Risk-based Decision-making Guidelines

Volume 2
Introduction to Risk-based Decision Making

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Volume 2
Introduction to Risk-based Decision Making

Basic Principles

Chapter 1 — Principles of Risk-based Decision Making

Chapter Contents

This chapter provides a basic introduction to risk-based decision making. Following are the major topics addressed in this chapter:

Risk-based Decision Making

A process that organizes information about the possibility for one or more unwanted outcomes into a broad, orderly structure that helps decision makers make more informed management choices

1.0 Definition of Risk-based Decision Making

The best place to begin this *Introduction to Risk-based Decision Making* is with the definition of risk-based decision making.

A process ...

Risk-based decision making involves a series of basic steps. It can add value to almost any situation, especially when the possibility exists for serious or catastrophic outcomes. The steps can be used at different levels of detail and with varying degrees of formality, depending on the situation. The *key* to using the process is in completing each step in the most *simple, practical way* to provide the information the decision maker needs. Some situations are so complex that detailed risk assessments are needed, but most can be addressed with more simple risk assessments.

... that organizes information about the possibility for one or more unwanted outcomes ...

This information about the possibility for one or more unwanted outcomes separates risk-based decision making from more traditional decision making. The consideration of possible losses for any set of stakeholders is unique to risk-based decision making. These losses can include such things as harmful effects on safety and health, the environment, property loss, or mission success. The risks for an engineered system or activity are determined by the types of possible losses, the frequency at which they are expected to occur, and the effects they might have. Although not certain, these possible losses present real risks that must be considered in most decision-making processes.

… into a broad, orderly structure …

Most decisions require information not only about risk, but about other things as well. This additional information can include such things as cost, schedule requirements, and public perception. In risk-based decision making, all of the identifiable factors that affect a decision must be considered. The factors may have different levels of importance in the final decision. Therefore, an orderly decision analysis structure that considers more than just risk is necessary to give decision makers the information needed to make smart choices.

… that helps decision makers …

The only purpose of risk-based decision making is to provide enough information to help someone make a more informed decision. The process focuses on organizing information for logical understanding. It does not replace the decision maker. Neither should it force the decision maker into burdensome risk assessments to gather information that is either irrelevant to the decision or too late to affect it.

… make more informed management choices

The goal of risk-based decision making is to help people make better, more logical choices without complicating their work or taking away their authority. A *good* decision made quickly is much better than a *perfect* decision made too late. Also, a *good* decision does not always result in a *good* outcome. The best we can hope for is to equip intelligent decision makers with good information based on a number of decision factors and the interests of stakeholders. On average, and over time, *good* decisions made through this process should provide the best outcomes. They will also provide logical explanations for decisions when the outcomes are not favorable.

Do you need risk-based decision making?

2.0 Do You Need Risk-based Decision Making?

We make hundreds of risk-based decisions every day:

- Should I change lanes on the interstate?
- How often should I change the oil in my car?
- What can I do to lower my risk of cancer?
- Can I put off this task until later without affecting my project?

For almost every decision, there is a chance for some unwanted outcome. We include this possibility in our decisions, along with the consequences of the unwanted outcomes and the effort that would be needed to make the unwanted outcomes less likely or less severe.

2.1 Informal risk-based decision making

For most of our decisions, we do not formally assess the likelihood and consequences of possible unfortunate outcomes. For example, we do not study traffic statistics before changing lanes. Instead, we rely on our *feel* for the situation to create a level of comfort. If we are uncomfortable, we look for ways to change the situation to make ourselves more comfortable with the risks. For these types of decisions, the risk-based decision-making process takes place within seconds and becomes second nature.

2.2 Formal risk-based decision making

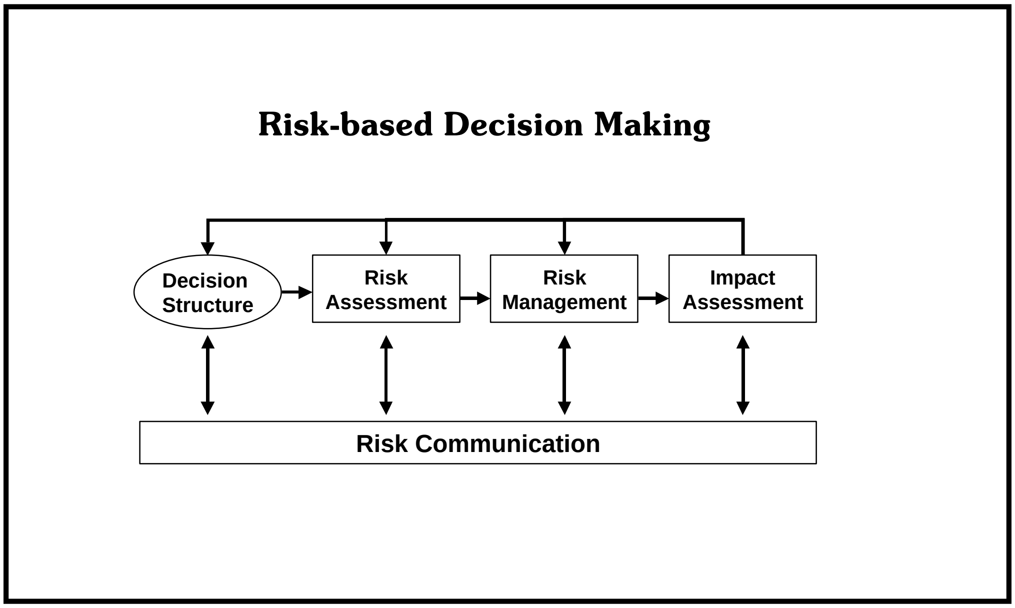
For some decisions, we are more formal about assessing the frequencies and consequences of possible unwanted outcomes. For example, when we decide how to provide for our families in case we are injured or killed, we rate a number of factors, including the following:

- The possible losses we face (from short-term disabilities to death)
- The chances of those losses
- The economic consequences of those losses
- The ways in which we can protect against the effects of the losses; for example, we can buy insurance
- The acceptability of the risks and impacts of the protections; for example, can we afford the insurance or are we willing to give up certain extras?

For these types of decisions, the risk-based decision-making process is more structured and more defensible, but it takes more time.

2.3 To use or not to use

The question is not, "Should I use risk-based decision making in the marine industry?" The question is, "How can I use risk-based decision making most effectively for my needs?" These *Guidelines* present several tools used in risk-based decision making so that you can choose the most useful approach for you. Your emphasis should always be on using the most suitable tools for the situation, not just on following one approach. It is, however, important to follow some standard procedures and techniques for (1) improving the efficiency of your efforts, (2) ensuring that your approach is technically sound, and (3) gaining acceptance of your work from others.



