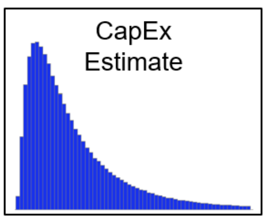
DECISION ANALYSIS IN COST ENGINEERING

John Schuyler, CCP, CMA, CMC, DRMP, PMP, and PE (CO)

Decision analysis (DA) and other operations research (OR) techniques came into prominence during and immediately after WWII. Mathematicians, who previously received little respect, assisted the war effort with military planning and other decisions to optimize resources. DA—where probabilities are involved—is a subset of OR.[1]

Ron Howard of Stanford University coined "decision analysis" in 1964, so in 2014 the DA discipline celebrated its 50th anniversary.

What does DA offer the cost professional?



1. More accurate estimates and forecasts for decision making.
2. Project risk management is logical and straightforward. Quantitative replaces qualitative. Contingency amounts and time buffers are among the decision variables that can solved for with computer optimization.
3. Clarity and usefulness of judgments and calculations about uncertainty. Calculation outputs, such as project value, cost, and completion time, are typically presented as distributions. DA fosters better communication between decision makers, managers, subject matter experts (SMEs), planners, model builders, and other stakeholders.

This article presents the key features of the DA tools and process. Probability is the language of uncertainty. The fundamental concepts and methods should be understood and used by all cost professionals and allied professionals. Various elements of Total Cost Management Framework, Recommended Practices, and the new Decision and Risk Management Professional certification indicate high interest within AACE International. Project Management Institute's *A Guide to the Project Management Body of Knowledge, Fifth Edition* features project risk management in a separate section, though decision making is evident in most others.

INTRODUCTION

DA provides tools and techniques to explicitly recognize risks and uncertainties project feasibility studies, design optimization, and other forecasts. DA was leading-edge analysis technology in the 1960s. The subject is now routine in university business schools and has been since the 1970s. Though the theory, tools, and technique continue to advance, the methodology is proven and well-developed. DA has now become mainstream practice. Many of today's headline stories are about *predictive analytics* and *data mining*.[2] These have much in common with DA.

Back-of-the-envelope decision trees and hand-calculator calculations are sufficient for many decision problems. For more-substantial analyses, low- to

[1] See "Operations Research" and "Decision Analysis" articles at Wikipedia.org.

[2] A Google search on 11-Apr-2015: "Analytics" brought up more than 600M hits.

moderate-cost PC and cloud-based software are making the techniques increasingly accessible.

Risks and uncertainties often significantly impact value, cost, and schedule. DA provides the only logical, consistent way to incorporate judgments about risks and uncertainties into an analysis.

DA focuses on helping decision makers choose wisely under conditions of risk and uncertainty. It is a blend of statistics, systems theory, psychology, and management science/OR. **DA is perhaps the most powerful management tool since the invention of the organization hierarchy.**

The foundation concept is expected value.

The cornerstone is the *expected value* (EV[3]) concept. An *EV* is, simply, a probability-weighted average outcome. I'll show that calculation later.

As with many inventions, money was the incentive to develop probability theory. Humans have played games of chance since at least 5000 B.C. The initial formalization of probability is often attributed to interest in gambling and a letter-writing exchange between Blaise Pascal and Pierre de Fermat, probably in 1654.

DA techniques are now popular in business and engineering curriculums. Unfortunately, people who study DA in college often forget the classroom experience when they enter the real world. Many of them, now professionals, experience delight in becoming reacquainted with DA: There was some purpose for that statistics class, after all. Building upon competence in making conventional, non-probabilistic projections, DA offers a step-improvement in forecast model quality.

WHAT CHARACTERIZES DA?

Probability is the language of uncertainty.

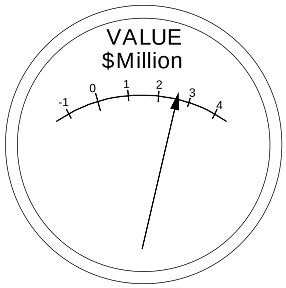
Probabilities and probability distributions are the formal, unambiguous language of uncertainty. The three distinguishing features of a decision analysis are:

1. Capturing judgments about risks and uncertainty as probability distributions
2. Having a single value measure for decision policy. This may be an *objective function* comprised of several decision metrics. Most often in business, the measure is *net present value, NPV*. –and–
3. Putting (1) and (2) together to calculate expected value (*EV*). We rank alternatives by their *EV*s.

