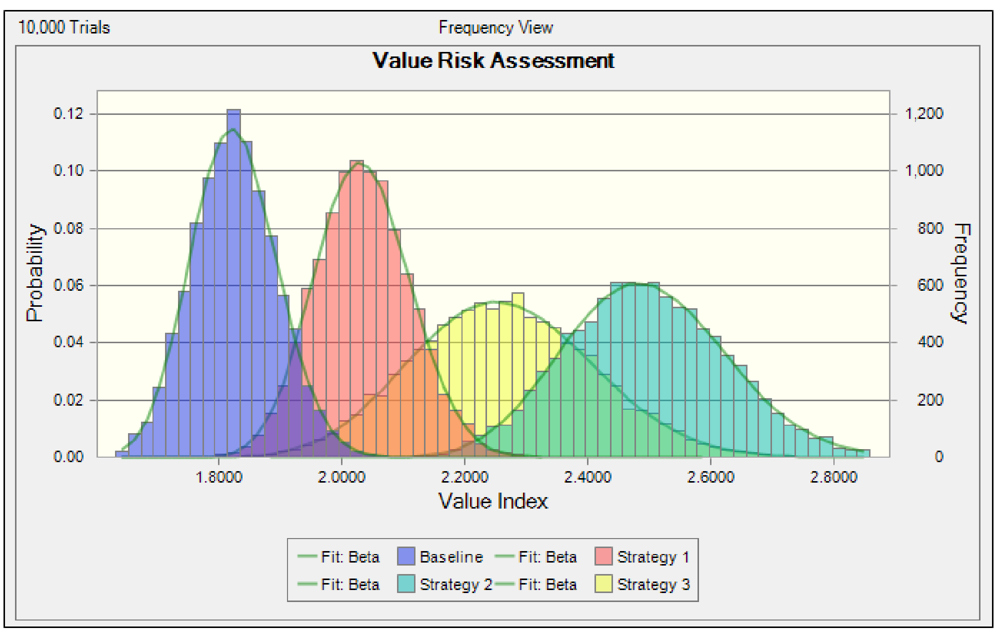


Figure 8 - Probabilistic comparison of value indices for four options

This comparison shows that Strategy 2 completely dominates the Baseline concept form a total value perspective, even when considering the “worst” case conditions for Strategy 2 and the “best” case conditions for the Baseline Concept. Further, it is significantly better than Strategy 1 and moderately better than Strategy 3. Therefore, based on this analysis, decision makers can proceed with greater confidence that Strategy 2 offers the best value when considering cost, time, performance and risk.

Conclusions

Uncertainty and risk must be given due consideration if we are truly interested in improving value. As demonstrated in this paper, there are a number of probabilistic methods to consider uncertainty and how it affects cost, time, performance and value. We cannot know the future, nor can we pretend that the alternatives developed during the course of a VM study were conceived without flaws. As value practitioners, we must be mindful of this. Based upon the experience of the authors, one of the primary reasons that seemingly “good” alternatives are rejected by decision makers is that they are considered to be “risky” propositions. It is therefore incumbent upon us to evaluate how uncertainty can, and does, influence outcomes.

It is neither realistic nor practical to go to this level of quantitative analysis on every VM study to be sure; however, where major decisions are involved for an organization, such efforts are worth considering.