3.0 The Risk-based Decision-making Process

Regardless of how formally you address risk-based decision making or the specific tools you use, risk-based decision making is made up of five major components, which are shown in the figure above.

Components of risk-based decision making

The following sections introduce the five components of risk-based decision making.

Step 1 — Establish the decision structure

Understanding and defining the decision that must be made is critical. This first component of risk-based decision making is often overlooked and deserves more discussion. The following steps must be performed to accomplish this critical component:

Step 1a — Define the decision. Specifically describe what decision(s) must be made. Major categories of decisions include (1) accepting or rejecting a proposed facility or operation, (2) determining who and what to inspect, and (3) determining how to best improve a facility or operation.

Step 1b — Determine who needs to be involved in the decision. Identify and solicit involvement from key stakeholders who (1) should be involved in making the decision or (2) will be affected by actions resulting from the decision-making process.

Step 1c — Identify the options available to the decision maker. Describe the choices available to the decision maker. This will help focus efforts only on issues likely to influence the choice among credible alternatives.

Step 1d — Identify the factors that will influence the decisions (including risk factors). Few decisions are based on only one factor. Most require consideration of many factors, including costs, schedules, risks, etc., at the same time. The stakeholders must identify the relevant decision factors.

Step 1e — Gather information about the factors that influence stakeholders. Perform specific analyses (e.g., risk assessments and cost studies) to measure against the decision factors.

Chapter 5 of this *Introduction to Risk-based Decision Making* provides an overview of common decision analysis tools to help you structure your overall decision-making process.

Step 2 — Perform the risk assessment

Different types of risk are important factors in many types of decisions. Very simply, risk assessment is the process of understanding the following:

- What bad things can happen
- How likely they are to happen
- How severe the effects may be

The bad things of interest can be safety and health losses, property losses, environmental losses, schedule impacts, political issues, etc.

Risk assessment can range from very simple, personal judgments by individuals to very complex assessments by expert teams using a broad set of tools and information, including historical loss data. The key to risk assessment is choosing the right approach to provide the needed information without overworking the problem. The following steps must be performed to assess risk:

Step 2a — Establish the risk-related questions that need answers. Decide what questions, if answered, would provide the risk insights needed by the decision maker.

Step 2b — Determine the risk-related information needed to answer the questions. Describe the information necessary to answer each question posed in the previous step. For each information item, specify the following:

- Information type needed
- Precision required
- Certainty required
- Analysis resources (staff-hours, costs, etc.) available

Step 2c — Select the risk analysis tool(s). Select the risk analysis tool(s) that will most efficiently develop the required risk-related information.

Step 2d — Establish the scope for the analysis tool(s). Set any appropriate physical or analytical boundaries for the analysis.

Step 2e — Generate risk-based information using the analysis tool(s). Apply the selected risk analysis tool(s). This may require the use of more than one analysis tool and may involve some iterative analysis (i.e., starting with a general, low-detail analysis and progressing toward a more specific, high-detail analysis).

Chapter 2 of this *Introduction to Risk-based Decision Making* explores the topic of risk assessment in more detail.

Chapter 6 provides an overview of many of the most common risk assessment tools for marine applications.

Step 3 — Apply the results to risk management decision making

One goal in most decision-making processes is to lower risk as much as possible. Sometimes the risk will be acceptable; at other times, the risk must change to become acceptable. To reduce risk, action must be taken to manage it. These actions must provide more benefit than they cost. They must also be acceptable to stakeholders and not cause other significant risks. The following steps must be performed to manage risk:

Step 3a — Assess the possible risk management options. Determine how the risks can be managed most effectively. This decision can include (1) accepting/rejecting the risk or (2) finding specific ways to reduce the risk.

Step 3b — Use risk-based information in decision making. Use the risk-related information within the overall decision framework to make an informed, rational decision. This final decision-making step often involves significant communication with a broad set of stakeholders.

Chapter 3 of this *Introduction to Risk-based Decision Making* explores the topic of risk management in more detail.

Step 4 — Monitor effectiveness through impact assessment

Impact assessment is the process of tracking the effectiveness of actions taken to manage risk. The goal is to verify that the organization is getting the expected results from its risk management decisions. If not, a new decision-making process must be considered.

Step 5 — Facilitate risk communication

Risk communication is a two-way process that must take place during risk-based decision making. At every step in the process, encourage stakeholders to do the following:

Provide guidance on key issues to consider. Stakeholders identify the issues of importance to them. They present their views on how each step of the process should be performed, or at least provide comments on plans suggested by others.

Provide relevant information needed for assessments. Some or all of the stakeholders may have key information needed in the decision-making process.

Provide buy-in for the final decisions. Stakeholders should agree on the work to be done in each phase of the risk-based decision-making process. They can then support the ultimate decisions.

Chapter 4 of this *Introduction to Risk-based Decision Making* explores the topic of risk communication in more detail.

Example application of the risk-based decision making process

The following table illustrates how each of the five steps of the decision-making process were addressed for a specific application at an MSO.

Approving Reduced Lifesaving Requirements for Passenger Vessels with an MSO

Step 1: Establish the Decision Structure

Step 1a: Define the decision	
Description: Specifically describe what decision(s) must be made. Major categories of decisions include (1) accepting or rejecting a proposed facility or operation, (2) determining who and what to inspect, and (3) determining how to best improve a facility or operation.	**Example Result:** Changes in the Code of Federal Regulations (CFRs) have increased lifesaving capacity requirements for small passenger vessels operating in both cold and warm water. In addition, changes in how the Coast Guard designates cold-water operations will cause a number of small passenger vessels operating in the MSO's AOR to comply with cold-water lifesaving requirements (which are more demanding than requirements for warm-water operations). These upgrades are likely to be expensive for many vessels and may result in reduced passenger capacity (or other operational restrictions), which could have negative economic effects on the industry. For operations in bays, lakes, sounds, and rivers, the CFRs allow the Officer in Charge of Marine Inspections (OCMI) some discretion in the enforcement of the new requirements. The OCMI wanted to determine under what conditions should waivers be considered.
Step 1b: Determine who needs to be involved in the decision	
Description: Identify and solicit involvement from key stakeholders who (1) should be involved in making the decision or (2) will be affected by actions resulting from the decision-making process.	**Example Result:** The unit chose to involve only USCG personnel in the demonstration workshop. Ordinarily, the team would have involved the owners/operators in developing the decision framework and any vessel analysis.
Step 1c: Identify the options available to the decision maker	
Description: Describe the choices available to the decision maker. This will help focus efforts only on issues likely to influence the choice among credible alternatives.	**Example Result:** The unit decided that the following options were available to the decision maker for each vessel: • Do not grant a waiver, forcing strict regulatory compliance • Help the vessel find operational changes to achieve compliance without changing lifesaving equipment • Under acceptable conditions, allow a vessel to comply with the warm-water lifesaving requirements instead of the cold-water requirements

