Corps Risk Analysis Gateway Training Module

Risk Assessment - Quantitative Methods

Series:
Corps Risk Analysis Online Training Modules

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Contents

Risk Assessment - Quantitative Methods

This module was originally developed as a web-based training on the Corps Risk Analysis Gateway. The content has been modified to fit this format. Additional modules are available for download on the IWR website.

As noted throughout the Risk Analysis Gateway, there are three key tasks of risk analysis, including the following:

- **Risk assessment:**
  Risk assessment defines the nature of the risk, its probability, and the consequences, either quantitatively or qualitatively (or a combination).

- **Risk management:**
  Risk management is the actions taken to accept, assume, and manage risk.

- **Risk communication**:
  Risk communication is the multi-directional exchange of information to allow better understanding of the risk.

The goal of **risk assessment** is to identify and describe the risk(s) associated with a decision problem and to examine and evaluate the potential impacts of the risk.

Risk assessment procedures include both qualitative and quantitative methods. The goal of the assessment is to identify and describe the risk(s) associated with a decision problem and to analyze the potential impacts of the risk. This module will expand upon quantitative risk assessments and the tools available to assist with this task. It is not the intent of this module to teach all of the possible methods for conducting quantitative analyses. Rather, the intent is to provide a broad understanding of the wide range of approaches and to provide resources to obtain more information about the various methods.

Quantitative tools rely on numbers to express the level of risk. Typically, quantitative risk assessments have more transparency and the validity of the analysis can be more easily determined. Quantitative risk assessment relies on models. Models can range from simple to complex.

After completing this module you will be able to do the following:

- Describe the USACE model for quantitative risk assessment.
- Identify several commonly used quantitative risk assessment methods, including modeling, event trees, Multi-Criteria Decision Analysis, Monte Carlo Analyses, scenario analysis and sensitivity analysis.
- Locate these quantitative tools and additional resources detailing their methods.

You are encouraged to read through the examples, which look at specific concepts in more depth. Additional learning modules about risk assessment are available for exploration, including *Introduction to Risk Assessment* and *Risk Assessment – Qualitative Methods*.

This training is approximately one hour.

This course includes a self-assessment; it's recommended that you be able to achieve 70% for successful course completion.

Chapter 1 - Quantitative Methods for Analyzing Risk

1.0 Quantitative Methods for Analyzing Risk

Risk assessment can be described as the process of compiling, combining and presenting evidence to support a statement about the risk of a particular activity or event. There are a number of defined processes, techniques, tools, and models that can be used to support the assessment. Risk assessments can be qualitative, quantitative, or a combination of both.

In **qualitative** assessments, the risk characterization produces non-numerical estimates of risk. **Quantitative** tools rely on numbers to express the level of risk. Typically, quantitative risk assessments have more transparency and the validity of the analysis can be more easily determined. Quantitative risk assessment relies on models, and can range from simple to complex. This course focuses on quantitative methods of risk assessment.

The starting point for any risk analysis (either qualitative or quantitative) should be a risk narrative. Simply, a risk narrative characterizes and describes an identified risk. It includes a narrative description of each of the four generic risk assessment steps: identify hazard or opportunity, consequence assessment, likelihood assessment and risk characterization. You can explore the risk narrative and other qualitative methods in-depth in the Risk Assessment – Qualitative Methods learning module.

EXPLORE - BEACH-FX

Beach-fx is a risk-based economic tool for examining short protection benefits. The Beach-fx model combines a historical storm record, shoreline response information, and damage estimation based on erosion, flooding, and wave damage, to assist planners with determining the economic feasibility of shore protection projects. The model simulates the response of a shoreline over time as storms, natural recovery, and management methods combine to continually evolve the beach profile.

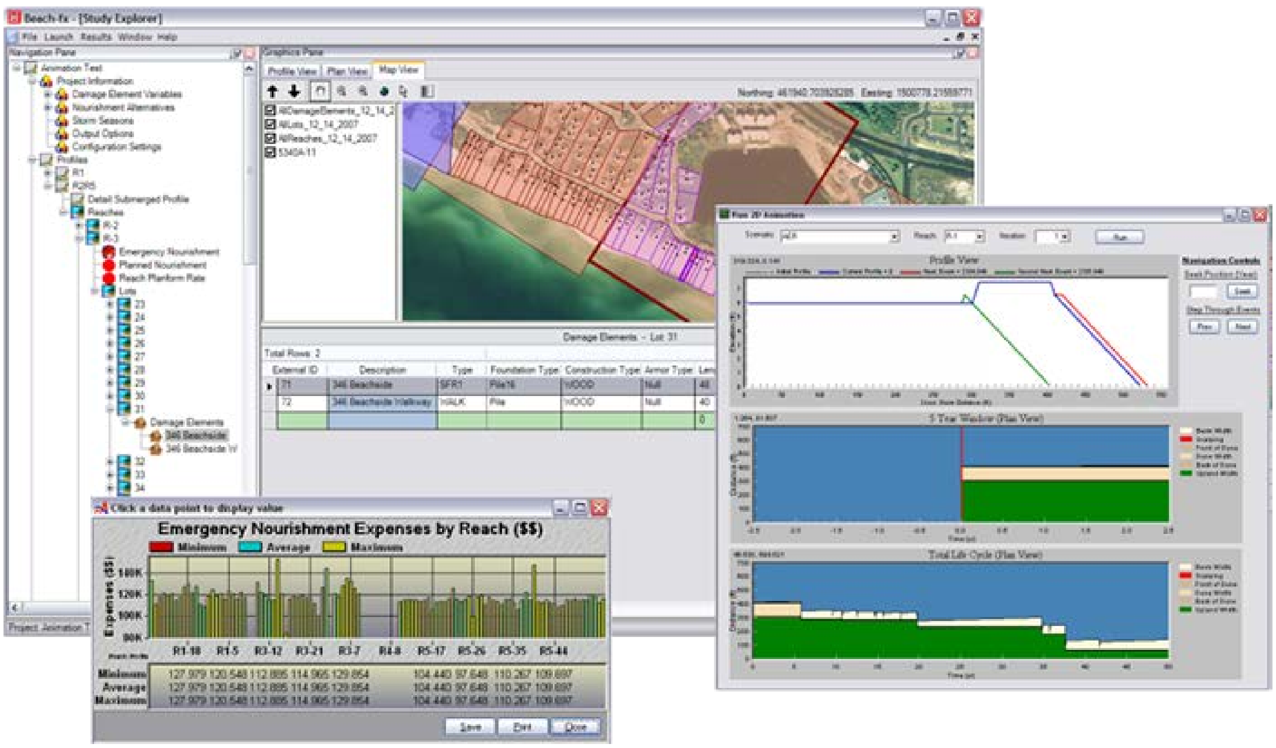

Figure 1. Beach-fx

The Beach-fx modeling software employs an event-based Monte Carlo life cycle simulation. Past approaches to storm damage estimation and shore protection benefits have typically relied on a frequency-based evaluation framework. Beach-fx uses an event-driven approach Geographic Information System (GIS) framework and a database of plausible storms which:

- Evaluates shoreline changes and economic consequences
- Categorizes three damage drivers: inundation, wave-attack and erosion
- Tracks individual damage drivers to allow for evaluation of alternative plans and responses
- Illustrates shoreline changes and resulting damages graphically
- Facilitates evaluation and communication of findings

The analyses that Beach-fx makes are a combination of meteorology, coastal engineering and economic evaluations which trigger an action based on the occurrence of previous events. As a data-driven transparent model, its technical framework incorporates:

- Inherent risk and uncertainty associated with shore protection
- Represented coastal processes
- Combination of engineering and economic behavior

Beach-fx predicts morphology evolution and the associated damages caused by coastal storm events. The system also predicts the costs of shore protection alternatives with risk and uncertainty over multiple project life cycles.

For further information, see: http://www.erdc.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/9254/Article/476718/beach-fx.aspx

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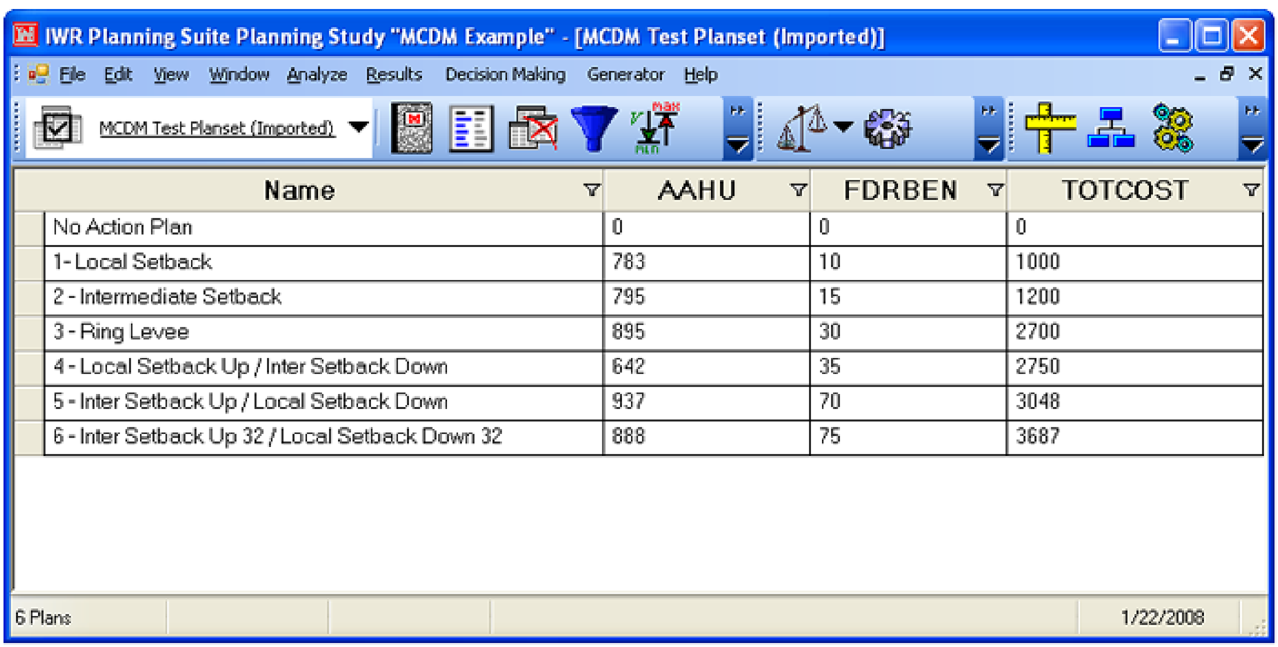
Source: USACE, Engineering Research and Development Center. Retrieved October 25, 2013 from: http://www.erdc.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/9254/Article/476718/beach-fx.aspx

EXPLORE - IWR PLANNING SUITE MCDA MODULE

The Corps' IWR Planning Suite was initially designed to assist with the formulation and comparison of alternative plans for ecosystem restoration and watershed planning studies. However, the program can be applied to planning studies addressing a wide variety of problems. Risk and uncertainty assessment was included into the IWR Planning Suite tool:

- To improve the quality of environmental investment decisions.
- To include levels of uncertainty about how much a plan will cost or how much output it will produce

A Multiple Criteria Decision Analysis (MCDA) tool was incorporated into the IWR Planning Suite. The primary purpose of the MCDA tool is to explore relationships and further the analysis of planning alternatives in order to refine the decision set and better understand how a particular decision set has been derived. This tool is a stand-alone system that provides a framework for conducting multiobjective analysis of alternatives based upon user-defined criteria. Once a decision matrix consisting of alternatives and criteria has been constructed, the MCDA tool provides sophisticated treatment of alternatives and a ranking that decision makers can use to make more informed choices.