The workhorse tools for calculating *EV*s are *decision trees* and *Monte Carlo simulation* (simulation).

[3] Unfortunately, "EV" is also the abbreviation for *earned value*.

Type Problems



Having a way to measure value under uncertainty—symbolized by the *value meter*—provides a means to solve three types of problems:

1. **Ranking alternatives** and picking the best one. This is what comes to mind when people think of decision making.
2. **Optimizing.** Finding the best chose of one or more decision variables. For example, finding the optimal bid about in an auction (whether offering to buy or sell). This is really the same as (1) except there may be several decision variables and each has two to perhaps infinite choices.
3. **Appraising.** Assessing the value of an asset, risk, or opportunity. While not a decision itself, the value often drives the decision.

DA helps answer questions such as:

- What is the optimal design capacity for the plant?
- What is our optimal bid? What is the probability of winning the contract? And, if we do win, what is the EV Profit?
- How much contingency should we put into the estimate so that we have a 90% confidence of making a profit?
- What is the Project Completion Date with a 90% confidence?

Decision Policy Measures Value

There are three key areas representing the decision maker's attitudes or *preferences*:

Decision policy is about preferences.

- Preferences for different *objectives*. In business, the overriding concern is usually maximizing shareholder value. For this situation, the objective is to maximize value measured in dollars or other currency. Decisions in the public and non-profit sectors are often more difficult because of competing and conflicting objectives. [4]
- *Time* preference. *Present value* (PV) discounting is the well-accepted approach to recognize the time value. Usually, the objective is about money, though discounting can be used on any metric where there is a time preference. *Net present value* (*NPV*) is the PV of future net cash flow. The most objective discount rate is the company's marginal, after-tax cost of capital. Whether or not cashflow projections include inflation should be matched in the choice of PV discount rate.
- *Risk* preference. Most often, the risk profiles of various alternatives are compared intuitively by the decision maker. Alternatively, the corporate risk policy can be succinctly and completely represented by a utility function.

[4] For objectives other than *NPV* maximization, non-monetary measures may be expressed in monetary equivalents. This is the easiest way to handle multi-criteria decision making.

Good Decisions versus Good Outcomes

One of DA's key tenets is distinguishing good decisions versus good outcomes. A *good outcome* is simply when the decision maker or organization is better off than before.

A *good decision* is one that is consistent with the attitudes (including values and beliefs) of the decision maker and all the information available at the time.

EXPECTED VALUE

As mentioned earlier, EV is the foundation concept of DA. An *EV* is not "the value we expect." Rather, this "expected" adjective comes from the *mathematical expectation* concept.

The principal calculations in decision analysis

EV is the *mean* or probability-weighted average of a probability distribution. It is the unbiased and best single value to represent a distribution. In DA, each alternative is simplified to a single value, its *EV*. Then the decision is simply to choose the alternative with the best *EV*.

Typical value optimization is maximizing *expected monetary value*, *EMV*, which is EV *NPV*. With cost problems, the common objective is to minimize EV PV Cost.

> The meaning of "expected cost" must be clear. To help communicate that this refers to an EV calculation, I prefer to call this "Expected Value Cost" which I recommend labeling:
>
> EV Cost or E(Cost).
>
> It is important that everyone understand in context whether this is pre- or post-tax, inflated or not, and time-value discounted or not.

There are two principal EV calculation methods: *decision tree analysis* and *simulation*. Each method has its advantages and disadvantages. Often, it is useful to use both methods on different parts of an analysis. Decision trees are common in assessing risk and analyzing alternative actions. Probabilistic (*stochastic*) project modeling requires simulation.

Model Context and Output

The feasibility model, **Figure 1**, should be a permanent feature of a project's documentation. It should reflect the current scope definition and general plan. The model should be updated for new information and project developments as they unfold. A sub-model is a high-level project schedule and cost model. When the delivered project becomes an asset placed in service, then the updated feasibility model becomes part of the enterprise portfolio model.

