AACE INTERNATIONAL RECOMMENDED PRACTICE

85R-14

USE OF DECISION TREES IN DECISION MAKING

AACE INTERNATIONAL

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TCM Framework: 2.3 – Strategic Asset Management Process Map
3.3 – Investment Decision Making
7.6 – Risk Management

Rev. November 14, 2014

Note: As AACE International Recommended Practices evolve over time, please refer to www.aacei.org for the latest revisions.

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Disclaimer: The opinions expressed by the authors and contributors to this recommended practice are their own and do not necessarily reflect those of their employers, unless otherwise stated.

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SCOPE

This recommended practice (RP) of AACE International defines the use of decision trees in evaluation of alternatives around project strategy in the presence of uncertainty and their potential implications. A large part of the risk management process involves looking into the future, trying to understand what might happen and determining whether it matters to an important decision we need to make.

The decision tree technique can be applied to many different uncertain situations. For example:

- Distinguishing the costs or benefits of using a low-price bidder when[1] delivery time and quality are uncertain.
- The relative costs or benefits of adopting a state-of-the-art technology or staying with the proven technology.
- The relative attractiveness of building a greenfield[1] plant or retrofitting an existing plant.

Decision tree techniques involve determining the objective (e.g., maximizing profit, minimizing cost), specifying the objective (e.g., choosing among bids for the EPC contractor) and creating a decision tree that distinguishes between choices to be made (decision nodes) and potential consequences (chance nodes). The cost of taking a particular path to the end point (e.g., project completion) and the probabilities of specific uncertain outcomes are key data inputs into the decision tree model.

This recommended practice shows the application of decision trees for two types of organizations: one is risk neutral and the other is risk averse. The decision process used for both types of organizations is to maximize the expected utility.[2] This recommended practice then looks at two different approaches to expressing the organization's utility. These approaches are generally those of a risk-neutral organization or a risk-averse organization[3]:

- Maximize utility based on the expected value of a linear function of monetary value, which is a hallmark of a risk-neutral organization.
- Maximize expected utility based on the expected value a non-linear function of monetary value, which is the appropriate measure of merit for a risk-averse or a risk-seeking organization[4].

The results (e.g., which contractor to choose) are examined using sensitivity analysis to decide whether it is worth gathering more data since improving the accuracy of the data could result in changing the decision. This decision depends on the accuracy of the existing data and whether a reasonable variation in the numbers could change the decision.

Finally, continuous distributions of the uncertain variables usually approximate reality better than selecting and representing alternative outcomes using a limited number of discrete outcomes. Uncertain future outcomes can be represented by the use of Monte Carlo simulations of continuous distributions.

This recommended practice is consistent with the *Total Cost Management (TCM) Framework* Section 2.3.5.5 *Decision Analysis* which specifies:"A set of analysis techniques that considers all relevant performance and requirements data about a set of asset investment options and produces a decision to pursue or not pursue one or more of the options evaluated." It is also consistent with TCM Section 7.6.1.2 *Decision and Risk Analysis*: "The full

[1] A "greenfield" plant is developed from the foundation up, in contrast to a renovation or expansion of an existing plant

[2] In multi-criteria decision making (MCDM) an objective's function comprised of several objective measures representing outcome quality.

[3] Risk-seeking behavior is rather rare in organizations that exist in commercial or even governmental environments, but is technically handled by decision trees.