Name	AAHU	FDRBEN	TOTCOST
No Action Plan	0	0	0
1-Local Setback	783	10	1000
2 - Intermediate Setback	795	15	1200
3 - Ring Levee	895	30	2700
4 - Local Setback Up / Inter Setback Down	642	35	2750
5 - Inter Setback Up / Local Setback Down	937	70	3048
6 - Inter Setback Up 32 / Local Setback Down 32	888	75	3687

Figure 2. Sample Decision Matrix from the MCDA Tool (where AAHU is Average Annual Habitat Units Gained, FDRBEN is Flood Damage, Reduction Benefits and TOTCOST is Total Cost)

This tool supports the decision-making process by illuminating preferable alternatives based upon criteria values, criteria scoring, ranking methods, and robust outputs. The MCDA tool is an integrated component of the IWR Planning Suite and as such can extract alternatives (plans), criteria (variables), and plan-criteria values (variable values) for analysis in the MCDA tool.

A key component of the tool is the ability to have multiple decision matrices for analysis, as shown in the **sample decision matrix**. The MCDA tool accomplishes this by grouping criteria into planning sets, where each set limits the analysis to a user-specified set of criteria, enabling analysis to focus upon a primary set of objectives, or broadening analysis to include many measures. Each planning set houses a particular decision matrix where alternative-criterion values are entered for all alternatives. Because each planning set creates a separate matrix, analysis can be performed to evaluate what-if situations by entering augmented criteria values into one scenario and creating a base-value scenario for comparison following analysis.

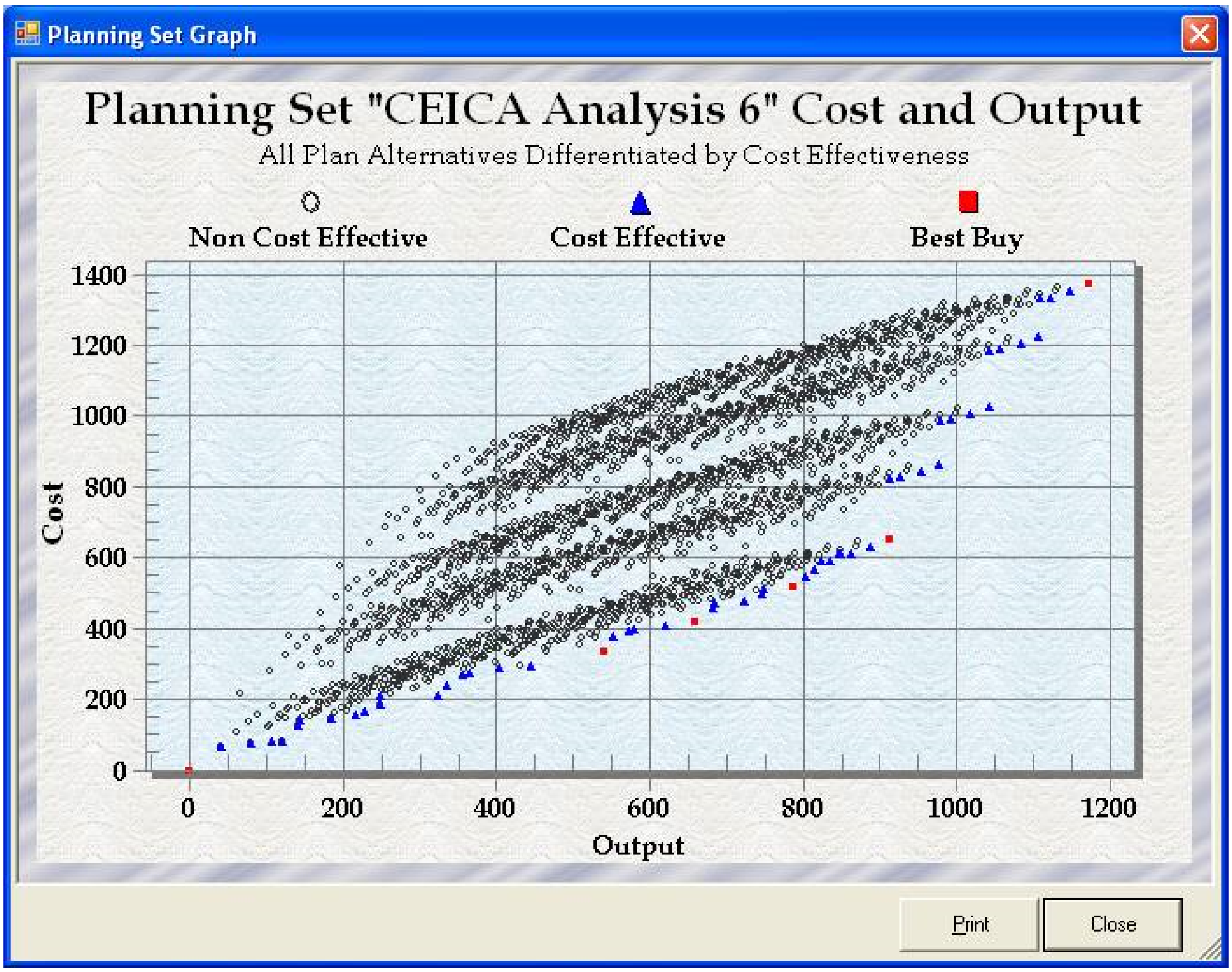


Figure 3. Example Output from IWR Planning Suite for Displaying Cost Effective and Best Buy Alternatives

1.1 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.

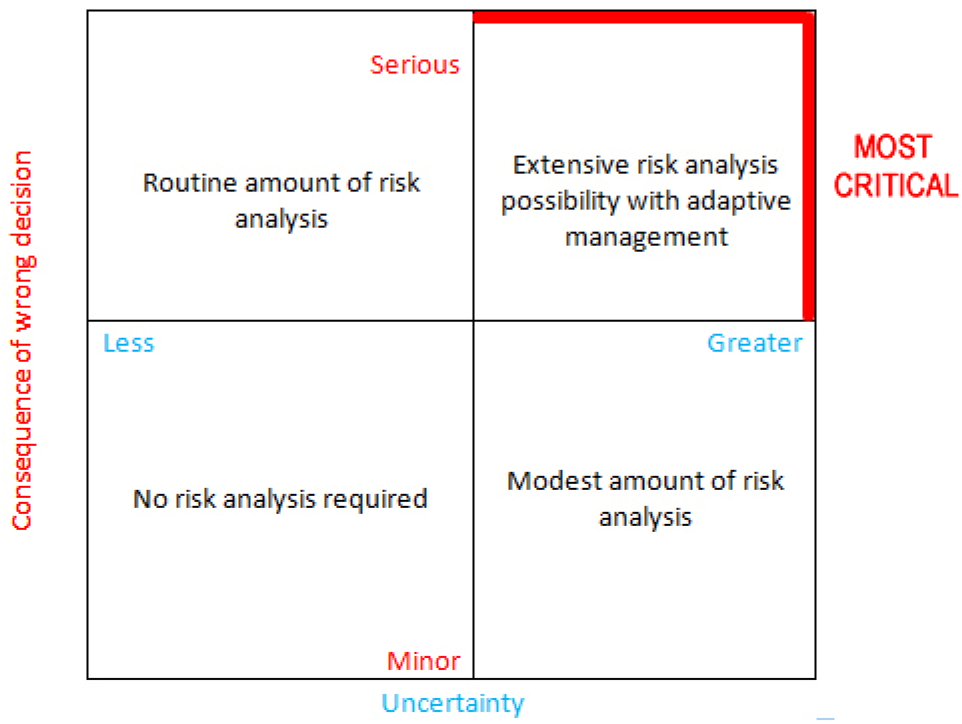


Figure 4. Consequences of making the wrong decision

Oftentimes, risk assessments use a combination of analysis tools, sometimes a combination of both qualitative and quantitative methods. For example, qualitative rating or ranking methods may be used in conjunction with more quantitative based analytical tools, which allow for weighting and/or prioritizing criteria.

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 scenarios, mathematical, statistical and graphical analysis.

- **Scenario Analysis**

  When the future is very uncertain, scenarios can be used to describe the most significant ways it might turn out. Scenarios are coherent narratives created to describe uncertain conditions, usually found in the future. Scenario analysis enables assessors to identify a limited number of futures in order to explore how different risks might unfold in the future. Both deterministic and probabilistic scenario analysis take a range of possible futures into account.

- **Uncertainty Decision Rules**

  This approach addresses uncertainty in decision making, especially when the consequence of making a wrong decision is a concern. A number of decision rules have been developed for making decisions under uncertain conditions. Some examples include: Maximax criterion, choosing the option with the best upside payoff, or Maximin criterion, choosing the option with the best downside payoff.

- **Subjective Probability Elicitation**

  Subjective probability elicitation can be considered a special case of expert elicitation where the specific purpose of the elicitation is to capture an expert’s knowledge about the uncertain probability of some event. This situation arises often enough to warrant separate consideration

- **Safety Assessment**

  Safety assessment usually consists of some form of a ratio of an actual value compared to a standard or value considered to be safe for the population. This method requires some authority to make a specific determination of a level of performance that will be considered safe. The denominator contains the safety standard and the numerator contains the measurement.

- **Vulnerability Assessment**

  Vulnerability assessment identifies a system’s vulnerabilities to specific threats that could result in adverse consequences. Vulnerability assessment is used to identify elements of a system that are most vulnerable so that vulnerability can be reduced through risk management measures. Inputs required for a vulnerability assessment include a well-defined risk management problem, a vulnerability assessment team, a vulnerability assessment methodology and an intimate understanding of the system to be assessed.

- **Environmental Risk Assessment**

  Environmental risk assessment (ERA) is a process that was developed in the U.S. by the Environmental Protection Agency (EPA) to address risks to ecosystems, plants, animals and humans as a result of exposure to a range of environmental hazards, including chemicals, anthropogenic activity, microorganisms and the like. The basic approach begins with the hazard or source of harm and the pathways by which the hazard can affect a susceptible target population. It culminates in an estimate of the likelihood and consequences of that harm. Model and model building are often complimentary tools to this method.

- **Root Cause Analysis**

  Root cause analysis (RCA), or root cause failure analysis, is used to identify what, how and why something happened, so that recurrences can be prevented. It is often used to analyze major asset losses and it is conducted after a failure event. When the process is applied to economic or financial losses, it is called loss analysis. RCA is used for accident investigations and to enhance occupational health and safety. It's also used to improve reliability and maintenance of technological, engineering and infrastructure systems as well as for quality control.

- **Fault Modes and Effects Analysis (FMEA and (FMECA))***

  FMEA and Fault Modes and Effects and Criticality Analysis (FMECA) are techniques used to ask what could go wrong. They identify the ways components or systems can fail to measure up to design levels of performance.

- **Cause Consequence Analysis***

  This technique was invented by RISO Laboratories in Denmark to conduct risk analysis of nuclear power stations. Cause-consequence analysis (CCA) combines fault tree and event tree analysis. It blends cause analysis (described by fault trees) and consequence analysis (described by event trees). CCA has the ability of fault trees to show the different ways factors can combine to cause a risky event and the ability of event trees to show the many possible outcomes. By combining deductive and inductive analysis CCA can identify chains of events that can result in multiple undesirable consequences.

- **Cause-and-Effect Analysis**

  Cause-and-effect analysis helps you to think through causes of a risk (i.e., a problem or opportunity). This structured method pushes the team to consider all the possible causes of the risk, not just the obvious ones. This method is often supplemented with cause and effect diagrams, also called a fishbone diagram.

- **Layers of Protection Analysis (LOPA)***

  LOPA is an engineering tool used to ensure that the risk associated with a process is successfully managed to a tolerable or acceptable level. It was developed as a more rational and objective alternative to subjective engineering judgment. It is a simplified semi-quantitative risk assessment method for evaluating the risk of specific hazard scenarios and comparing it with risk tolerance criteria to decide whether existing safeguards are adequate or more safeguards are needed (PrimaTech, 2005).