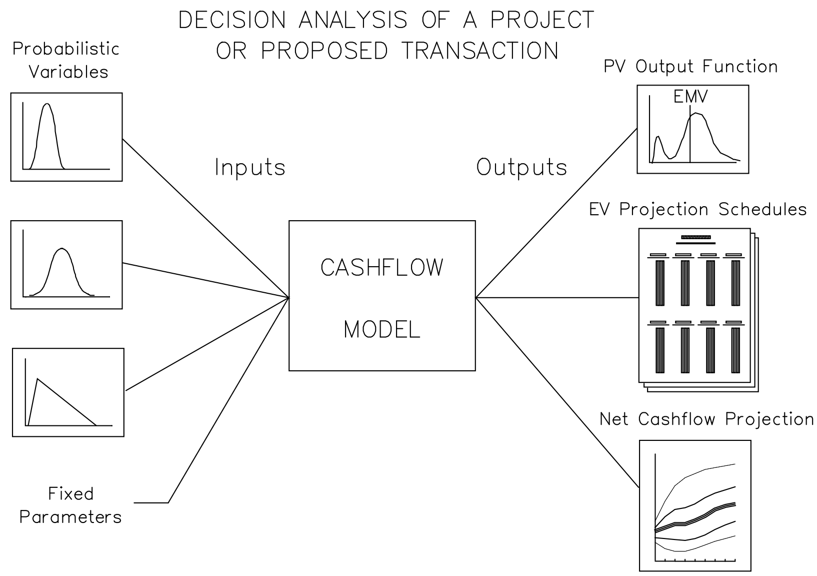


Figure 1. Project Feasibility Forecast Model. A deterministic net cash flow model is at the core. With even a single distribution input, the outcome will be a distribution.

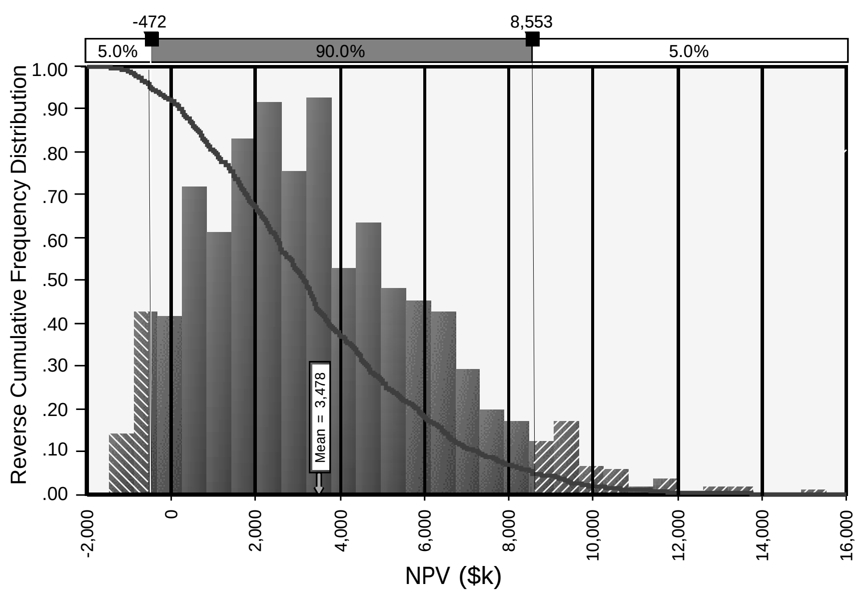


Figure 2. Cumulative Frequency Distribution (and frequency histogram). With the cumulative curve, one can directly read confidence levels or intervals. Shown is the "cumulative greater-than" or "exceedance" form of the curve which is popular when expressing an *NPV* or other value distribution. The complement cumulative curve—ramping up left-to-right—is more common when looking at distributions of schedule and cost. This is a modified chart produced by @RISK.