Step 1: Establish the Decision Structure (continued)	
Step 1d: Identify the factors that will influence the decision (including risk factors)	
Description: Few decisions are based on only one factor. Most require consideration of many factors, including costs, schedules, risks, etc., at the same time. The stakeholders must identify the relevant decision factors.	**Example Result:** The management team identified the following decision factors: • Waivers can only be granted if the operator implements the 15-minute communication protocol specified in the CFRs (or if the vessel participates in a vessel traffic service [VTS]) • Factors that (1) minimize the number of people exposed to loss, (2) reduce the likelihood of initiating events that require the use of lifesaving equipment, and/or (3) increase the likelihood of quickly rescuing people from the water (before hypothermia occurs) could justify allowing a vessel to comply with warm-water requirements instead of cold-water requirements. (The team actually used a simple, informal event tree model during the RBDM workshop to explore these factors.) • Certain types of vessels and services should not be eligible for waivers because of the generally recognized risks
Step 1e: Gather information about the factors that influence stakeholders	
Description: Perform specific analyses (e.g., risk assessments and cost studies) to measure against the decision factors.	**Example Result:** The unit decided to perform risk analysis for each vessel's unique configuration/operation to evaluate the risks associated with a possible waiver.

<table>
<tr><th colspan="2">Step 2: Perform the Risk Assessment</th></tr>
<tr><td colspan="2">Step 2a: Establish the risk-related questions that need answers</td></tr>
<tr><td>Description:

Decide what questions, if answered, would provide the risk insights needed by the decision maker.</td><td>Example Result:

The unit decided that the basic risk-related question was as follows: "What combination of vessel and operational characteristics poses sufficiently low risk to justify allowing compliance with warm-water lifesaving requirements instead of applicable cold-water requirements?"</td></tr>
<tr><td colspan="2">Step 2b: Determine the risk-related information needed to answer the questions</td></tr>
<tr><td>Description:

Describe the information necessary to answer each question posed in the previous step. For each information item, specify the following:
• Information type needed
• Precision required
• Certainty required
• Analysis resources (staff-hours, costs, etc.) available</td><td>Example Result:

<u>Information Type Needed</u>
An index value that represents accumulated risk credits for vessel and operational characteristics that lower the risk of losses requiring deployment of lifesaving devices

<u>Precision Required</u>
The index number does not have to be highly precise (e.g., integer values), but the risk factors considered must be defined very specifically

<u>Certainty Required</u>
The RBDM team needs to have high confidence that high index scores reflect a sufficient number of risk credits to warrant consideration of a waiver

<u>Analysis Resources Available</u>
Application of the risk-scoring process to a particular vessel must be very efficient (e.g., requiring only minutes to hours to apply) and must not require a risk analysis expert. However, the unit was willing to spend a couple of days developing a risk analysis job aid.</td></tr>
<tr><td colspan="2">Step 2c: Select the risk analysis tool(s)</td></tr>
<tr><td>Description:

Select the risk analysis tool(s) that will most efficiently develop the required risk-related information.</td><td>Example Result:

Based on the decision-making situation and the type of information needed, the unit decided to create a simple relative ranking/risk indexing tool (as described in Volume 3, Chapter 5 of the Guidelines). The team also used event tree analysis to help ensure that the right risk factors were built into the index tool. (A copy of the index tool is provided at the end of Volume 3, Chapter 5 of the Guidelines.) The team determined that the following actions should be taken for certain risk index values:
• Less than 0: Do not consider a waiver
• 0 or greater: Consider a waiver</td></tr>
</table>

Step 2: Perform the Risk Assessment (continued)	
Step 2d: Establish the scope for the analysis tool(s)	
Description: Set any appropriate physical or analytical boundaries for the analysis.	**Example Result:** The unit focused only on vessels that either (1) have an acceptable 15-minute radio communication plan with an operations base or (2) participate in a VTS. The unit's analysis considered only the risk factors that the team explicitly built into the risk index tool (i.e., no other brainstorming was performed). In addition, the unit did not apply the tool to wood boats, high-speed craft, vessels with no subdivision, or vessels with no stability letter because the decisions for these vessels would not be affected by the risk scores. The unit had already determined that waivers would not be considered for these vessels.
Step 2e: Generate risk-based information using the analysis tool(s)	
Description: Apply the selected risk analysis tool(s). This may require the use of more than one analysis tool and may involve some iterative analysis (i.e., starting with a general, low-detail analysis and progressing toward a more specific, high-detail analysis).	**Example Result:** First, the unit applied the risk index tool to a number of test case vessels to ensure that the tool was "tuned" properly. The unit compared the resulting decisions to its own subjective priorities assigned from experience. Based on these tests, the unit made some revisions to the index tool. This reality check helped validate the tool before it is used in actual RBDM applications for vessels. Then, the unit began applying the risk indexing tool for specific vessels requesting waivers. The unit uses the results to help make risk management decisions for each vessel. Vessel owners/operators (or their representatives) are directly involved with unit personnel in this process.

<table>
<tr><th colspan="2">Step 3: Apply the Results to Risk Management Decision Making</th></tr>
<tr><td colspan="2">Step 3a: Assess possible risk management options</td></tr>
<tr><td>Description:

Determine how the risks can be managed most effectively. This decision can include (1) accepting/rejecting the risk or (2) finding specific ways to reduce the risk.</td><td>Example Result:

For each vessel, the unit looks for simple vessel configuration or operational changes that either (1) make waivers unnecessary or (2) improve the level of risk credits that a vessel receives.

Once improvement options have been fully considered, the team uses the final risk index value to help make a decision about waivers.</td></tr>
<tr><td colspan="2">Step 3b: Use risk-based information in decision making</td></tr>
<tr><td>Description:

Use the risk-related information within the overall decision framework to make an informed, rational decision. This final decision-making step often involves significant communication with a broad set of stakeholders.</td><td>Example Result:

The index score strongly influences the decision as described previously, but the ultimate decision to issue a waiver rests solely with the OCMI.</td></tr>
<tr><th colspan="2">Step 4: Monitor Effectiveness Through Impact Assessment</th></tr>
<tr><td>Description:

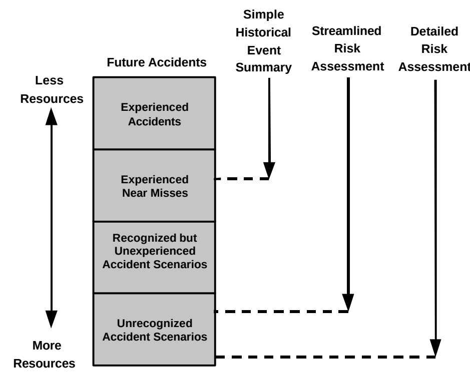
Track the effectiveness of actions taken to manage risks. The goal is to verify that the organization is getting the expected results from its risk management decisions. If not, a new decision-making process must be considered.</td><td>Example Result:

The unit is monitoring the long-term results of decisions made using this RBDM process. If (1) issues arise that were not predicted by the index tool or (2) other exclusions from the use of the tool become evident, the unit will revisit the RBDM process and make appropriate improvements.</td></tr>
<tr><th colspan="2">All Steps: Facilitate Risk Communication</th></tr>
<tr><td>Description:

Encourage two-way, open communication among all stakeholders so that they will:
• Provide guidance on key issues to consider
• Provide relevant information needed for assessments
• Provide buy-in for the final decisions</td><td>Example Result:

The unit directly involved the important stakeholders within the USCG in the process. Outside of the demonstration project, the vessel owners/operators would have been involved at various stages of the RBDM process through the following:
• An initial kickoff meeting to gather ideas, discuss issues, and solicit other input
• A review meeting to present a draft of the USCG's RBDM framework and index tools and to solicit comments
• Widespread distribution of the final RBDM framework and index tools before actual use
• Owner/operator participation in individual vessel reviews</td></tr>
</table>

Dealing with Information Precision, Uncertainty, and Resource Needs



4.0 Dealing with Information Precision, Uncertainty, and Resource Needs

Information needed for decision making is characterized by its precision and certainty. The level of precision and certainty is balanced by our willingness to expend resources to obtain it. Generally, highly precise, highly certain information is very expensive to obtain.

To make risk-based decisions, the decision maker must understand how future accidents can occur. For example, information on historical performance may be available, but the decision maker believes that this information does not adequately predict the existence of other potential accidents. Therefore, the decision maker commissions a risk assessment to provide more certain information about future accidents. As expected, additional resources were expended to obtain this more certain information. As more certain, more precise information is required to predict future performance, more resources are required to obtain it.

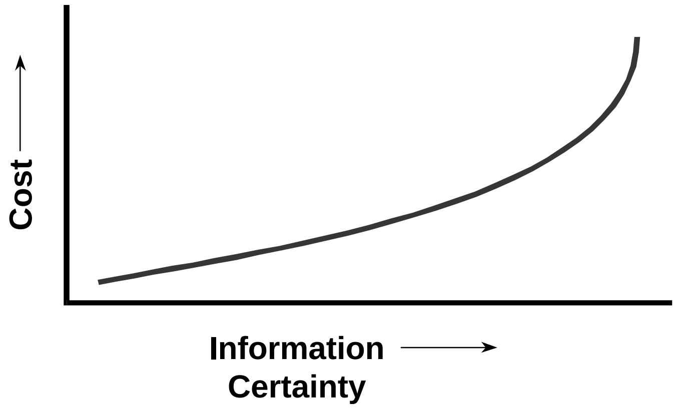
4.1 Dealing with information precision

The precision of information is characterized by its level of detail. For example, a person can be from the United States, Texas, or Dallas. Likewise, a number can be described by the number of places following the decimal point. The more precise the information, the more detail is inherent in it.

The decision maker must understand the precision required to make a decision. If knowing that a person is from Texas is sufficient to make a decision, there is no need to expend resources to determine which city in Texas the person is from. Likewise, if numerical information to one decimal place is precise enough to make a decision, information precise to three decimal places will not affect it.

4.2 Dealing with information uncertainty

In any decision-making process, there is constant struggle between the need for more and better information and the practicality of improving the information. This is illustrated by the simple figure below.



Even when a lot of information is collected, a great deal of uncertainty remains. So the decision makers and information suppliers must work together to make sure that the cost of collecting more accurate data does not outweigh the benefits of having it. This is why analysts should never use very complex risk assessment tools without first trying to meet decision-making needs with simpler tools.

Dealing with uncertainty is part of any decision-making process. Therefore, those taking part in decision making, either directly or indirectly, must be aware of the most likely sources of uncertainty: model uncertainty and data uncertainty.

Model uncertainty

The models used in both the general decision-making structure and in detailed risk assessments will never be perfect. The detail in a model and scope boundaries will determine how well the model reflects reality. Even if the data are perfect, the model usually brings some doubt into the results.

For example, Phil was asked to describe what factors would influence his choice of a new car. If Phil cannot describe all of the factors that influence his choice, then these factors will not appear in his decision model.

More detailed levels of risk analysis can reduce model uncertainty by more thoroughly accounting for potentially important loss sequences. However, more thorough analysis also costs more.

The simplest risk assessments are historical event summaries and account only for known accidents, and possibly some near misses, that have occurred during some reporting period. Streamlined risk assessments require more resources, but they also account for more near misses, as well as other recognized accident scenarios that did not occur. More detailed risk assessments require even more resources, but they systematically identify and account for previously unrecognized accident scenarios.

Data uncertainty

Data uncertainty causes much concern during decision making. Data uncertainty arises from any or all of the following:

- The needed data do not exist
- The analysts do not know where to collect the data, or they do not have the staff, funds, or time to collect it
- The quality of the data is questionable, usually because of the methods used to gather it
- The data vary widely, making their use complex

Although steps can be taken to reduce uncertainty in data, all data have some uncertainty. This uncertainty cannot be ignored. Following are methods available for dealing with data uncertainty:

Subjectively characterize uncertainty (for example, as high or low). A simple approach in which doubt in the final answer is estimated based on personal experience or belief.

Perform calculations using best-case and worst-case situations. An approach that uses different calculations for best-case and worst-case conditions to reflect the range of possible outcomes.

Analyze a number of possible situations (i.e., what-if scenarios). An expanded version of the previous approach that involves calculations for many other sets of conditions, usually including an estimate of how likely each set is to occur.

Decrease the precision requirements. Using broader ranges when categorizing the frequency and consequence of accidents increases the certainty in the selection.

Perform calculations using probability distributions in place of discrete estimates. A more complicated approach that uses statistics to describe data used in a model so that statistical descriptions of the expected outcomes can be formed.

Choose a simple method first for dealing with uncertainty. If decision makers need better estimates, the uncertainty can be reduced for the issues that most affect the model.

4.3 Dealing with resource needs

The objective is to use the minimum resources necessary to develop the required information. One effective means of minimizing resources involves starting with the lowest-cost approach that can possibly provide needed information with the required precision and certainty. This strategy most often relies on "streamlined" forms of traditional risk assessment tools. For example, before requesting any detailed modeling, the decision maker might contact one or more system experts and simply ask their perception of the answer to the risk-based question. Based on their experience, the experts may be able to provide the needed results with adequate precision and certainty. The need for more detailed analysis is therefore avoided. Be ready to commission more detailed risk assessments, though, if results from the less detailed approaches are not suitable for making a decision.