- **Human Reliability Assessment (HRA)***

  Human reliability assessment is designed to estimate the likelihood that particular human actions that may prevent hazardous events will not be taken when needed and that other human actions that may cause hazardous events by themselves or in combination with other conditions will occur.

- **Bow Tie Analysis**

  Bow tie analysis is a simple diagram used to help conceptualize the interaction of causes, controls and consequences of a risk. Although it reflects elements of both event tree and fault tree logic, it differs by its focus on the barriers between the causes and the risk, and the risk and consequences.

- **Reliability Centered Maintenance***

  Reliability Centered Maintenance (RCM) is designed to produce the least maintenance costs for low operational risk and high equipment reliability. It was initially developed for the commercial aviation industry in the late 1960s, but it has since been adapted for use by other industries. It provides a process to identify applicable and effective preventive maintenance requirements for equipment in accordance with the safety, operational and economic consequences of identifiable failures considering the degradation mechanism responsible for those failures. The process supports decision making about the necessity of performing a maintenance task. As such, it may be useful to a wide range of the Corps operation, maintenance, replacement, and rehabilitation issues.

- **Markov Analysis**

  Markov analysis provides a means of analyzing the reliability and availability of systems whose components exhibit strong dependencies as befits many of the engineering and even natural systems with which the Corps works. A critical insight for Markov analysis is that in the present moment, the future is independent of the past. Thus, older information produces less accurate predictions and the future is best predicted by the information known now.

- **Bayesian Statistics and Bayes Nets**

  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 comes in, one will revise the probability to what is called posterior probability.

- **Risk Control Effectiveness***

  RCE analysis can be used to provide a relative assessment of the actual level of risk control that is currently present and effective. This is then compared to the level of risk control that is reasonably achievable for a particular risk.

- **Frequency Number (FN) Curves**

  FN curves graphically present the frequency of a given number of casualties occurring for a specified hazard. They show the likelihood of a risk causing a specified level of harm to a specified population. Most often they show the cumulative frequency (F) at which N or more members of the population will be affected. High values of N that occur with a high frequency F are likely to be unacceptable risks. FN curves are one way of representing the outputs of a risk assessment.

- **Cost Benefit Analysis**

  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.

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.

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[1]There is any number of academic descriptions of deterministic versus probabilistic methods. For some discussions see: http://www.riskeng.com/downloads/deterministic or http://www.palisade.com/risk/risk_analysis.asp.

1.2 SOFTWARE TOOLS

Some quantitative methods have been built into software tools that facilitate the risk assessment. Some of these tools have been developed specifically by USACE.

For example, **Beach-*fx*** (http://hera.cdmsmith.com/beachfx/default.aspx) is a shore protection engineering economic software tool developed by USACE that consists of a Monte Carlo simulation model for estimating shore protection project performance and benefits. It can be used to perform economic evaluations of federal hurricane and storm damage reduction projects under a risk and uncertainty framework.

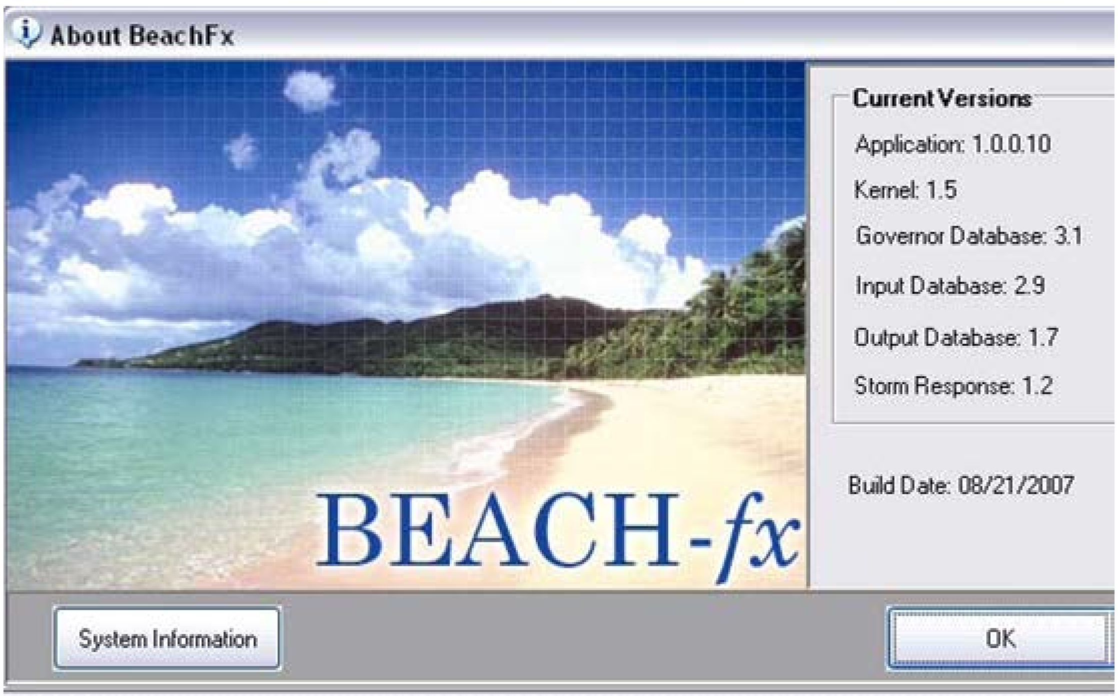

Figure 5. Beach-fx

The Corps' IWR Planning Suite MCDA Module (http://www.pmcl.com/iwrplan/MCDAUsersGuideSep10.pdf) allows the comparison of alternatives according to weighted criteria and supports conducting multi-criteria decision analysis and exploring multiple dimensions of a planning decision.

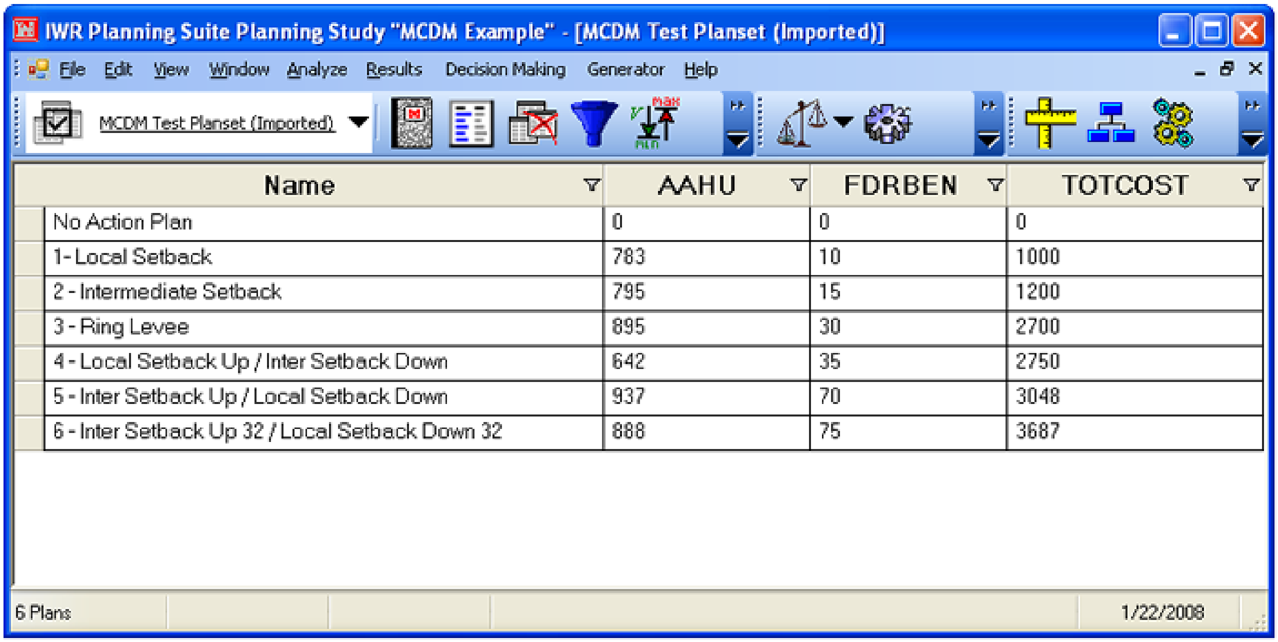

Figure 6. Sample Decision Matrix from the MCDA Tool

In other cases, there are commercial off-the-shelf (COTS) software tools available that use these quantitative methods. For example, **@risk** (http://www.palisade.com/risk/) is a Microsoft Excel add-in tool from Palisade that performs risk analysis (http://www.palisade.com/risk/risk_analysis.asp) using Monte Carlo simulation (http://www.palisade.com/risk/monte_carlo_simulation.asp) methods, and provides outputs of probabilities and risks associated with different scenarios. In Chapter 8 of this module is an example analysis demonstration using @risk.

Figure 7. Palisade's @RISK software

Criterium Decision Plus (http://infoharvest.com/ihroot/index.asp) is a software tool from Infoharvest® for multi-criteria ranking of alternatives.