DECISION TREE ANALYSIS

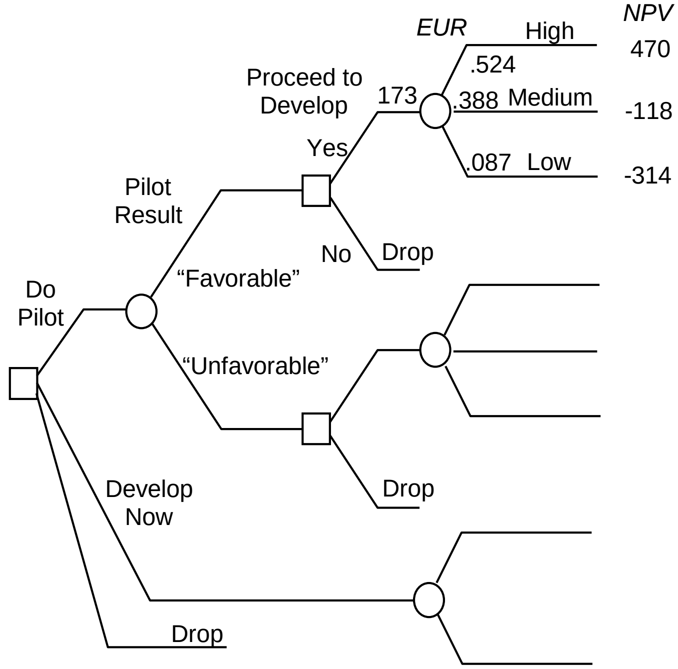


Figure 3a. Schematic Decision Tree. This is to evaluate whether to do a pilot flood on an oil field. *EUR* is the Estimated Ultimate Recovery. Amounts are in $million.

Decision trees, such as **Figure 3a**, provide a graphical template for *EV* calculations. Decision trees are solved using this discrete *EV* formula at every chance node (represents a risk or uncertainty event):

$$EV = \sum_{i=1}^{N} x_i \ \mathrm{P}(x_i)$$

where x_i is the outcome value

$\mathrm{P}(x_i)$ is the probability of outcome x_i

N is the number of possible outcomes

Here is an example *chance node* representing the Estimated Oil Recovery (*EUR*) node in the **Figure 3a**:

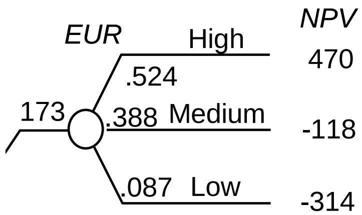


Figure 3b. Chance node with EV calculation.
EMV at the *EUR* node = .524(470) + .388(-118) + .087(-314) = $173M

A decision tree is a graphical template for calculating *EV*s. Most often, we draw trees in chronological sequence, left-to-right.

Then, working backward, right-to-left, we determine *EV*s for each node:

- Replacing chance nodes with their *EV*s,
- Replacing decision nodes with the *EV* of the best alternative branch.

Working backward is required so that we know what alternative to choose at each decision node.

Strengths

- The tree diagram clarifies the decision problem as a graphic. The diagram clearly shows all important decision elements:
    - Contingencies (outcomes of chance events)
    - Decisions and alternatives
    - Logical sequence of decision points and chance events.
- One can often solve decision trees by hand.
- Decision trees can easily handle evaluations involving low-probability events, such as risk of a hazardous spill or loss of life.
- Trees are best for "value of information problems" having subsequent decision points after more information is revealed.

Weaknesses

- One must reasonably represent all possibilities by a finite number of paths through the tree.
    - This limits the practical number of random variables (chance events and decisions) that can be accommodated.
    - Discrete approximations must replace judgments as continuous probability distributions; thus, some detail is lost.
    - The analyst is limited in the representation of uncertain timespread events, such as for prices and inflation, to a few scenarios.
- An output probability distribution (risk profile curve) is usually not obtained, only the *EV*. However, with extra effort or software, the outcome distribution can be charted from outcomes and their joint probabilities.
- Branch and outcome values must be value measures (*NPV* works, though, for example, Internal Rate of Return (*IRR*) does not).
- Probabilities must be assessed or calculated for all chance event outcomes.