Risk-based Decision vs.
"It's always been done this way"

5.0 Barriers to Risk-based Decision Making

A common barrier to risk-based decision making is the perception that mounds of highly precise, technical data are required before a decision can be made. Overcome this perceived barrier by trying to develop the data from information that is already at hand. Even though the precision and certainty of this data may not be high, they may be high enough for the decision maker. When more detailed data are required, then you know that you have at least tried to develop the required decision-making information from what was immediately available to you using the minimum resources.

Another common barrier to risk-based decision making is the perception that the risk assessment part of the process takes far too much time. There is no question that more time is required for complicated decisions that use information developed from highly precise and certain data. However, risk-based decisions are often not this complicated. Do existing risk-based decision-making tools like checklists and risk indexes work? These tools take very little time, but they often end up providing the information needed to make the decision.

One impediment to risk-based decision making is found in the culture of "it's always been done this way." Challenge this thinking. Why has it always been done this way? Do regulations REQUIRE this decision to be made this way, or is this simply a convenient interpretation of a flexible rule?

Sometimes the prescriptive requirements that appear to be inflexible can be changed. Use the risk-based decision-making process to help change prescriptive requirements that do not effectively manage important risks.

Risk-based decision making is for everyone. An inexperienced person given basic training in the use of a well-developed risk-based checklist will make good risk-based decisions. Tear down barriers that cause people to believe risk-based decision making is only for the most experienced. Use the experienced people to help develop information for complex decisions and to create new risk-based decision-making tools. No one should perceive experience as a barrier to risk-based decision making.

RISK-BASED DECISION-MAKING GUIDELINES

Volume 2
Introduction to Risk-based Decision Making

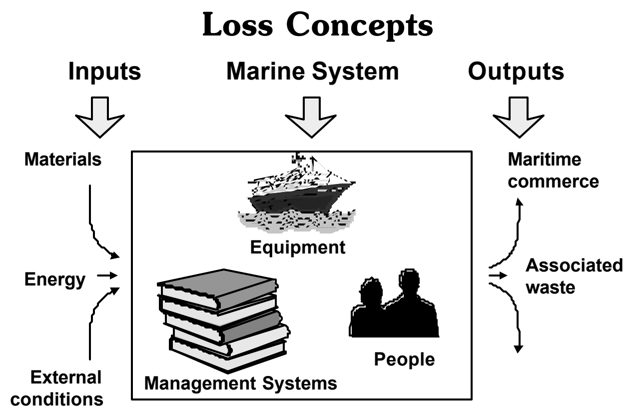
Basic Principles

Chapter 2 — Principles of Risk Assessment

Chapter Contents

This chapter provides an overview of basic risk assessment principles that play a key role in the risk-based decision-making process. This chapter is divided into six main topic areas:

Chapter Contents (cont.)



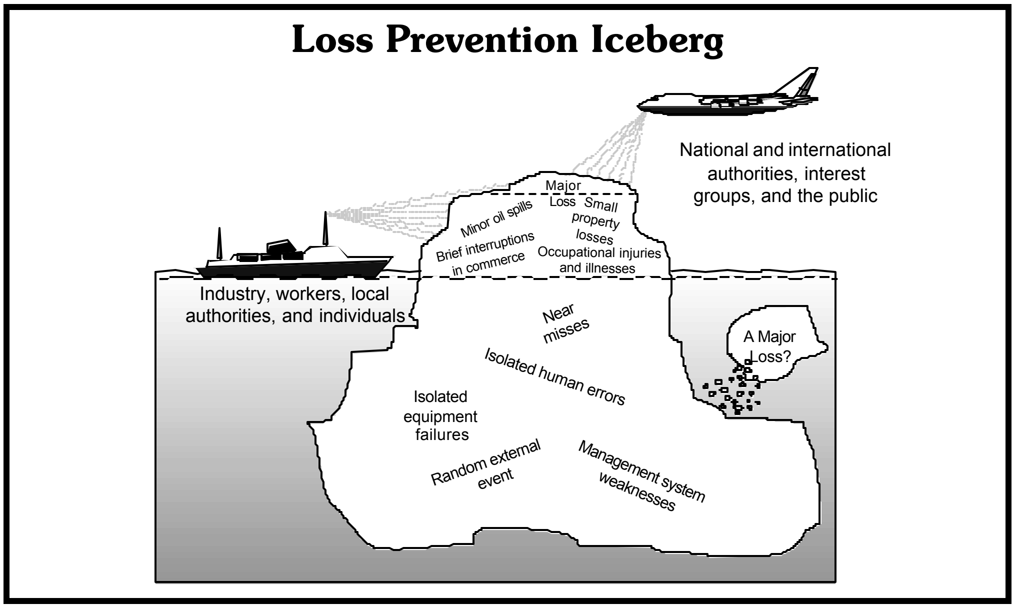
1.0 Loss Prevention Basics

Before you can learn to perform risk assessments, you need to understand how marine casualties occur and how they can be prevented.

What is a marine casualty?

A marine casualty is any event associated with a marine system (vessel, terminal, port, offshore platform, etc.) that leads to adverse effects on mariners, the public, property, commerce, or the environment. Marine casualties have the following characteristics:

- They are unplanned
- They involve human errors, equipment failures, or external events
- They have an impact on the economy, safety and health, or the environment
- They generally have underlying root causes that create error-likely situations for people and conditions leading to equipment failure
- They are frequently preceded by related events that can be detected and corrected
- They will always be possible, but can be effectively managed



1.1 Loss prevention iceberg

The loss prevention iceberg is an effective model for understanding marine casualties. The following sections describe how different groups view the events that make up the iceberg.

Iceberg structure

Top. The top of the iceberg is a small but critical area representing major losses. Major marine casualties are usually caused by many of the same problems that cause less severe, but more frequent, day-to-day problems.

Visible remainder. The visible remainder above the water is a significant area representing the day-to-day marine casualties that produce safety, environmental, or economic losses.

Shallow submerged. The shallow submerged area represents abnormal events that almost resulted in losses. Generally, these near misses largely outnumber actual day-to-day marine casualties and can be considered prior events leading to actual losses.

Deeper submerged. The deeper submerged area represents the many human errors, equipment failures, and external events that cause marine casualties and near misses.