[4] Another valuable decision metric is net present value (NPV) which takes into account the time value of money. In a cost problem minimizing expected cost is equivalent to maximizing expected monetary value except for a sign change on the amounts.

risk management process, as mapped in this section, is designed for addressing uncertainty in project outcomes (i.e., from a project control context). However, the process generally applies and is critical to addressing uncertainty in the outcomes of any decision. As discussed in Section 3.3, a key challenge in strategic asset planning and investment decision making is bringing an awareness of risk and probability concepts to those processes whether they result in an implemented project or not. Traditional economic analysis used in investment decision making may be somewhat meaningless when there are significant risks." It is also consistent with TCM Section 3.3.1 *Description* that includes: "*Decision analysis* (DA) is the foremost process for helping decision makers choose wisely under uncertainty. DA involves concepts borrowed from probability theory, statistics, psychology, finance, and operations research. The formal discipline is called decision science, a subset of operations research (management science). The essence of DA involves (1) capturing judgments about risks and uncertainty[5] as probability distributions, (2) having a single value measure of the quality of the outcome, and (3) putting these together in expected value calculations. An *expected value* (EV) is the probability-weighted outcome, and this is synonymous with the *mean* statistic."

PURPOSE

This RP is intended to provide guidelines (not a standard) for applying decision tree methods to making strategic project or program decisions where a decision is to be made between at least two alternatives and the implications of taking at least one of these alternatives are uncertain. In general, a decision may involve a choice among several available options and each of those might have further decisions to be made and the outcome of making those decisions may not be certain. Most practitioners would consider this RP to describe good practices that can be relied on and that they would recommend be considered for use where applicable.

The decision tree approach requires the organization to understand clearly not just the description of the alternatives immediately facing them but also the future decisions and uncertainties that are implied by making one decision or another. This requires organizations to think clearly and completely about a decision and to follow its implications into the future. This process usually encounters uncertainties that can only be described by alternative scenarios and their probability of occurring. Alternatively, continuous distributions of possible outcomes (grafting Monte Carlo simulation techniques onto decision trees) can be implemented.

The benefit of using decision trees can be seen when this method is compared to decision making at many organizations. Often a decision is not represented clearly or without bias toward one or another result; the decision is commonly made by examining only the near-term implications.

In contrast, the decision tree method:

- Leads the organization to think clearly about all of the relevant alternatives
- Specifies alternatives in an unbiased way
- Investigates the future follow-on implications
- Requires the organization to confront directly uncertainties that are unknowable, while providing a method using probability to characterize those alternatives
- Requires the organization to examine its decision-making process and particularly its utility function, at least to distinguish whether it is a risk-neutral or a risk-averse (or even risk-seeking) organization

Often these issues are not adequately addressed in strategic decision making.

[5] Key input variables in a model may be either discrete or have a continuous range of possible values. Most often, discrete variables (especially the binary type) are called risks and each outcome is assigned a probability of occurrence. Continuous drivers are most-often called uncertainties and judged as continuous probability density functions. However, in TCM, risk is defined as being the same as uncertainty (see TCM Framework Section 7.6).

BACKGROUND

A large part of the risk management process involves looking into the future, trying to understand what might happen and how it might affect an important decision. Decision trees help organizations choose between alternative courses of action when some of the results of such actions are uncertain.

The decision tree technique can be applied to many different uncertain situations. For example:

- Should the low-price bidder be awarded when delivery and quality are uncertain? Is there a case to be made for using a high-priced bidder?
- Should the project incorporate a state-of-the-art technology if it is new to the company?
- How should you decide between the alternatives of building a greenfield facility, renovating an existing facility or to do nothing, to maximize profits?

This recommended practice looks at two different approaches to making the decision:

- Maximize expected utility based on a linear function of monetary value where each dollar, positive or negative, is equivalent, which is the approach of a risk-neutral organization.
- Maximize expected utility based on a non-linear function of monetary value where each dollar of possible loss represents increasingly negative utility. This is the appropriate measure of merit for a risk-averse organization.