MONTE CARLO SIMULATION

Simulation approximate an integral equation for the *EV* of a continuous variable:

$$EV = \int_{-\infty}^{\infty} x \, \mathrm{f}(x) dx$$

where f(x) is a probability density function

Monte Carlo simulation offers a simple way to do some complex calculus.

Don't be alarmed by the integral. Even the best mathematicians can seldom solve this directly except for simple distributions. Instead, the approximate the *EV* is solved with simulation using this formula:

$$EV \approx \frac{\sum_{i=1}^{n} NPV}{n}$$

where *NPV* is the outcome, or another value measure

n is the number of trials in the simulation run

Simulation allows us to replace single-value inputs into any model or formula with probability distributions. In effect, simulation provides the means to propagate distributions through the model calculations.

By generating possible futures (realizations) for a project or other system—hundreds or many thousands of times—simulation provides good approximations to the model's outcome *EV*s, probabilities, and forecasts.

Strengths

- A simulation model is a straightforward extension to the conventional, deterministic model (Cashflow Model component in **Figure 1**). Fundamentally, the analyst just substitutes probability distributions for single-point input variables.[5]
- The normal simulation output is a frequency distribution (such as **Figure 2**), displaying the full range of possibilities and approximating the true probability density function. Confidence curves can be generated for timespread variables such as commodity prices or net cash flow (figure 3).
- The distributions can be captured for any meaningful output variables (unlike decision trees that work only with value measures).
- We can model risks and uncertainties in as much detail as desired. There is little cost to additional random variables. All possible eventualities can be modeled in whatever detail is necessary. Simulation is better than decision trees for dynamically modeling system contingencies, such as strikes and breakdowns. Portfolio problems have a multitude of possibilities and are easily represented.

[5] While somehow representing correlations among variables.

- One can represent continuous probability distributions directly, without discretizing to n-level estimates. Timespread variables, such as a commodity price, can be modeled in rich detail, reflecting the company's best understanding of price dynamics. **Figure 4** illustrates a price forecast.
- Complex problems are sometimes easier because conditional probabilities can be calculated automatically by the sampling process.

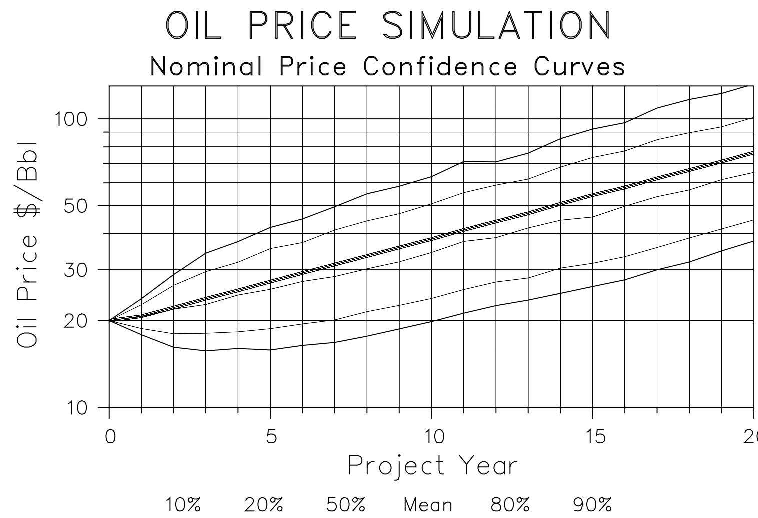


Figure 4. Confidence Curves for a Timespread Variable. As example, there is an 80% chance that the price at any particular time will lie between the two outermost bands.

Weaknesses

- The result is not algorithmically precise. The confidence of a sample mean in approximating the true *EV* may require a very large number of trials. Very large models requiring many trials to converge can be time-consuming and expensive to run.
- Low-probability events are seen rarely in the simulation and, thus, are represented poorly. This exacerbates the problem in the prior point.
- The decision structure is less obvious. Lucidly presenting the model logic depends on the documentation skills of the analyst.
- It less straightforward to revise probability distributions based on later information. Thus, value of information problems are more difficult.

Tree or Simulation?

Many people are unaware that decision trees and Monte Carlo simulation are essentially equivalent methods. Both provide the means to calculate *EV*s and outcome distribution curves (recall **Figure 2**).