Bottom. The bottom of the iceberg represents the underlying management system weaknesses that create the following:

- Error-likely situations for people
- Conditions leading to equipment failures
- Inadequate protections against external events

Different views of loss prevention

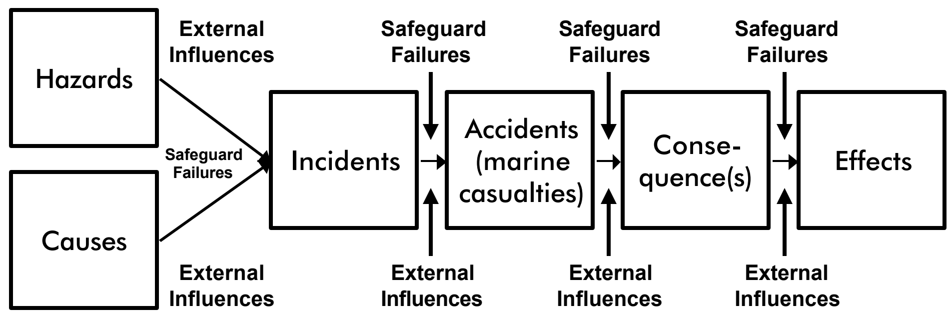
People see parts of the loss prevention iceberg differently.

- **National and international authorities, interest groups, and the public.** These people focus on the top of the iceberg to avoid major marine casualties, or large numbers of less severe casualties, that threaten the organization or lead to significant negative publicity. They leave less severe marine casualties and loss prevention management to others.
- **Industry, workers, local authorities, and individuals.** These people focus on the visible remainder of the iceberg to reduce routine marine casualties that impact productivity and cause management headaches. They pay attention to events that almost cause casualties (i.e., near misses), although they usually have trouble seeing these events. They have difficulty finding the time and resources to investigate and prevent the underlying problems.

Buoyancy principle as a guide for loss prevention

- Removing large portions of the iceberg above the water causes the iceberg to rise. Addressing only the visible events helps reduce the size of the iceberg, but it will rise and make other events (actual marine casualties) visible.
- Removing portions of the iceberg below the water causes the iceberg to sink. Addressing the underlying problems helps reduce the size of the iceberg and the number of visible events (actual marine casualties) above the water.

Remember, we cannot get rid of the entire iceberg. Even if there are no visible problems, danger still exists below the water. Major events can also break off from the iceberg without warning. However, our attention must certainly focus on identifying and correcting the underlying root causes of our loss exposures as represented by the portion of the iceberg below the waterline. We clearly cannot simply wait until types of marine casualties become visible, by actually causing loss, and then taking actions to prevent recurrence.



1.2 The accident sequence: Elements of a marine casualty

Marine casualties usually occur through a chain of events ending in one or more unwanted effects. This chain of events begins with *hazards* capable of causing casualties. If there are no hazards, there are no casualties. An equipment failure, human error, or external event is necessary for a hazard to cause an accident (i.e., a marine casualty). The Coast Guard refers to this *initiating event* as an *incident*. Sometimes one or more equipment failures, human errors, or external events must take place after the initial incident (i.e., the initiating event) for an accident to occur. An accident has at least one unwanted *consequence* with a measurable *effect.* This outcome is influenced throughout the chain of events by the presence of *safeguards* and their success or failure.

Causes are the underlying reasons why the initial incident occurs and safeguard failures allow the chain of events to progress. These are sometimes also called root causes of the accident. The following pages describe the chain of events in more detail.

Definitions of terms commonly used in risk assessment

Hazards — Situations, conditions, characteristics, or properties that create the possibility of unwanted consequences

Incidents or initiating events — Events in an accident sequence that begin a chain of events. This chain of events will result in one or more unwanted consequences with measurable effects unless planned safeguards interrupt the progression of the chain.

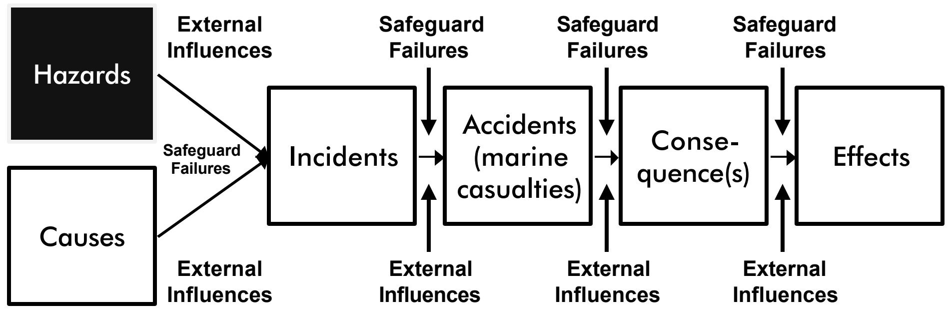
Accidents — Marine casualties such as a collision, grounding, allision, capsizing, sinking, or exposure of a mariner to a specific hazardous condition

Consequences — Unwanted events that can negatively affect subjects of interest. These include property damage or loss, mariner injury or illness, oil spill, loss of marine commerce, etc.

Effects — Measurable negative impacts on subjects of interest (i.e., the magnitudes of the consequences)

Safeguards — Planned protections that are intended to interrupt the progression of accident sequences at various points in accident chains of events. Safeguards can be applied as barriers at any or all of the transitions (i.e., arrows) in the accident sequence model. These planned protections may be physical devices, human interventions, or administrative policies.

Causes — Underlying reasons why the initial incident occurs and safeguards fail to interrupt the chain of events. The causes, sometimes called root causes, are typically weaknesses in management systems, which create error-likely situations for people and vulnerabilities in equipment.



1.2.1 Elements of a marine casualty: Hazards

The following sections describe the major categories of hazards likely to be encountered in traditional marine systems.

Combustible or flammable hazards. Combustible or flammable hazards exist when there is the potential for one or more materials to quickly react with air or some other oxidant, releasing energy in the form of heat and light.

Examples:

- Hydrocarbons and hydrocarbon derivatives (oil, LNG, LPG, etc.)
- Hydrogen
- Other gases (e.g., carbon monoxide)
- Finely powdered nonflammable materials
- Various metals (depending on the oxidizer)
- Wood products
- Cloth materials

Explosion hazards. Explosion hazards exist when there is the potential for one or more substances to release energy over a short period of time, creating a pressure wave that travels away from the source.

Examples:

- Many flammable materials
- Powders and dusts
- Nitrates
- Peroxides
- Highly reactive materials
- Strong oxidizers
- Cryogenic liquids
- Compressed or liquefied gases

Toxic hazards. Toxic hazards exist when there is the potential for one or more materials to cause biological damage to surrounding organisms by being absorbed through the skin, inhaled, eaten, or injected.

Examples:

- Chlorine or bromine
- Cleaning and maintenance fluids
- Contaminated food, water, and medical supplies

Asphyxiant hazards. Asphyxiant hazards exist when there is the potential for one or more materials to prevent organisms from breathing.

- **Simple asphyxiants.** Simple asphyxiants are usually nontoxic gases that replace the oxygen necessary to support life. Common simple asphyxiants are carbon dioxide and nitrogen.

