Risk Assessment - Quantitative Methods

Chapter 1 - Quantitative Methods for Analyzing Risk

1.0.3 Types of Methods

Quantitative risk assessment relies on numerical characterizations of risk. Quantitative risk assessment relies primarily on the use of good
techniques, methods and models from the many disciplines employed by USACE. Thus, it comprises good engineering, economics and environmental
analysis. Because probability defines half of the simple risk equation, it is essential that the risk assessment process include the use of probability
concepts and theory. The probability concept is more specifically addressed in the Uncertainty module of the Learning Center.

Generally, quantitative risk characterizations address risk management questions with greater levels of detail than pure qualitative assessments. This
need for additional detail may require more sophisticated treatment of probabilities and uncertainties in the risk analysis than might otherwise be
performed with qualitative tools. Also, as noted in Figure 1 below, a high consequence of being wrong with the risk analysis may drive the need for
more detailed analyses.

Quantitative assessment can be deterministic or probabilistic.[1] In deterministic assessments, the possible outcomes are known in advance, and may
be a single result or a set of results, such as best case, worst case, or no action. In probabilistic assessments, the results will vary and, because of
uncertainty and the range of possible responses to it, there are often an infinite number of possible outcomes.

The choice of the quantitative assessment method depends on the questions to be answered by the assessment, the available data and evidence, the
nature of the uncertainties, the skills of those conducting the assessment, the effectiveness of the outputs in informing and supporting decision
makers and the number and robustness of the assumptions made in the assessment.

There are a wide range of methods and approaches for conducting quantitative risk assessments. This list below provides an overview of many of
these methods:

- **Statistics** +/−
  Use statistics to characterize the various parameters.

- **Interval Analysis** +/−
  This method calculates the upper and lower ends of a variable or a “best case” versus “worst case.”

- **Thresholds** +/−
  Determine the point at which a decision is made, that an outcome is unacceptable, or that another action must be taken to keep a parameter within a certain range of
tolerable risk.

- **Simple Probabilistic Risk Assessment** +/−
  Probability X Consequence = Risk or Opportunity. The probability includes the probability of an event, exposure to the event, system response and vulnerability.

- **Multi-criteria Decision Analysis (MCDA)** +/−
  MCDA is a well-established operations research technique used for making trade-offs of quantitative or qualitative information that involves the personal preferences of
decision makers. It is designed for decision problems that involve multiple-criteria. There are a number of methods and software tools that utilize this technique.

- **Models and Model Building** +/−
  Risk-based models are used to explore the effects of uncertainty on model outputs and real world outcomes. All models require knowledge, theory, data and information
  in many forms. Risk analysis requires models that enable analysts to explore “what if” questions. These models often require probability distributions among their inputs.

- **Event Trees** +/−
  An event tree is a qualitative or quantitative analytical technique for modeling a system or sequence of events. It is a sequence of nodes and branches that describe the
  possible outcomes of an initiating event. Each unique pathway through the tree describes a unique sequence of events that could result from the initiating event. A
distinguishing characteristic of the event tree is that all the events or nodes are assumed to be determined by chance.

- **Fault Trees** +/−
  Fault tree analysis is almost the mirror image of event tree analysis. While an event tree uses forward logic to proceed from a single initiating event to a number of potential
  outcomes, a fault tree begins with a single outcome and uses backward logic to proceed to a number of potential initiating events or causes. This technique is used for
  identifying and analyzing factors that can contribute to a specific undesired outcome or fault, also called the top event. Causal factors are deductively identified, organized
  in a logical manner and usually represented from top to bottom, rather than horizontally as an event tree is. The pathways through the tree show causal factors and their
  logical relationship to the top event.

- **Monte Carlo** +/−
  The Monte Carlo process is a numerical technique used to replace uncertain parameters and values in models and calculations with probability distributions that represent
  the natural variability and knowledge uncertainty in those inputs. The Monte Carlo process is a popular simulation technique that enables analysts to propagate the uncertainty
  in a decision problem and produce a numerical description of the range of potential model outputs. These output distributions can be subjected to statistical
  analysis to inform decision making.

- **Sensitivity Analysis** +/−
  Sensitivity analysis is used to systematically investigate how the variation in a risk assessment output can be apportioned, qualitatively or quantitatively, to different
  sources of knowledge uncertainty and natural variability. Sensitivity analysis is sometimes called “what if” analysis. There are four classes of quantitative sensitivity
  analysis tools. These are scenario, mathematical, statistical and graphical analysis.

- **Scenario Analysis** +/−
  Scenario analysis is a method of exploring the possible future outcomes of a decision. It involves identifying key factors that affect the decision, and then creating
  hypothetical scenarios that represent different combinations of those factors. The scenarios are then analyzed to determine the potential outcomes.

![Figure 1. Consequences of making the wrong decision](image-url)
Risk assessments can demand and use a combination of tools and, therefore, these methods may not necessarily be mutually exclusive. For example, Cost Benefit Analysis (CBA), environmental health risk assessment, and uncertainty analysis are all complementary tools that can be used in combination to assess risks. CBA is also a well-established method used to evaluate risks and risk management options. Comparing the costs of risk management to the benefits of the treatment is, at least, an implicit part of risk evaluation. CBA has also been used to identify the “best” risk treatment for a risk management activity.

The premise of Bayesian statistics, attributed to Thomas Bayes, is that any already known information (the prior) can be combined with subsequent information (the posterior) to establish an overall probability. Bayes' Theorem builds on the notion that information can change probabilities, which is useful for updating probabilities on the basis of newly obtained information. Often one begins with an initial or prior probability that an event will occur. Then, as uncertainty is reduced or new information occurs, the posterior probability is calculated. Bayesian methods are particularly useful in situations where prior information is available or where it is desirable to incorporate prior knowledge into the analysis. They are also used in decision analysis, where the goal is to choose among several alternatives based on the available information.

Risk assessments can demand and use a combination of tools and, therefore, these methods may not necessarily be mutually exclusive. For example, from the list of quantitative methods, model building may be used to conduct scenario analyses or sensitivity analyses. Event trees can be used with a subjective probability elicitation. Some of these methods are complex and may require specialized skills and/or training. It is not intended that this module teach how to conduct analyses with all of these methods. However, it is the intent that those conducting risk assessments better understand the broad range of methods available and have opportunity to note if a specific method might be a better fit for a specific risk problem or need.