The choice of calculation method depends on the situation, and many evaluations can benefit from using both at appropriate stages. The following outlines summarize the key differences, strengths, and weaknesses of each technique:

Trees are usually the method of choice when:

- There are low probability risk events, say, less than .02.
- There are subsequent decision points (options), when more information will be available (value of information problems).

Simulation is usually preferred when:

- There are many important risks and uncertainties.
- The problem is to optimize one or more continuous decision variables (e.g., competitive bidding)

There are other management science techniques which, while outside mainstream DA, are very useful aids to decision making. For perspective, it's worth noting the best known of these:

- Critical path method (CPM)
- Linear Programming (LP), genetic algorithms, and other optimization methods
- System dynamics
- Regression, cluster analysis, and other methods in data analytics
- Artificial intelligence, including expert systems and neural networks.

DECISION ANALYSIS APPROACH

Decision analysis is a straightforward, structured process. Here is an abbreviated outline of the typical steps:

1. Frame the problem: What decision is to be made? If there is no decision policy, determine the objective(s) and what criteria will be used to make the decision. What are the decision alternatives? What risks and uncertainties affect outcome value? A structural decision model will clarify the decision problem.
2. Develop a deterministic cashflow model to calculate outcome values each pathway through decisions and chance events. A *deterministic model* is a conventional model where every input parameter is a determined, single-point estimate. Engineers, with their design and operating knowledge, are often the persons developing these cashflow models. Accountants may be needed to provide guidance on tax calculations, and other disciplines may be called upon for their special expertise.
3. Elicit judgments about key uncertain variables in the form of probability distributions. Use sensitivity analysis to identify which inputs and model parameters significantly impact project value. Sensitivity analysis helps prioritize variables on which to spend more time with SMEs and in obtaining additional information.
4. Substitute the probability distributions into the model (see figure 1) and solve for outcome distributions and *EV*s. Use a decision tree or simulation as the *EV* calculation technique. In simple situations, a *payoff table* will suffice. Many problems employ both decision trees and simulation for different parts of the analysis.

5. Choose the best alternative or combination of decision variables.

WHY COST PROFESSIONALS SHOULD USE THESE METHODS

Most cost professionals work to provide information for others to use. Professionals in any discipline work to master one or more processes. Applying a proven process is a hallmark of professionalism. For professionals in information-providing jobs—that is readers—their work product is analysis.

Credible Analysis

A *credible analysis* is one suited to the purpose at hand. The quality analysis features:

Objectivity is the foremost characteristic of a credible analysis.

- Objectivity, meaning free from unintentional bias. Value is measures value in a way that matches the organization's objective(s)[6]
- Integrity of the model and calculations, that it reflects the stated assumptions and performs as represented
- Adequate disclosure and communication
- The basis for the analysis is usually a *credible model* that has been:
    - *Validated*: its specifications have been accepted as being reasonably representative of reality; and
    - *Verified*: that it performs according to specifications.

Credible analysis requires explicitly recognizing all important risks and uncertainties in the project forecast. The following sections describe the key features and benefits of using DA. The techniques have universal application.

Benefits of Using DA

Wrapping up, following are some key benefits to cost professionals

1. More accurate estimates

Cost professionals have always dealt with risk and uncertainty when planning, scheduling, and evaluating. A good decision analysis model faithfully and completely represents professional judgments about uncertainty in the form of probability distributions. This model then provides the best way to calculate a forecast. Resulting probability distributions provide the logical means to express uncertainty and to establish any contingency amount.

When uncertainties are significant, a credible evaluation can be achieved only by using these techniques. In addition to characterizing risks, estimation and other types of forecasts are more accurate. Using probability distributions through the calculations corrects for a sometimes-significant error in conventional analysis.

---

[6] Decision policy may have an intentional bias, such as *conservatism* prescribed by the organization’s risk policy.

It is interesting and prudent to compare two value approaches:

1. Base case analysis. This is a deterministic model solved using the best single-point estimates, i.e., *EV*s, for input values. When money is the measure, then *NPV* is the value.
2. A probabilistic (stochastic) model solved with probability distribution inputs. When money is the measure and the decision maker is neutral about risk, then *EMV* is the value.