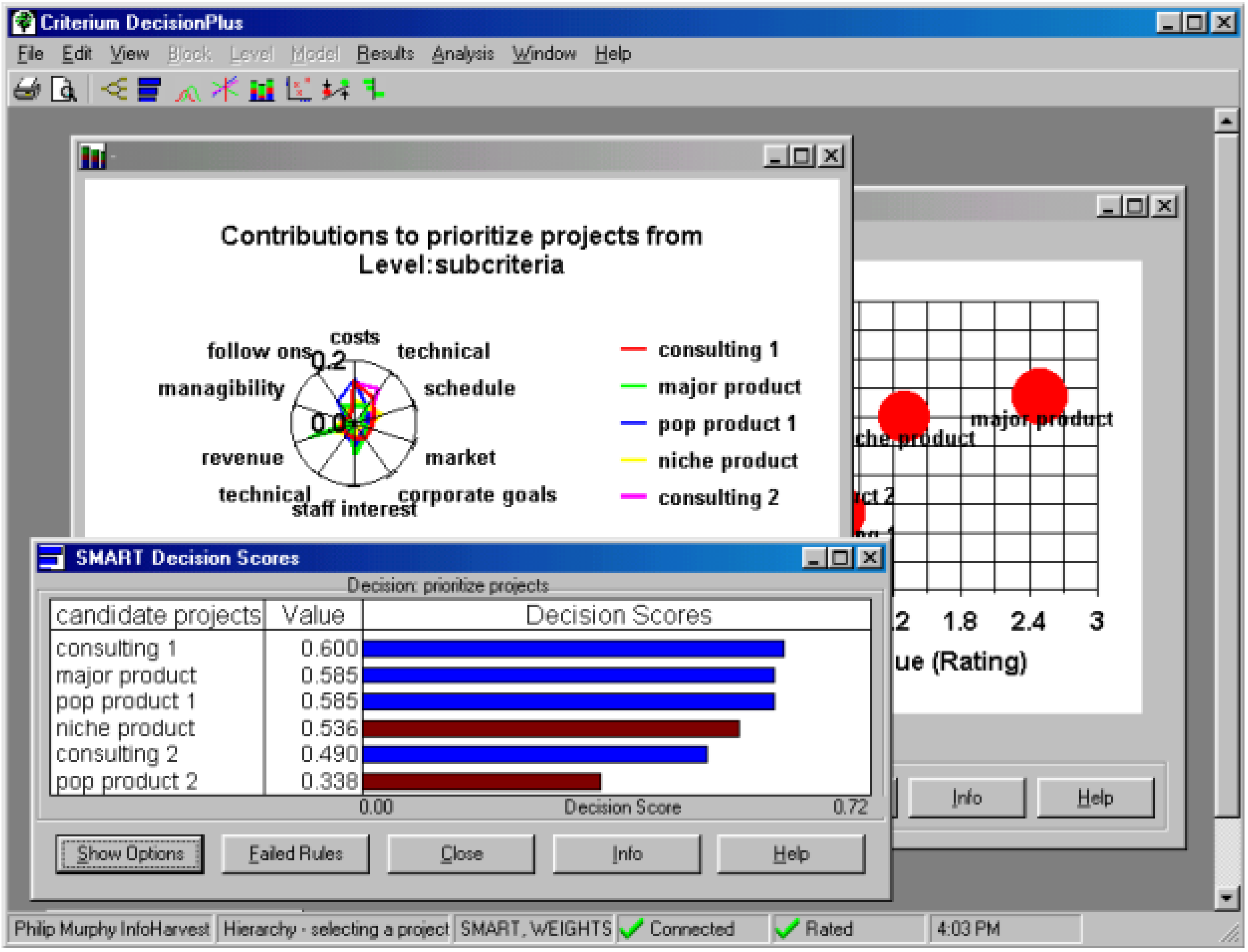

Figure 8. Criterium Decision Plus

1.3 PLANNING MODEL CERTIFICATION

It should be noted that USACE does require the use of certified or approved models for all formal USACE planning studies to ensure the models are technically and theoretically sound, compliant with policy, computationally accurate and based on reasonable assumptions. Planning models are defined as any models and analytical tools that are used to define water resources problems and opportunities, to formulate potential alternatives to address the problems and take advantage of the opportunities, to evaluate potential effects of alternatives and to support decision making. The [Corps Planning Community Toolbox](https://planning.erdc.dren.mil/toolbox/current.cfm?Title=Model%20Certification&ThisPage=ModelCert&Side=No) website has specific information about the model certification process and currently certified models (https://planning.erdc.dren.mil/toolbox/current.cfm?Title=Model%20Certification&ThisPage=ModelCert&Side=No).

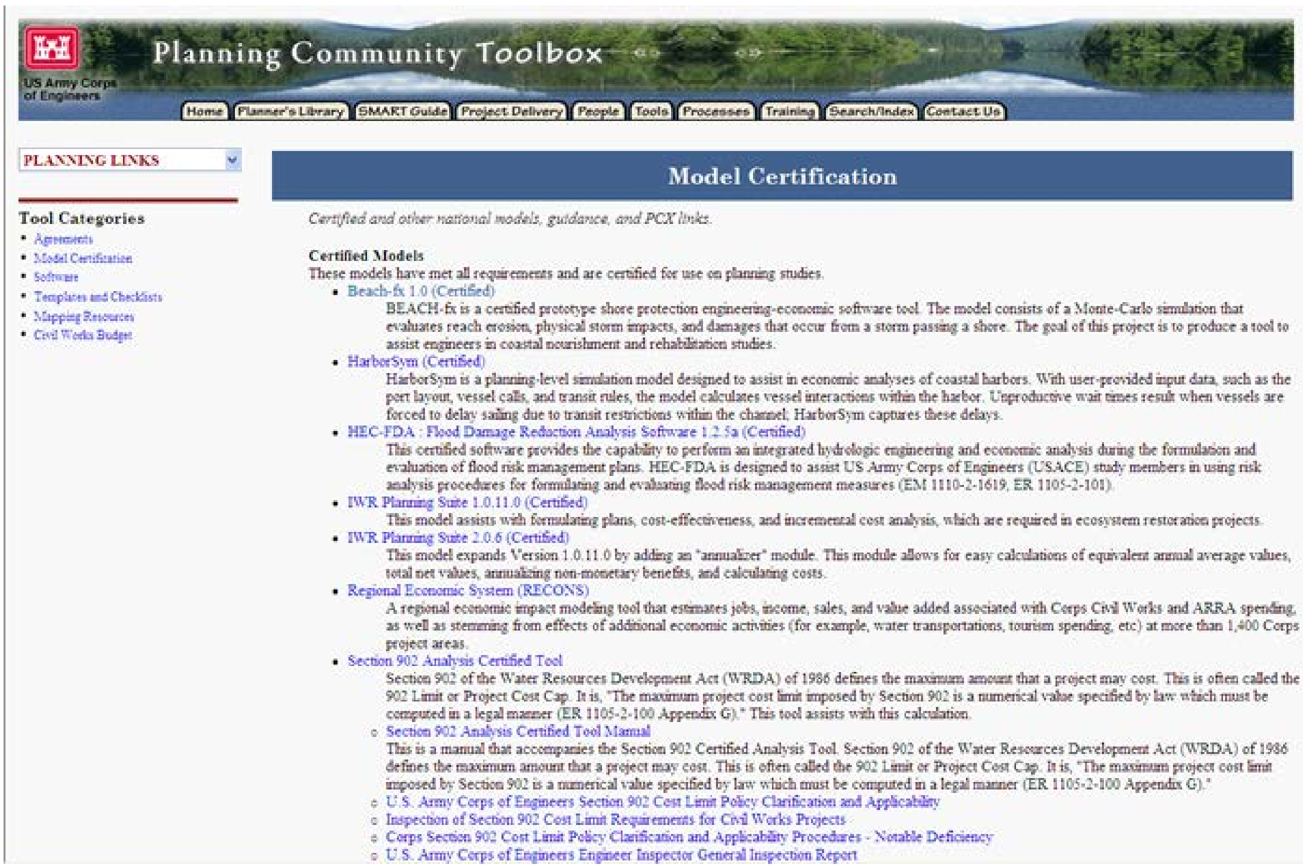

Figure 9. USACE Planning Community Toolbox

The following course sections provide more detailed information about some of the more commonly used quantitative methods and approaches for risk assessment. These include the following tools and methods:

- Modeling and model building

- Event trees
- Multi-criteria decision analysis tools
- Monte Carlo analyses
- Scenario analysis
  - Deterministic Scenario Analysis
  - Probabilistic Scenario Analysis
- Sensitivity analysis

Chapter 2 - Modeling and Model Process

2.0 Modeling and Model Process

A model is a device, demonstration, equation, explanation, picture or replica of something else. Models are used to describe how actual things behave. USACE makes extensive use of quantitative models in many of its areas of responsibility. There are physical models, mathematical models, statistical models, computer models, and blueprints, maps and drawings that function as models. Models are used by USACE to understand stream flows, storm paths, the transport and fate of substances in water, ecological responses to changes in the environment, and economic responses to new infrastructure. Risk-based models are used to explore the effects of uncertainty on model outputs and real world outcomes. Models are also used to achieve goals like maximizing net economic development or efficiently allocating operations and maintenance (O&M) funding. Simulation models are routinely used to explore the effects of channel improvements on navigation. Some of the USACE models are used repeatedly and throughout the organization. Other models are developed for one-time use in a unique analysis. Models can be used in every stage of a project's lifecycle, in every business line, and in every functional area of responsibility.

All models require knowledge, theory, data and information in many forms. Other inputs to a model depend on the nature of the model. Physical models are built as replicas of a real thing. Mathematical equations are flexible and relatively cost-effective models. Systems of equations and mathematical relationships are common inputs to these models. USACE also makes extensive use of statistical models. Risk analysis requires models that enable analysts to explore "what if" questions. These models often require probability distributions among their inputs. Modeling may be the most idiosyncratic part of the risk assessment process. It can be helpful to have a process in mind.

The outputs of models are even more varied than the models themselves. Some produce insights, some provoke discussion, some provide numerical estimates of values of interest for decision making, while other produce distributions of possible outcomes or extensive databases. The substance of these model outputs can touch on any subject matter. It may be useful in risk analysis to distinguish between deterministic and probabilistic models. The former tend to produce point estimates, or a single output (which may be more complex than a single point), while the latter produces probabilistic outputs.

Models allow analysts to conduct controlled experiments. They can reveal new facts about problems during their construction and their use. The broad range of applications makes them a practical tool for analysis. They can also be effective training tools. One of the advantages of mathematical and statistical modeling is their flexibility. Models can often be built in a modular or patchwork approach that enables analysts to re-use parts of models in new applications and to add to an existing model when new features or capabilities are desired.

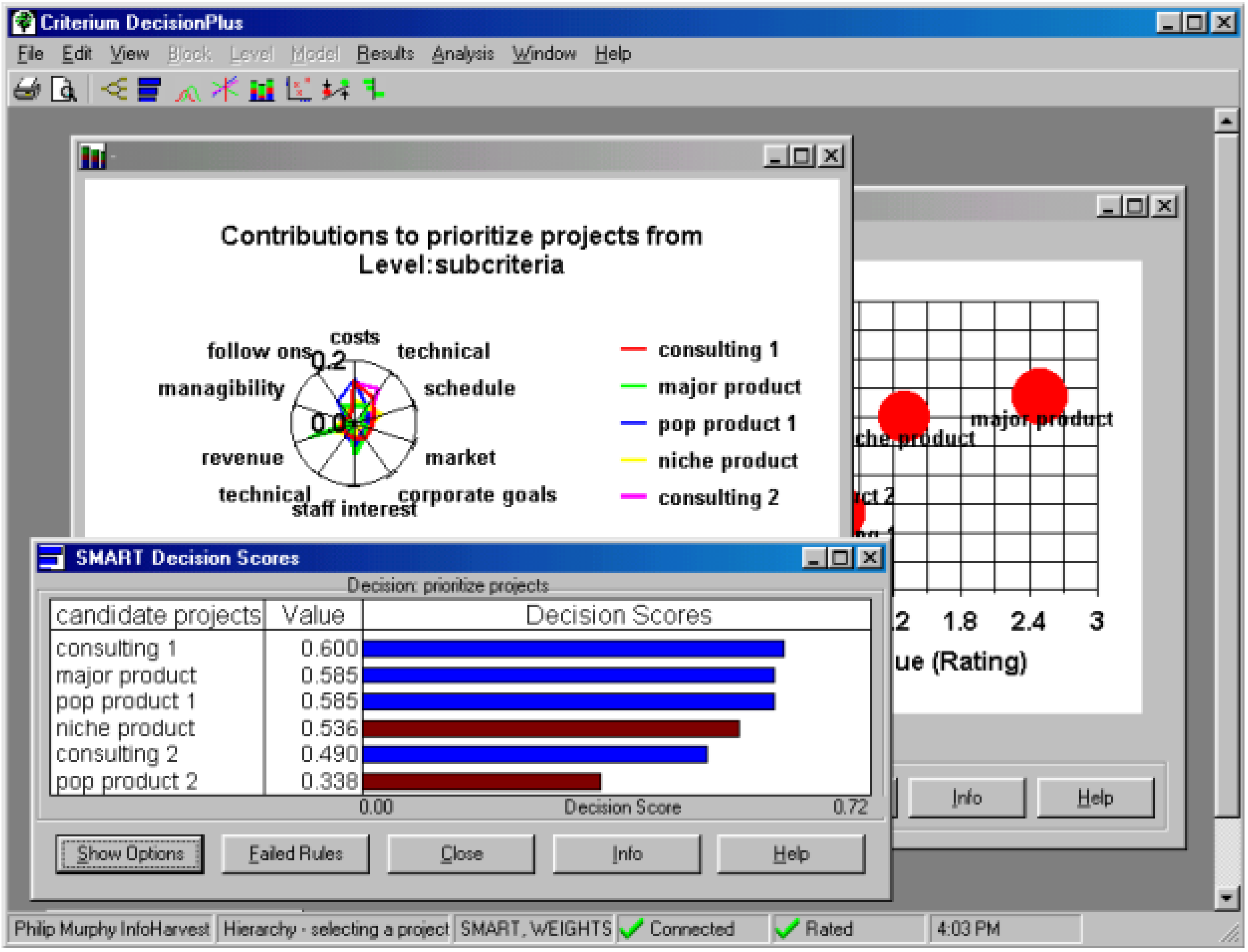

Figure 10: Criterium Decision Model

Potential weaknesses include the fact that models can be costly or time-consuming to build. The results of models are very sensitive to model formulation. There is no guarantee a model will produce an optimal solution and more than a few models have been found to produce incorrect outputs.