- **Chemical asphyxiants.** Chemical asphyxiants are materials that stop organisms from using oxygen. Carbon monoxide is a chemical asphyxiant that prevents hemoglobin from carrying oxygen.

Corrosivity hazards. A corrosivity hazard exists when there is the potential for one or more materials to chemically burn body tissues, especially the skin and eyes, or to excessively erode or dissolve materials of construction or emergency response equipment.

Examples:

- Cleaning and maintenance fluids
- Battery acid
- Bleach

Chemical reactant hazards. A chemical reactant hazard exists when there is the potential for one or more materials to chemically combine, or to self-react, and produce unwanted consequences.

Examples:

- The side-by-side storage of reactive materials
- Reactive contaminants in materials

Thermal hazards. A thermal hazard exists when there is the potential for very hot or cold temperatures to produce unwanted consequences affecting people, materials, equipment, or work areas.

Examples:

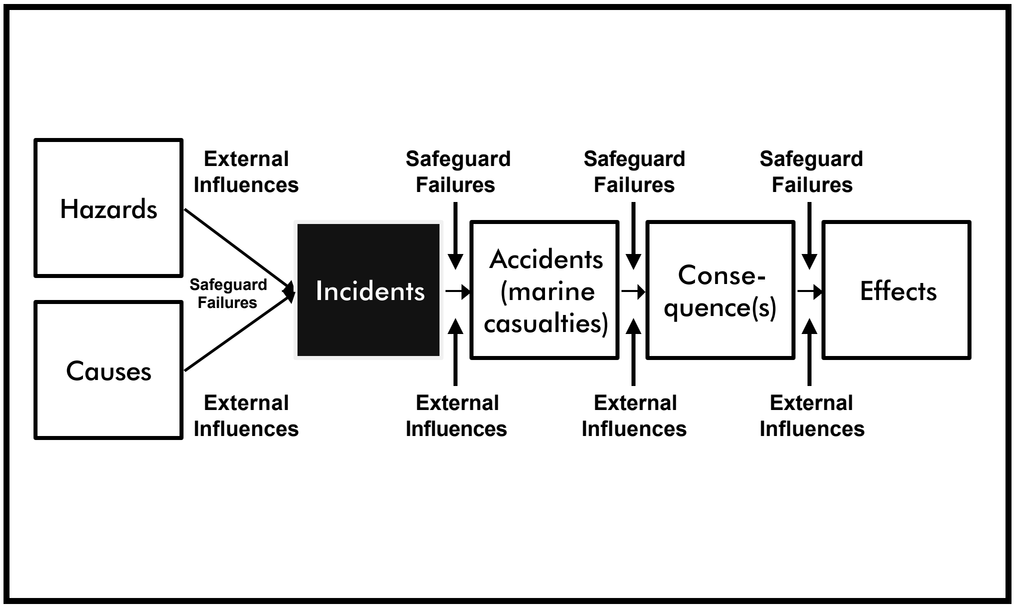
- Exposed or uninsulated high- or low-temperature equipment or materials
- Fires or explosions
- Chemical reactions
- Extreme ambient conditions and other equipment or operations in the area
- Phase changes
- Gas compression or expansion
- Friction

Potential energy hazards. Potential energy hazards exist when unwanted consequences can result from the following:

- High pressures other than explosions (e.g., normal operational pressures)
- Low pressures (e.g., vacuum conditions)
- Mass, gravity, or height (e.g., lifting operations)

Kinetic energy hazards. Kinetic energy hazards exist when unwanted consequences can result from motion of materials, equipment, or vehicles.

Electrical energy hazards. Electrical energy hazards exist when unwanted consequences can result from contact with, or failure of, manufactured or natural sources of electrical voltage or current. Examples include lightning, electrical charges, short circuits, stray currents, and loss of power sources.



1.2.2 Elements of a marine casualty: Incidents (initiating events)

Incidents are also known as initiating events. As defined by the Coast Guard, they start the actual chain of events leading to marine casualties. In some cases, this chain of events can be quite long, when many layers of protection exist against losses.

Incidents can be equipment failures, human errors, external influences, or any action or occurrence.

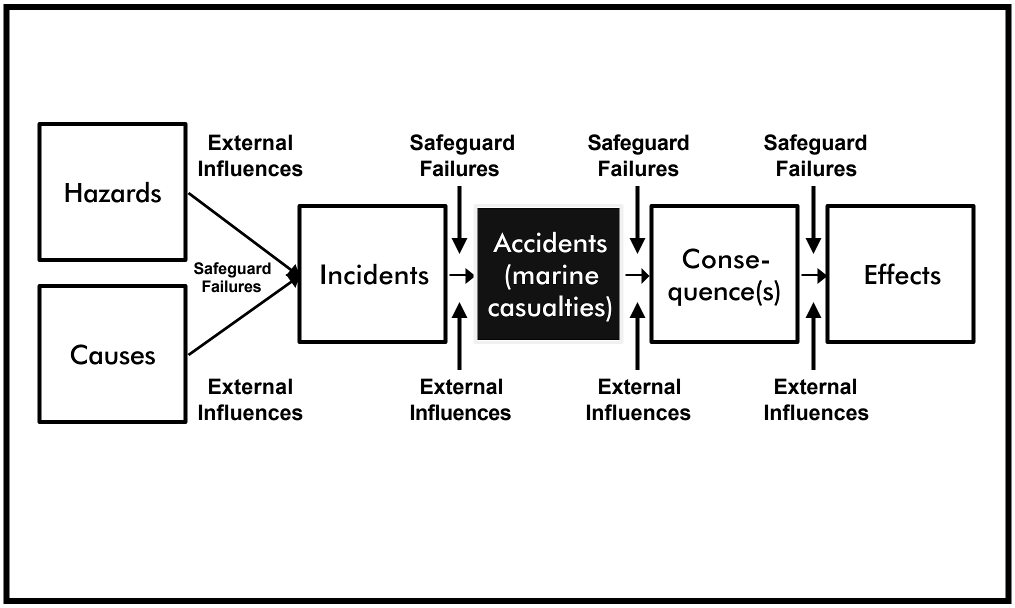
Examples:

- A rudder breaking
- An engineer incorrectly setting a control
- A fuel leak developing
- A rogue wave

Often, an initial incident challenges protective features that also must fail before an incident can become an accident. These special types of safeguards are call **demanded events.** Demanded events can be failed responses to initiating events by equipment or humans. Sometimes, other external events or conditions also influence the progress of an event chain and can be considered a demanded event.