Stochastic variance is the value *correction* realized when migrating from deterministic to stochastic analysis

Stochastic variance is the difference between (1) the conventional (without probabilities) analysis (*NPV*) and (2) the value obtained using decision analysis (*EMV*). The difference can be substantial. Stochastic variance should be a line item on a variance analysis report.

2. Project Risks Management is Natural

Identifying inputs to a feasibility model and identifying activities for the work breakdown structure are important to modeling. It is natural to start thinking about what actions might be available to improve the risks and uncertainties.

Decisions are what makes DA most interesting. There is typically an array of decision variables to optimize. Though it is possible to optimize a project in isolation, the analysis context should always be in the context of the investment and asset portfolio.

3. Clarity in Expression and Communication about Uncertainty

When focusing on a single uncertainty, a probability distribution completely captures an SME’s judgment about that variable. The SME is asked how the variable relates to other model features.

Even if the model doesn’t use distributions, just thinking about the distribution shape, range, and parameters often provides a much better single value.

The forecast will always be wrong. The decision maker deserves to have the best estimate as well as a description of uncertainty in that value. The output distributions provide this information.

A project presentation is incomplete without DA:

- The decision maker or other audience rightfully expects an appropriate and well-executed process behind the analysis or plan.
- The model is indefensible unless judgments about uncertainty are quantified and incorporated in the model.
- A thoughtful, well-crafted decision policy is the basis for measuring value.

There is incessant pressure for cost professionals to provide increasingly better projections, gauged by objectivity, accuracy, and completeness. Those professionals not already using decision DA encouraged to do so. This will improve their work quality and facilitate analysis and communication.

Decision analysis is gaining popularity due to increasing business intensity, having more people trained in the methods, and the proliferation of applicable and easy-to-use software. Many people are surprised to discover, or rediscover, the power and simplicity of the EV concept.

Some people might think DA is too complicated. Actually, the foundation concepts are very straightforward. Our youth can and should learn these methods in high school or before.

And the analysis work is mostly done the deterministic model is complete. Assessing and adding probabilities into the model is a relatively modest effort. The overall process can be faster because the stochastic model has what-if analysis built in. Considering the alternatives and quickly pruning those not viable can avoid a lot of analysis rework.

Decision DA is as much a matter of attitude and philosophy as it is a collection of calculation tools. The keys to successful application are being committed to good analysis and ensuring that everyone understands the basic concepts. DA is not rocket science, merely good practice.

Further Reading

Clemen, Robert T., and Terence Reilly, 1997, *Making Hard Decisions: An Introduction to Decision Analysis, 2nd ed.*, Duxbury Press, Boston, 664 p.

A leading textbook for college instruction. Clemen and Reilly wrote a 2004 version for use with Palisade Corp.'s DecisionTools® Suite.

Hertz, David B., 1979, "Risk Analysis in Capital Investment," *Harvard Business Review*, v. 57, n. 5, Sept.-Oct., p. 169-81. (an earlier version appeared in the Jan.-Feb., 1964, issue).

An early, classic article of the application of simulation to business decisions. Still relevant except for his choice of decision criterion.

Howard, Ronald A., and Abbas, Ali E., 2015, *Foundations of Decision Analysis*, Prentice Hall.

Despite some unconventional notation and terminology, this may become a leading college textbook.

Newendorp, Paul D., and Schuyler, John, 2015, *Decision Analysis for Petroleum Exploration, 3.0 Edition*, Planning Press, ~580 p.

This has a petroleum industry emphasis, though offering universal techniques. Written as a reference handbook, this is the authors' most complete compilation of DA tools and techniques.

Schuyler, John, 2016, *Risk and Decision Analysis in Projects, 3.0 Edition*, Planning Press, Aurora, CO, USA, 411 p.

First two editions based upon an 18-part tutorial series in *PM Network*.

■

For comments or further information please contact:

John Schuyler
Decision Precision®
303-693-0067
john@maxvalue.com
www.maxvalue.com

Original 20150422.
Revised 20150527 and 20170329.
DAinCE_20150527a.docx 14p 31-Mar-17