A significant USACE initiative to improve model outputs and the quality of the decisions they inform is found in EC 1105-2-412, *Assuring Quality of Planning Models* (EC_1105-2-412_2011Mar.pdf), issued in 2011. The Corps Planning Community Toolbox website has specific information about the model certification process and the currently certified models (https://planning.erdc.dren.mil/toolbox/current.cfm?Title=Model%20Certification&ThisPage=ModelCert&Side=No).

For further information about computer models and tools, see the Corps Shared Vision Planning Resources page. The site provides descriptive information and resources for problem definition tools, analytical tools, and synthesis tools.

EXPLORE: MODEL BUILDING PROCESSES

Dr. Charles Yoe, a recognized expert in both risk analysis and USACE planning processes, provides the following 13 steps that describe a model building process:

1. **Get the question right.**

   The first step in developing any model is to understand what question(s) the model needs to be able to answer. Know what information the model needs to produce. Different questions can lead to very different models, requiring different data and a different model structure.

2. **Know how your model will be used.**

   Understand how the model is expected to be used. Know what the model can and cannot do. Anticipate as many potential uses of the model before you begin to build it as possible. Will it be used to identify research needs, developing a baseline risk estimate, or to evaluate risk management options? Will it be shared with others or used again? Will it be added to over time or is it to be completed once and for all? Who will use it?

3. **Build a conceptual model.**

   This is where a model building effort is most likely to succeed or fail. Models do not fail so much due to data and parameter value issues as they do for a faulty conceptualization of the problem to be represented. This step takes you from the abstract ideas and notions to the hard reality of details. The best modelers include the important processes and exclude unimportant ones. The typical conceptual risk model will identify the sequence of events necessary to lead to an undesirable consequence. It will lead to an answer to the specific questions that have been asked. A conceptual model is well-served by a risk narrative that answers the four basic questions: What can go wrong? How can it happen? What are the consequences? How likely are they? Transform your narrative answer to these questions to a sketch. For example, one could develop an influence diagram to show how the problem will be modeled.

4. **Specify the model.**

   The specification model defines the calculations and other inner workings that will make the model run. It may help to think of it as the paper and pencil exercise of figuring out the calculations that will be needed to make the conceptual model produce answers that are useful to you. It is more than this, but that provides a good mental image of the essence of this task. The functional form of all relationships and the model logic are built in this step. Place holders and dummy values can be used in lieu of data.

5. **Build a computational model.**

   The output of this step is a fully functional model. In this step you complete the computer program needed to run the model you have specified. To complete a computational model you'll need to collect the data you needed to make the model operational.

6. **Verify the model.**

   You want to get the equations, calculations, logic, references and all the details just right. Verification ensures that the computational model is consistent with the specification model and that the specification model is correct. It is important to be sure the model is built correctly. This is when the model is debugged, reviewed, and tested to ensure the conceptual model and its solution are implemented correctly and that the model works as it is intended to work.

7. **Validate the model.**

   Does the model represent reality closely enough to provide information that supports decision making? One can validate model outputs, model inputs, or the modeling process. Historical data validity uses historical inputs to see if the model reproduces historical outputs. When the outputs cannot be validated, it may help to validate the input data. Data validity means you have clean, correct, and useful data that are truly representative of the system modeled. When neither the inputs nor the outputs can be validated the best remaining option may be to try to validate the reasonableness of the process. A model has face validity when it looks like it will do what it is supposed to do in a way that accurately represents reality.

8. **Design simulation experiments.**

   If you sit down with your model and just start making runs, it is likely that, sooner or later, you will get what you need. It is also likely you'll waste a lot of time making runs you did not need. Carefully identifying the various conditions for the scenarios or simulations you want to run is essential to an efficient modeling process. Arrange your series of experiments efficiently. It may make sense to do them in a specific order if significant adjustments must be made to the model for different conditions. Write down the runs in the order they will be done. Take care to verify all alterations to a model and save significantly different versions of the model as separate files.

9. Make production runs.

Be systematic in making your runs. Carefully record the nature and purpose of the run (e.g., existing risk estimate to establish a baseline measure of the risk) and make note of your model's initial conditions, input parameters, outputs, date, analysts and so on. Enter this information into a log kept for the model. Keep it up to date. Take special care to save all outputs from a production run and to carefully identify them. Unless you are absolutely sure about the outputs you will and will not need to complete a risk assessment, save all simulation outputs if possible. It is far better to save outputs you will never need than to need outputs you never saved.

10. Analyze simulation results.

This is getting useful information from data. Analyze the results and learn what the simulations have taught you about the problem. The analysis of simulation results will provide information needed to answer the questions. Always take care to characterize the remaining uncertainty in useful and informative ways.

11. Organize and present results.

The information gleaned from the model runs needs to be organized and presented to decision makers in a form that is useful.

12. Answer the question(s).

Answer each question specifically. Do it in a question and answer format. Take care to portray the extent to which lingering uncertainty affects those answers. Once you have adequately answered the questions, feel free to summarize the insights you gained, offer specific observations, and even conjecture in a responsible way.

13. Document your model and results.

A careful documentation of the results is assumed. The model must be documented as well. Explain the structure of the model, including relevant descriptions of the preceding steps, the conceptual and specification models, the source and quality of the data, the results of the verification and validation efforts, as well as the history of production runs. Provide enough user instruction that another person can run the model if there is a chance that might happen. As familiar as you are with the model today, there is a good chance it will look like someone else's work in six months' time. The time taken for this step is time well spent.

Source information based upon Yoe, Charles. (2012). *Principles of risk analysis: decision making under uncertainty.* CRC Press: Boca Raton, FL. http://www.crcnetbase.com/doi/pdf/10.1201/b11256-1.

Chapter 3 - Event Tree

3.0 EVENT TREE

An event tree can be either 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. An example is shown in Figure 7 below. [2]

A distinguishing characteristic of the event tree is that all of the events or nodes are assumed to be determined by chance. There are no decisions to be made along any of the pathways. When decision points are added to an event tree, it is more appropriate to call the technique a decision tree. Event trees that only assess the frequency of the various possible outcomes are sometimes called probability trees.

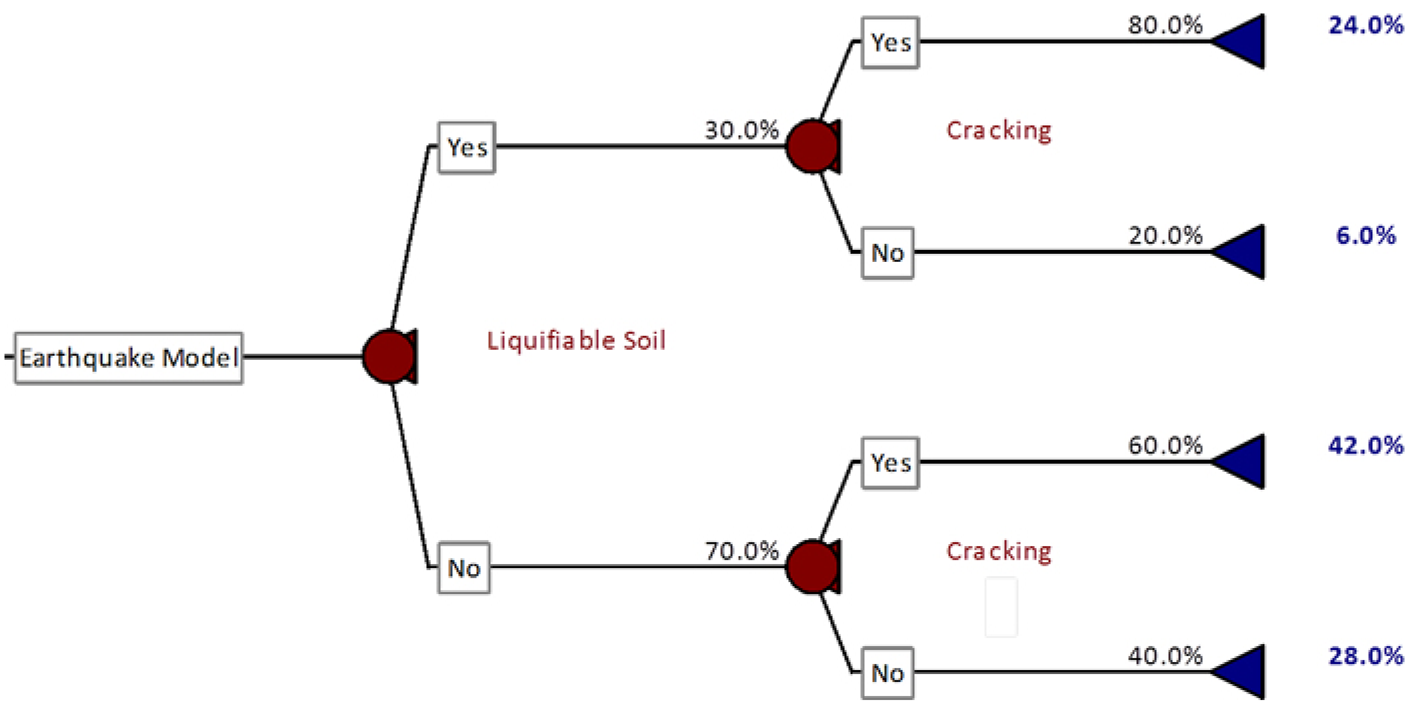

Figure 11. Simple event tree of earthquake effect on a concrete monolith

The event tree is an inductive logic technique that answers the basic question "what happens if...?" Possible scenarios fan out like a tree.[3] An event tree is useful for identifying both aggravating and mitigating events that might follow the initiating event.

An event tree can be used at any stage in the lifecycle of a project or process. It has value as a qualitative tool because the process of developing a tree aids the understanding of a risk situation by identifying the potential scenarios and sequences of events that can lead to undesirable or more desirable outcomes. Quantifying the tree with probability and consequence information enables the risk assessor to characterize the risk numerically. A quantitative model can be very useful in evaluating the efficacy of different risk control strategies. The trees are most often used to model failure modes where there are multiple safeguards and/or multiple modes of failure.

A tree model requires an explicit understanding of the process that is being modeled. The initiating events, sequences of follow-on events, and outcomes or endpoints must be known. A quantitative event tree requires sufficient data to numerically describe the function and failure of the system under consideration. One of the critical inputs to an event tree is a clearly and concisely defined initiating event. A new tree is required for each distinct initiating event.

As mentioned, an event tree begins with an initiating event. Events are represented by nodes. Chance events are represented by circles, decisions by squares, and endpoints by triangles. The initiating event may be a natural event, an infrastructure failure, an operator error or any other causal event. A chance event will have more than one potential outcome. Each potential outcome is represented by a branch emerging from the preceding node. Subsequent events that may aggravate or mitigate the outcome are listed in sequence from left to right. Each event outcome is represented by a chance node. The potential outcomes of each are represented by branches. This node-branch sequence continues until an endpoint is reached. An endpoint represents the point at which the sequence of events from the initiating event is concluded for the purposes of the decision problem at hand.

In **quantitative** event trees, probabilities are estimated for each branch emerging from a node. These probabilities are usually listed above the branch. If additional consequences are quantified (e.g., dollars, lives lost, people affected) these are listed below the branch. Each probability is a conditional likelihood predicated on the nodes and branches that preceded it. Consider Figure 7 again. Each path through the tree represents the likelihood that all of the events in that path will occur. Often art is involved in defining the sequence of events on the paths. This process enables assessors to calculate the likelihood of any identified outcome by the product of the individual conditional probabilities and the frequency of the initiating event. Conditional probabilities provide the quality of independent events.