These two alternatives are distinguished by the way they evaluate decisions. "Risk tolerance" is a generic term covering the range of attitudes toward risk. This recommended practice distinguishes between two types of risk tolerance:

- "Risk neutral" means a risk tolerance wherein an organization will play a game of chance if it delivers a positive expected value – risk neutral is an "expected value decision maker," in other words. [2] A risk-neutral organization values gains and losses by their dollar value no matter how large the gain or loss is. A loss of $1 million is equally as bad as a gain of $1 million is good. A risk-neutral organization is indifferent to an uncertainty that has an equal chance of gaining or losing $1, or $1 million. The risk neutral organization evaluates alternative decisions using a utility function based on maximizing the expected value of a linear function of monetary value, calculated by multiplying the value of each possible result by its probability of occurring and adding the probability-weighted values of all possible results. This is equivalent to applying a linear utility function. Generally if the value of a decision calculated this way is not large enough the organization will not do it.[6]

- "Risk averse" means a risk tolerance wherein an organization will not make a decision that may deliver a positive expected value unless this value is large."[2] "A risk-averse person or group feels uncomfortable with uncertainty, has a low tolerance for ambiguity, and seeks security and resolution in the face of risk." [3] A risk-averse organization has a stronger aversion to losses of a given value than attraction to gains of the same value. Whereas the negative utility of losing $1 may not be much different from the positive utility of gaining $1, the disparity in values increases as the value of the loss / gain increases. A loss of $1 million has more negative utility than the positive utility of gaining $1 million. The risk-averse organization will reject a proposition that has an equal chance of gaining or losing $1 million. Risk-averse organizations typically use expected utility that is based on a non-linear utility function to value outcomes. These may be individuals, closely-held enterprises, or smaller organizations that have one or only a few projects or one project that if it fails the company will be severely affected.

Sensitivity analysis can be used to look at the importance of data accuracy in decision-making, whether it is worth improving the accuracy of the data or gathering more data. This decision depends on the accuracy of the existing data and whether a reasonable variation in the numbers will actually change the decision.

[6] There are many other factors such as strategy, competitive advantage, customer relationships, market share and reputation that could cause a risk-neutral organization to make a decision to do something with negative expected value. Those factors are not considered in this document.

Finally, continuous distributions of the uncertain variables usually approximate reality better than selecting and representing alternative outcomes using a limited number of discrete outcomes. Uncertain future uncertain outcomes can be represented by the use of Monte Carlo simulations of continuous distributions.

RECOMMENDED PRACTICE

Summary of Inputs

Inputs to the decision tree analysis model and solution include:

- A clear and complete description of a decision to be made, describing the issues it addresses and any constraints on its solution that may make alternatives appropriate or inappropriate.
- A complete list of alternatives available that can be used to address the problem under decision making consideration. This should include alternatives that will present themselves as a consequence of taking each alternative.
- An estimate of costs and benefits of each alternative approach under each scenario related to uncertain outcomes of decisions.
- Identification of the main uncertainties associated with each alternative, along with their costs or benefits if applicable.
- Unbiased estimates of the probability of different uncertain scenarios that will be used in the calculation of the results.
- An understanding of the decision making process and the utility function of the organization that will be applied to the decision at hand. Often this is unknown or vague, depending in part on a committee decision with unstated rules and preferences.

Summary of Tools

The main tool is specialized software for creating decision trees, populating them with data and solving them. Most such software will have as an option of whether to use a utility function reflecting expected monetary value (defined in this RP as a risk-neutral approach) or alternative ways to specify a non-linear utility curve (defined in this RP as a risk-averse approach, but could also be appropriate for a risk-seeking approach).

In this RP the use of Monte Carlo simulation in conjunction with decision trees is discussed briefly. The tool would be a Monte Carlo simulation engine in the decision tree software or a way to connect the decision tree nodes to a simulation engine, perhaps developed in a spreadsheet environment.

Summary of Outputs

Outputs from the decision tree exercise include:

- Unit of merit (e.g., utility based on dollars of cost or profit) associated with the alternatives considered.
- Identification of the alternative that is preferred given the model, the input data and the decision rule (expected monetary value or expected utility).
- Analyses of the sensitivity of the results to input data, indicating which data are crucial for the answer computed.
- Probability distributions of the results if Monte Carlo simulation tools are used in conjunction with the decision tree model.