A good event tree model provides a **qualitative** description of a potential risk. It fleshes out problems and their consequences as different combinations of events are shown to produce variations of the problem and a range of outcomes that can result from an initiating event. Figure 7 above, for example, suggests the different ways damage to a concrete structure may occur as a result of an earthquake. Quantitative estimates of event consequences and their likelihoods can be obtained when the tree model is quantified. The best models can assist with understanding the relative importance of different sequences of events and failure modes. The efficacy of different risk management options can often be tested and quantified by changing critical model inputs. Event trees can be used to examine part of a risk, for example, the likelihood assessment, and its outputs may become inputs to other risk assessment models.

Event trees provide an effective visual map of risks. The strengths of event trees include:

- The ability to display potential scenarios following an initiating event.
- Accounting for timing, dependence and domino effects that are cumbersome to handle in verbal descriptions and other models.
- Event trees are useful for helping USACE analysts anticipate the range of effects associated with natural disaster events or infrastructure failures.

Event tree weaknesses include some of the following:

- They require analysts to be able to identify all relevant initiating events.
- Each event may require a separate model.
- When nodes are constructed with dichotomous branches, it is difficult to represent delayed success or recovery events.
- Any path is conditional on the events that occurred at previous branch points along the path; thus, probabilities must reflect these conditions accurately.
- These models can quickly grow very large.

Some additional resources for event trees include the following:

- Clemens, P.L., (1990). *Event tree analysis*. Retrieved January 13, 2013 from: http://www.fault-tree.net/papers/clemens-event-tree.pdf.
- Event Tree analysis website. Retrieved January 13, 2013 from: http://www.eventtreeanalysis.com/.
- Fault-tree.net website. Retrieved January 13, 2013 from: http://www.fault-tree.net/.
- U.S. Nuclear Regulatory Commission. (1981). Fault tree handbook. Washington, DC. Retrieved January 13, 2013 from: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0492/.

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[2] A 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.

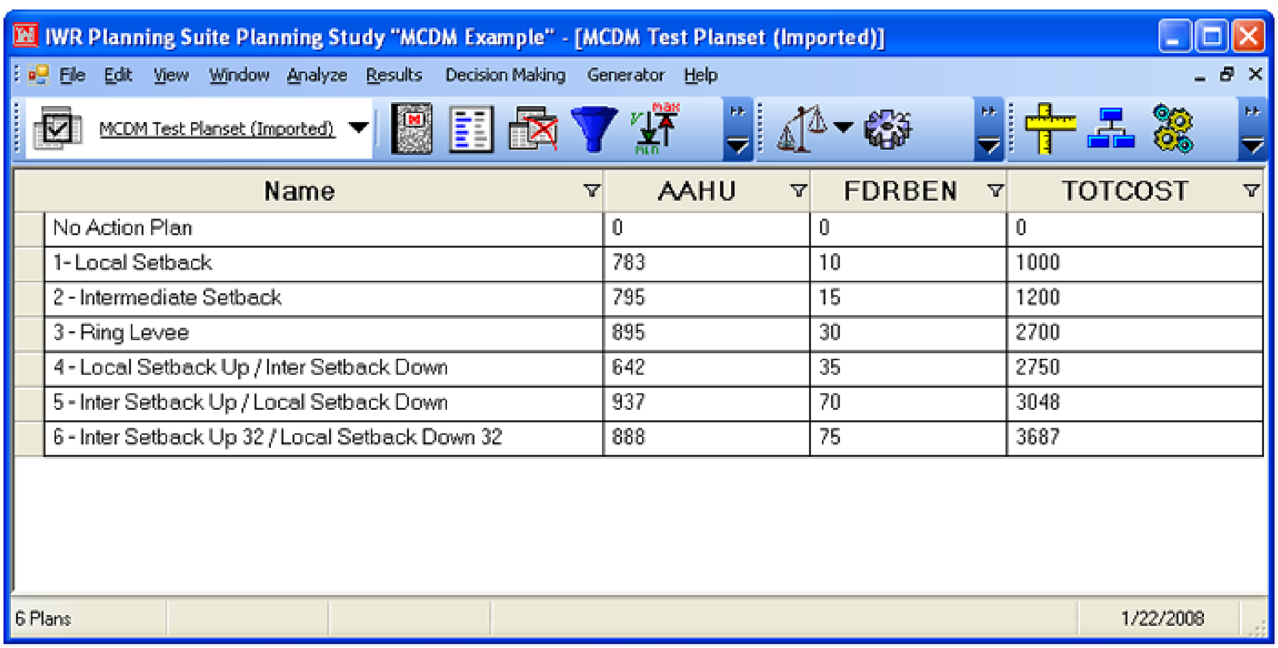
[3] International Electrotechnical Commission (IEC)/International Organization for Standardization (ISO). (2009). *ISO 31000:2009, Risk management—risk assessment techniques.* Retrieved January 13, 2013 from http://www.iso.org/iso/iso31000.

Chapter 4 - Multi-Criteria Decision Analysis (MCDA)

4.0 MULTI-CRITERIA DECISION ANALYSIS (MCDA)

Multi-Criteria Decision Analysis (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. Many different decision algorithms or methods of weighing and combining the criteria with decision maker preferences are included in the MCDA toolbox.[4]

MCDA has proven to be especially useful for group decision-making processes. Rather than identify the best solution, MCDA helps decision makers find a solution that best suits their goals, preferences and understanding of the problem they seek to solve. It has proven to be especially useful in establishing priorities, reducing a long list of things of concern to a short list, and in establishing a ranking among alternative parameters. Thus, MCDA might be used to help rank a number of potential operations and maintenance (O&M) activities where the decision may be based on costs, essential services produced, public perception, or systems considerations. It can also be used to help identify the best plan from among an array of alternative plans, or to identify the riskiest levee, mitre gate, or stone rubble breakwater from among a set of such structures.



Name	AAHU	FDRBEN	TOTCOST
No Action Plan	0	0	0
1-Local Setback	783	10	1000
2 - Intermediate Setback	795	15	1200
3 - Ring Levee	895	30	2700
4 - Local Setback Up / Inter Setback Down	642	35	2750
5 - Inter Setback Up / Local Setback Down	937	70	3048
6 - Inter Setback Up 32 / Local Setback Down 32	888	75	3687

Figure 12. Sample Decision Matrix from the MCDA Tool (where AAHU is Average Annual Habitat Units Gained, FDRBEN is Flood Damage, Reduction Benefits and TOTCOST is Total Cost)

The inputs to a MCDA process include:

- Problems
- Alternative solutions to the problems
- Criteria upon which a decision will be based
- Evidence, i.e., measurements of the criteria for each alternative
- Decision matrix of alternative and criteria measurements
- Subjective weights for the criteria
- Synthesis algorithm
- A decision

The *Risk Assessment – Qualitative Methods* learning module provides an example of the enhanced criteria-based ranking process. One of the assumptions of that example was that equal weights were applied to all criteria. However, the MCDA process allows for the consideration that different criteria have different weights in the analysis.

As a tool, an MCDA approach is often combined with other methods, such as qualitative rating and ranking, or expert elicitations. It may also be used in conjunction with scenario building techniques. The strength of the MCDA process is its ability to answer multiple criteria decision questions. It also enables decision makers to explore the sensitivity of the solution to different weights and, in some methods, to a range of uncertain criteria values. It is limited by the fact that it does require a subjective assignment of weights. The most appropriate set of weights is difficult to discern and attain agreement on in many decision problems. In addition, different synthesis algorithms can yield different rankings of alternatives.

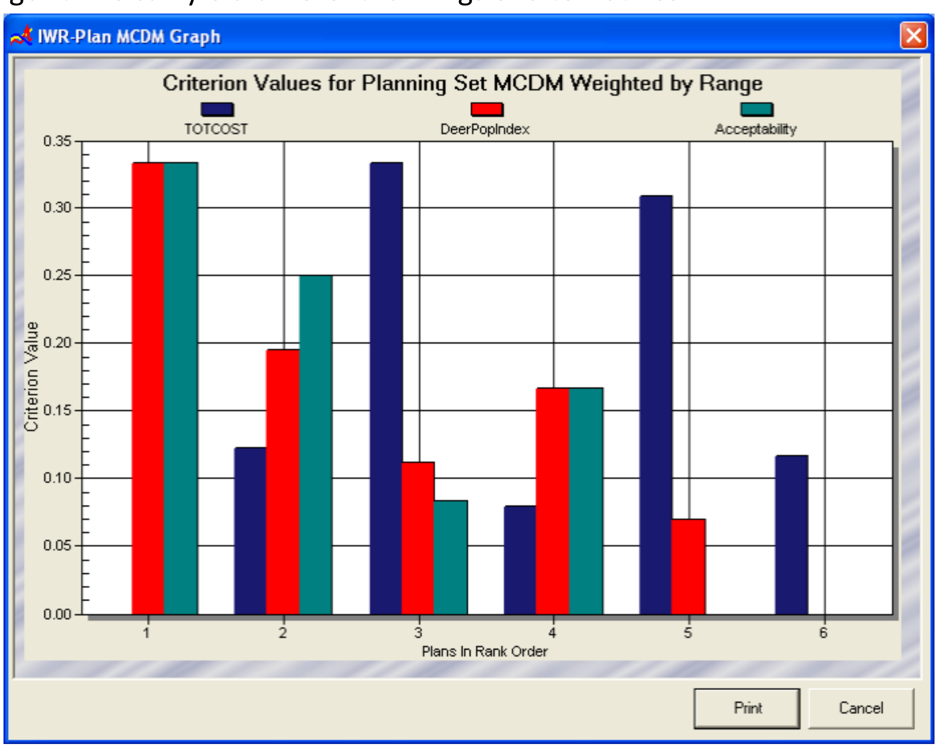


Figure 13. Multi-Criteria Decision Approach

Though specifically focused on tools that can be used in a collaborative planning process, Corps Shared Vision Planning Resources web page. The site) provides descriptive information about existing tools and computer models for problem definition, and the analysis and synthesis of alternatives (including MCDA approaches). Resources available on MCDA include the following:

- Hajkowicz, S. (2006). *A comparison of multiple criteria analysis and unaided approaches to environmental decision-making.* Environmental Science & Policy, 10, 3, 177-184. Retrieved January 13, 2012 from: http://www.sciencedirect.com/science/article/pii/S146290110600116X.
- International Society on Multiple Criteria Decision Making. Retrieved January 13, 2012 from: http://www.mcdmsociety.org/; http://www.mcdmsociety.org/content/software-related-mcdm.
- Stewart, T.J. (ed.). 2012. Journal of Multi-Criteria Decision Analysis. Retrieved January 13, 2012 from: http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-1360.

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[4] Among the more common methods for weighting and combining criteria are the analytic hierarchy process (AHP), ELECTRE (Outranking), multi-attribute utility theory (MAUT), PROMETHEE (Outranking), and Simple Multiattribute Rating Technique (SMART) among others.

Chapter 5 - Monte Carlo Analyses

5.0 Monte Carlo Analyses

The Monte Carlo analysis 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 samples an individual value from each probability distribution in the model. These values are then plugged into the model's equations and calculations so that the model's calculation can be completed and outputs generated. This process is repeated the desired number of times to generate a distribution of output values. These output distributions can be subjected to statistical analysis to inform decision making. When the Monte Carlo process is included in a simulation model, the model is often called a Monte Carlo simulation.

This process can be used to replace point estimates in any kind of model. Easy-to-use commercial software has made the method popular to use in spreadsheet models. Thus, the process can be used in any spreadsheet model USACE uses where one or more model inputs are uncertain, i.e., subject to natural variability or a matter of some knowledge uncertainty. This makes it a widely applicable tool for assessing risks. Its use is not restricted to spreadsheet models, however. It can be employed in virtually any quantitative model. Several of the models developed corporately by USACE employ this technique. This includes the Corps Flood Damage Reduction Analysis Model (HEC-FDA), which is a tool for evaluating flood risk management measures. Another USACE tool that uses a Monte Carlo technique is Beach Fx (http://hera.cdmsmith.com/beachfx/default.aspx), the shore protection engineering economic software tool which can be used to perform economic evaluations of federal hurricane and storm damage reduction projects under a risk and uncertainty framework. For more information see the EXPLORE - Beach-fx section of the module.

The strength of this technique is its widespread applicability. Many of the natural and physical systems the USACE deals with are too complex to assess the effects of uncertainty using analytical techniques. These effects can, however, often be assessed by describing input uncertainties and running simulations that sample the inputs to present possible outcomes. This method enables analysts to examine complex situations that are difficult to understand and solve by other means.

Substituting distributions for uncertain point estimates enables USACE analysts to honestly represent the uncertainty in a model and to explore its potential effects on model outputs. Models are relatively simple to develop and they can represent virtually any influences or relationships that arise in reality. The method can accommodate a wide range of distributions in an input variable, including empirical distributions derived from observations of real phenomena. The large amounts of data that can be generated lend themselves readily to sensitivity analysis to identify strong and weak influences on outputs. As noted previously, commercially available software makes it relatively easy to apply this numerical technique to any spreadsheet model.

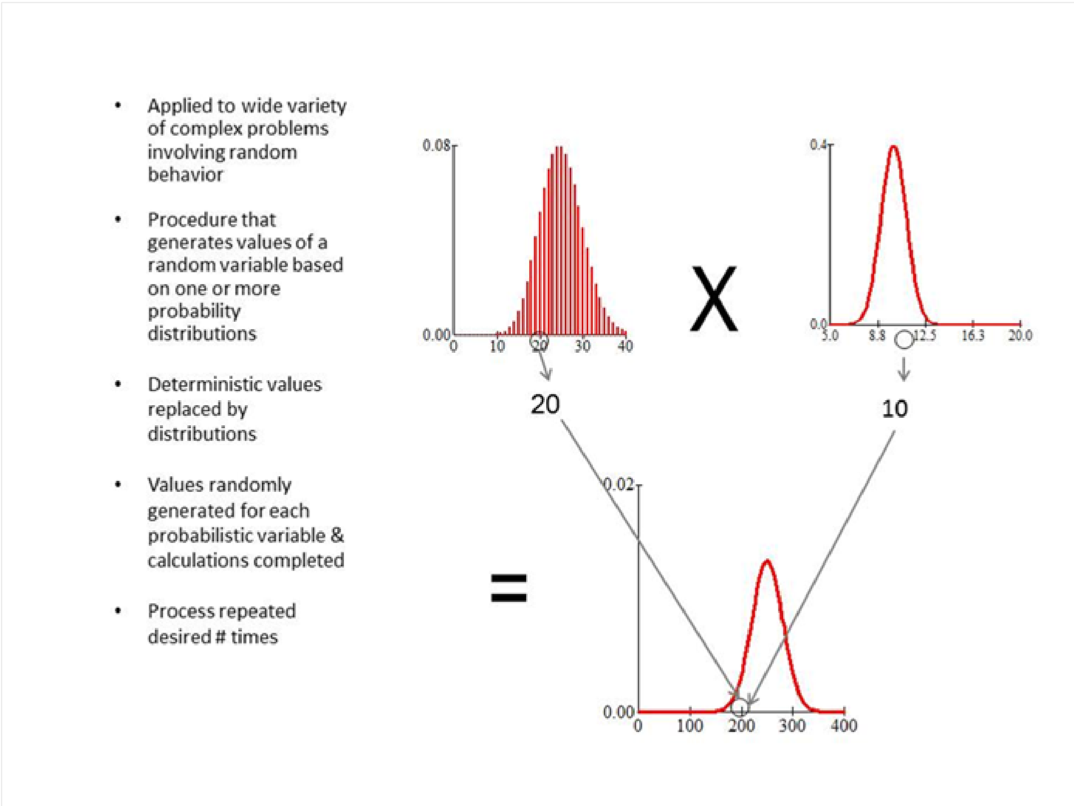

Figure 14. Monte Carlo approaches

The model's limitations include the fact that the solutions are not exact and their usefulness may depend on the number of iterations or simulations completed. It is not a transparent process and using the uncertain numbers represented by distributions makes it difficult for stakeholders to understand.

This technique is already widely used in benefit and cost estimation for USACE. It has great potential for application in program management, budgets and the preparation of estimates of any kind that require working with uncertain values.

Some resources for the Monte Carlo analysis technique, including some USACE applications, include the following:

- Patev, R. (2010). *Monte Carlo simulation using @Risk*. U.S. Army Corps of Engineers Risk Technology Workshop. Retrieved January *13, 2012 from:* Session%209b%20-%20@Risk%20Demo%20-%20Monte%20Carlo%20Simulation.ppt (series).
- U.S. Army Corps of Engineers website for HEC-FDA. Retrieved January 13, 2012 from: http://www.hec.usace.army.mil/software/hec-fda/.

- U.S. Army Corps of Engineers website for Beach-*Fx*. Retrieved January 13, 2012 from: http://www.iwr.usace.army.mil/Missions/Coasts/ToolsandReports.aspx.
- U.S. Environmental Protection Agency (1997). *Guiding principles for Monte Carlo analysis.* Risk Assessment Forum, Washington, DC, EPA/630/R-97/001. Retrieved January 13, 2012 from: http://www.epa.gov/raf/publications/guiding-monte-carlo-analysis.htm.

EXPLORE - MONTE CARLO ANALYSES

Inputs for this method include a clear understanding of the model and its inputs, the sources of uncertainty and the required output(s). Imagine estimating the number of containers off loaded at a port in a month. Clearly this is a variable. It can be calculated simply by multiplying the number of vessels calling at the port by the average number of containers offloaded per vessel. The number of vessels calling at a port will vary naturally with the state of the economy, weather conditions and the like. Suppose the average is known to be 38 and calls have a Poisson distribution as shown on the left of Figure Ex-1. Suppose we have no data about the average number containers offloaded but estimate the average to be between 40 and 65 as seen in the middle distribution. We have a simple multiplication that uses two probability distributions rather than two point estimates. The mathematics of arithmetic with distributions is complex and often has no closed form. Consequently, it is convenient and useful to estimate this model using the Monte Carlo process.

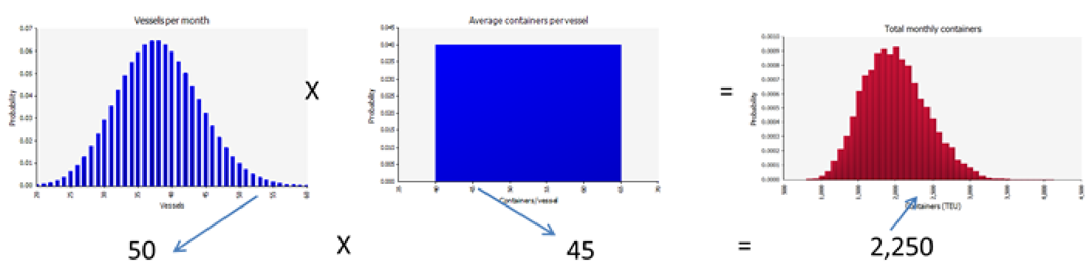

Figure 15. An illustration of the use of the Monte Carlo process

Let random values, 50 and 45, be selected from the two input distributions via the Monte Carlo process. These values are handled according to the structure of the model, in this case a simple multiplication. They yield an estimate of 2,250 containers per month. This is one iteration of the Monte Carlo process. The process is repeated 10,000 times and it yields the distribution on the right which characterizes the uncertainty about how many containers are offloaded in a month. The output distribution reflects the natural variability and knowledge uncertainty in the model.

Chapter 6 - Scenario Analysis

6.0 Scenario Analysis

Of all of the tools that exist, scenario analysis is the primary tool used by the USACE for quantitative risk assessment. At the most basic level, scenarios are the stories told, using numbers, to describe problems, plans and their effects.

Probability is the language of variability and uncertainty and it can be used in scenario analysis through techniques such as those shown in Chapter 1. Probability assessment is the complement to consequence assessment for determining risk. A probability assessment could be used to dismiss a scenario where the probability of occurrence of an event is so small that it would not make sense to analyze it further (as the likelihood of a consequence would be negligible).

When the future is very uncertain, scenarios can be used to describe the most significant possible futures. Scenarios are coherent narratives created to describe uncertain conditions, usually found in the future. Scenario analysis enables assessors to identify a limited number of futures in order to explore how different risks might unfold in the future.

USACE scenarios
Without condition(s)
With conditions
Base year
Existing condition
Failure

Figure 16. USACE scenarios

A scenario is best described in a narrative similar to a newspaper article written about a specific future condition. Once a future or alternative scenario is defined, it can be constructed and analyzed in a wide variety of ways. Scenario analysis is the name given to the development of this broad array of stories about the future, descriptive models and the analysis that can be done with them.[5]

Scenario analysis is used extensively in planning studies and it can be successfully adapted to operations and regulatory functions as well to support policy and other decisions, plan future strategies and courses of action, and consider existing activities. It can be a valuable tool to anticipate how risks of all kinds might develop in the short- and long-term timeframes.

The inputs for scenario analysis include the following:

- A well-defined question to be answered or problem to be examined.
- An interdisciplinary team of people that can identify the appropriate number of scenarios and an appropriate level of detail for each scenario structuring tool (which may be informal or formal).
- Analysts to do the appropriate analysis within each scenario identified.

The outputs of a scenario analysis include the following:

- A discrete number of clearly defined and well-articulated scenario narratives.
- The analyses that are conducted within that scenario.

As an example, the outputs for a hydraulic and hydrologic analysis for a specific location may be conducted for existing conditions (known as a no-change scenario), a scenario with maximum development in the watershed, and a scenario with significant climate change and sea level rise. This would give rise to three sets of analytical results that can be expected to be significantly different from one another.) Each set of analytical results would be comprised of multiple analyses.

There are two primary types of scenario analysis, including the following:

- **Deterministic scenario analysis.**
  This method looks at specific scenarios to identify the range of effects uncertainty can have on decision criteria. Some common scenarios include: best case, worst case, most-likely, locally preferred, non-structural and no action.

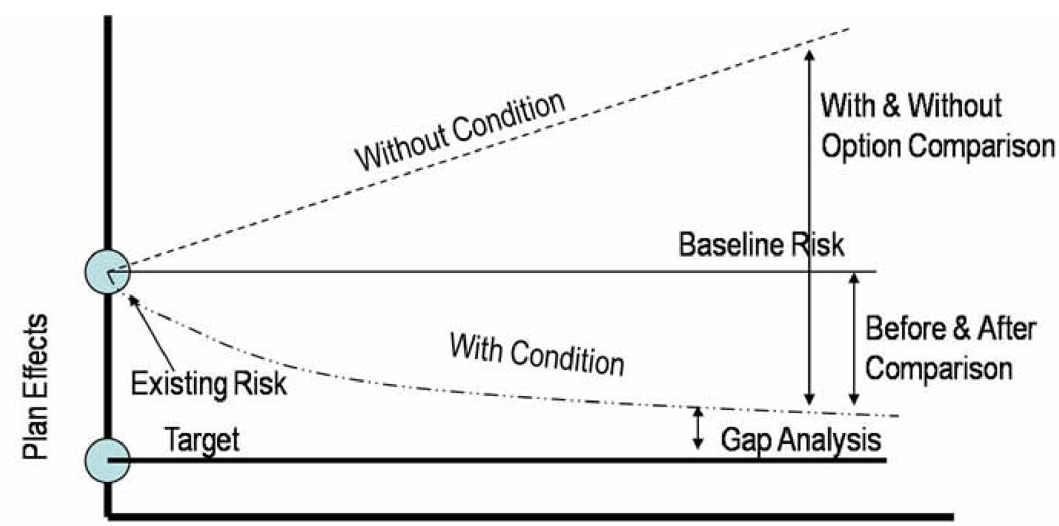

Figure 17. Deterministic scenarios

- **Probabilistic scenario analysis.**
  This is one of the most common and powerful quantitative tool sets. Because of uncertainty and the range of possible responses to it, there are often an infinite number of possible future scenarios. It is not possible to describe them all, but some of them may be important to the decision-making process. This type of analysis focuses on those scenarios that are most likely to affect decisions.

A third type of scenario analysis is the **monolithic scenario** analysis. This method is not usually a recommended process since it relies on the development of a single unchallenged scenario to describe an uncertain situation or future. USACE has used monolithic scenarios in the past to determine the most likely future condition in a planning area without a federal. Unfortunately, a single scenario forces analysts to ignore significant sources of uncertainty, which is why this method is usually not recommended.

Deterministic scenario analysis (DSA) defines and examines a limited number of discrete and specific scenarios. This tends to rely on a small number of possible future states of the system being modeled. Scenario planning relies on the development of a limited number of with- and without-project conditions and is a good example of deterministic scenario analysis.

This approach has limitations. Only a limited number of scenarios can be considered and the likelihoods of these scenarios cannot be estimated with much confidence. This approach is inadequate for describing the full range of potential outcomes. Although it can be very useful for planning and strategic decision making when there are a few very significant sources of uncertainty, it is less useful when there is more uncertainty with a few significant sources or more significant sources of uncertainty.

Probabilistic scenario analysis (PSA) can overcome the limitations of deterministic scenario analysis by combining probabilistic methods. For example, you can combine the Monte Carlo process with a scenario generation method like event tree models. Many of the USACE planning models produced by the Hydrologic Engineering Center could be considered probabilistic scenario analysis tools. These tools are useful for exploring the range of potential outcomes that may be encountered in the future.

Both deterministic and probabilistic scenario analysis take a range of possible futures into account. This is usually going to be preferable to considering a single scenario in an uncertain situation. It is also preferable to the traditional approach of relying on high-medium-low forecasts that assume future events will follow past trends. This is especially important for situations where there is little current knowledge upon which to base predictions (e.g., the effectiveness of large scale aquifer storage and recovery in Florida) or where risks are being considered in the longer-term future (e.g., sea level change). An associated weakness is that some of the scenarios may be unrealistic and unrealistic results may not be recognized as such. The availability of data and the ability of the analysts and decision makers to be able to develop realistic scenarios are the two most common constraints on this method.

Additional resources about scenario analysis include the following:

- U.S. Environmental Protection Agency. (2001) *Chapter 31, Probabilistic risk assessment*. http://www.epa.gov/ttn/fera/data/risk/vol_1/chapter_31.pdf.
- U.S. Environmental Protection Agency. (2001). *Risk assessment guidance for Superfund (RAGS) Volume III -Part A: process for conducting probabilistic risk assessment*. Retrieved January 13, 2012 from: http://www.epa.gov/oswer/riskassessment/rags3adt/.
- Yoe, C. (2010). *Probabilistic scenario analysis*. U.S. Army Corps of Engineers Risk Technology Workshop. Retrieved January 13, 2012 from: /data/docs/ref/Session%207a%20Probabilistic%20Scenario%20Analysis%202010.pdf

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[5] Yoe, Charles. (2012). Principles of risk analysis: decision making under uncertainty. CRC Press: Boca Raton, FL. http://www.crcnetbase.com/doi/pdf/10.1201/b11256-1.

Chapter 7 - Sensitivity Analysis

7.0 Sensitivity Analysis

*Sensitivity analysis i*s 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. This may be done by varying an assumption to see how a point estimate output responds to a change in the assumption by sophisticated analysis of probabilistic outputs, or by any number of methods between these extremes. Some risk assessment outputs and the decisions that rely on them may be sensitive to minor changes in assumptions and input values. When assessment outputs and the decisions that may be made based upon them are sensitive to changes in assumptions, scenarios, models, or any other kind of input, it is critically important to effectively convey that information to risk managers and other decision makers.

Sensitivity analysis provides the point in a risk management activity when attention is focused intentionally on better understanding the things that are not known and their importance for decision making. The results of the sensitivity analysis will provide insight into the importance of different sources of uncertainty.

Sensitivity analysis is sometimes called “what if” analysis. It may be the single best way to increase confidence in the results of a risk assessment or other risk-based analysis. It provides an understanding of how analytical outputs respond to changes in the inputs. Because risk assessments can be qualitative or quantitative, sensitivity analysis can likewise be qualitative or quantitative. To conduct a sensitivity analysis, an initial risk assessment needs to be completed and there needs to be an awareness of the most significant sources of uncertainty. These uncertainties are the avenues that a sensitivity analysis uses.

Qualitative sensitivity analysis is used to identify the sources of uncertainty that exert the most influence on the risk assessment outputs. A basic methodology for qualitative sensitivity analysis includes the following:

- Identifying specific sources of uncertainty.
- Ascertaining the significant sources of uncertainty.
- Qualitatively characterizing the significant uncertainty.

Making assumptions about uncertain values is one of the most common and expedient ways of addressing uncertainty. To the extent that assumptions are used to address uncertainty, one should routinely test the sensitivity of assessment outputs to those assumptions. The simplest way to do this is to first construct a list of the key assumptions of your risk assessment. There are two kinds of assumptions: those we know we make, i.e., explicit assumptions, and those we do not know we are making, i.e., implicit assumptions. Explicit assumptions should be identified and documented. Peer review by multidisciplinary reviewers is often needed to identify implicit assumptions that become embedded in the way that disciplines or organizations function.

There are four classes of quantitative sensitivity analysis tools, including:[6]

- Scenarios
- Mathematical
- Statistical
- Graphical analysis

The purpose of sensitivity analysis is to understand the uncertainties that could influence decisions and to develop appropriate strategies to address those uncertainties.

The strengths of sensitivity analysis include the following:

- It is usually easy to do some of the sensitivity analysis.
- Simple methods can reveal sensitivities that are useful to decision making.
- Commercially developed software and several of the USACE certified planning models support useful sensitivity analysis techniques.

The primary weakness of this approach includes the following:

- It is limited by the assessor's awareness of uncertainty.
- Some of the tools in use are quite sophisticated and require quantitative skills that are not always found on staff.

Resources about sensitivity analysis include the following:

- U.S. Department of Transportation, Office of International Programs. (2013). *Section 4.4: Outputs of risk analysis.* Retrieved January 13, 2012 from: http://international.fhwa.dot.gov/riskassess/risk_hcm06_04.cfm.
- U.S. Environmental Protection Agency. (2001). *Risk assessment guidance for Superfund (RAGS) Volume III -Part A, Appendix A: Sensitivity analysis: How do we know what's important?* Retrieved January 13, 2012 from: https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part.
- World Health Organization. International Programme on Chemical Safety. (2006). *Draft guidance document on characterizing and communicating uncertainty of exposure assessment, draft for public review.* Geneva: World Health Organization. Accessed January 14, 2013 from: http://www.who.int/ipcs/methods/harmonization/areas/draftundertainty.pdf.

[6] Ibid.

Chapter 8 - Example Demonstrations

8.0 Example Demonstrations

The following videos provide some examples using the methods discussed in this module, including using a combination of methods.

- Description of an event tree and its features using Palisades Corporation Precision Tree (http://www.palisade.com/precisiontree/) add-in tool for Microsoft Excel. PSA part I
- The event tree and its use in the analysis of probabilities and consequences. PSA part II
- Event tree enhanced with a probabilistic Monte Carlo analysis using Palisades Corporation @Risk (http://www.palisade.com/risk/) add-in tool for Microsoft Excel. PSA part III

Chapter 9 - Summary

9.0 SUMMARY

This concludes the discussion on quantitative methods for risk assessment. There are a wide variety of quantitative approaches that can be tailored and utilized for an identified risk problem.

Oftentimes, risk assessment uses a combination of analysis tools, sometimes a combination of both qualitative and quantitative methods. The choice of the quantitative assessment method depends on the questions to be answered by the assessment, 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. Sometimes risk analyses use a combination of tools, thus these methods may not necessarily be mutually exclusive.

In this module you have learned that:

1. Quantitative risk assessment can be deterministic or probabilistic.
2. There are a large and growing number of quantitative tools available to aid the assessment of risk, including some developed by the USACE and some that are commercial off-the-shelf tools.
3. Not all of the quantitative tools perform complete risk assessments; many of them have specialized and narrowly focused uses.
4. Probabilistic scenario analysis tools are a bundle of quantitative risk assessment tools that combine the power tools such as the Monte Carlo process with the utility of scenario-creating techniques like event and fault trees to support probabilistic risk assessment.
5. The best quantitative risk assessment methods include sensitivity analysis or some other means of addressing the significance of uncertainty on the assessment results.

Chapter 10 - Resources

10.0 Resources

Risk Assessment

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Chapter 11 - Self-Assessment

11.0 Self-Assessment

1. Quantitative risk assessments can only be probabilistic assessments, i.e., 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. T/F
2. The *IWR Planning Suite MCDA Module* allows the comparison of alternatives according to weighted criteria, and supports conducting multi-criteria decision analysis and exploring multiple dimensions of a planning decision. T/F
3. An event tree can be either a qualitative or quantitative analytical technique for modeling a system or sequence of events. T/F
4. A multi-criteria decision analysis (MCDA) approach can only be used with quantitative data. T/F
5. A Monte Carlo process is a qualitative technique that randomly assigns probabilities of risks. T/F
6. A sensitivity analysis can only be conducted with quantitative data. T/F
7. @Risk is a tool for conducing qualitative risk analysis. T/F

11.0 Self-Assessment - Answers

1. Quantitative risk assessments can only be probabilistic assessments, i.e., 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. T/F

   False. **CORRECT**. Quantitative assessment can be deterministic or probabilistic. 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, nonstructural, 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.

2. The *IWR Planning Suite MCDA Module* allows the comparison of alternatives according to weighted criteria, and supports conducting multi-criteria decision analysis and exploring multiple dimensions of a planning decision. T/F

   True. **CORRECT**

3. An event tree can be either a qualitative or quantitative analytical technique for modeling a system or sequence of events. T/F

   True. **CORRECT**

4. A multi-criteria decision analysis (MCDA) approach can only be used with quantitative data. T/F

   False. **CORRECT**. 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.

5. A Monte Carlo process is a qualitative technique that randomly assigns probabilities of risks. T/F

   False. **CORRECT**. 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.

6. A sensitivity analysis can only be conducted with quantitative data. T/F

   False. **CORRECT**. Because risk assessments can be qualitative or quantitative, sensitivity analysis can likewise be qualitative or quantitative. To conduct a sensitivity analysis, an initial risk assessment needs to be completed and there needs to be an awareness of the most significant sources of uncertainty. These uncertainties provide the avenues to investigate the sensitivity analysis. Qualitative sensitivity analysis is used to identify the sources of uncertainty that exert the most influence on the risk assessment outputs.

7. @Risk is a tool for conducing qualitative risk analysis. T/F

   False. **CORRECT**. "@RISK (pronounced "at risk") performs risk analysis (http://www.palisade.com/risk/risk_analysis.asp) using Monte Carlo simulation (http://www.palisade.com/risk/monte_carlo_simulation.asp) to show many possible outcomes in your spreadsheet model, and tells you how likely they are to occur. It mathematically and objectively computes and tracks many different possible future scenarios, then tells you the probabilities and risks associated with each different one. This means you can judge which risks to take and which ones to avoid, allowing for the best decision making under uncertainty."[7]

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[7] Palisade. (2013). @Risk: The future in your spreadsheet. Retrieved July 13, 2013 from: http://www.palisade.com/risk/