Examples:

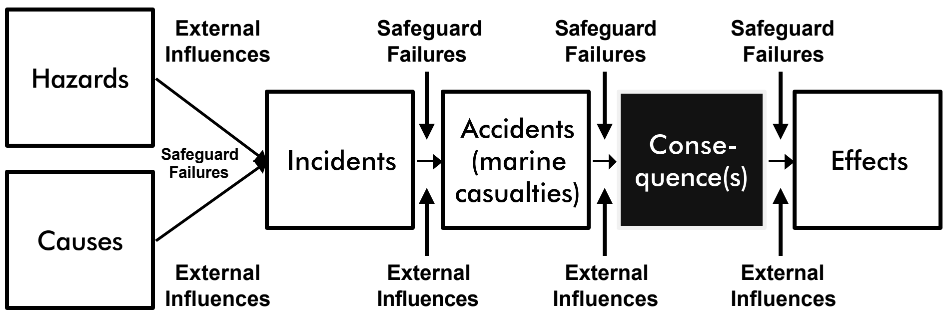
- Relief valve failing to act to reduce a pressure excursion
- Safety observer failing to interrupt an evolution to correct a safety problem



1.2.3 Elements of a marine casualty: Accidents (marine casualties)

The undesired marine casualties that are possible when a chain of events is completed can be classified in many ways. The following table provides an example of some marine casualties of interest.

Some Marine Casualties of Interest	
Capsizing	Drowning
Collision with another vessel	Person overboard
Allision	Spill of material
Collision with a floating object	Acute hazard exposure: workers
Grounding	Acute hazard exposure: public
Sinking	Nonconformance leading to loss of commerce
Fire or explosion	



1.2.4 Elements of a marine casualty: Consequences

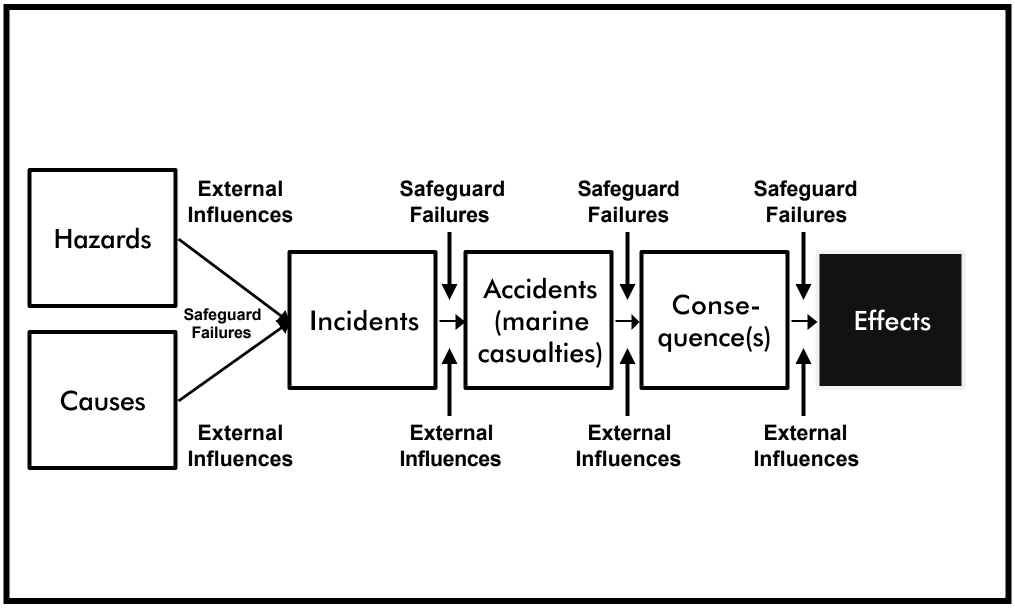
Marine casualties can result in different types of losses for various stakeholders. Some of these consequences include the following:

Mariner safety and health impacts (e.g., injuries or illnesses)

Public safety and health impacts (e.g., injuries or illnesses)

Economic impacts (property damage or loss of commerce)

Environmental impacts (releases of contaminants, such as oil or other hazardous materials)



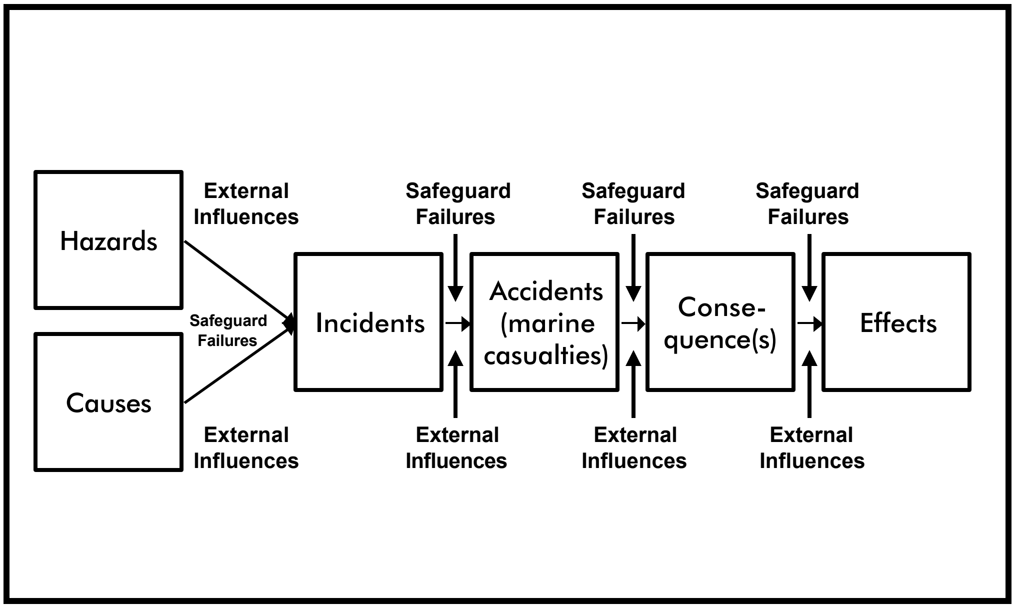
1.2.5 Elements of a marine casualty: Effects

The levels of effect related to consequences can be classified in many ways. The following table provides an example of how the Coast Guard has characterized levels of effect in at least one risk analysis.

Example Types of Effects*

Severity	Safety Impact	Environmental Impact	Economic Impact	Mission Impact
Major (1)	One or more deaths or permanent disability	Releases that result in long-term disruption of the ecosystem or long-term exposure to chronic health risks	≥ $3M	≥ $3M
Moderate (2)	Injury that requires hospitalization or lost work days	Releases that result in short-term disruption of the ecosystem	≥$10K and <$3M	≥$10K and <$3M
Minor (3)	Injury that requires first aid	Pollution with minimal acute environmental or public health impact	≥ $100 and <$10K	≥ $100 and <$10K

* Losses in these categories result from both immediate and long-term effects (e.g., considering both acute and chronic effects when evaluating safety and health).

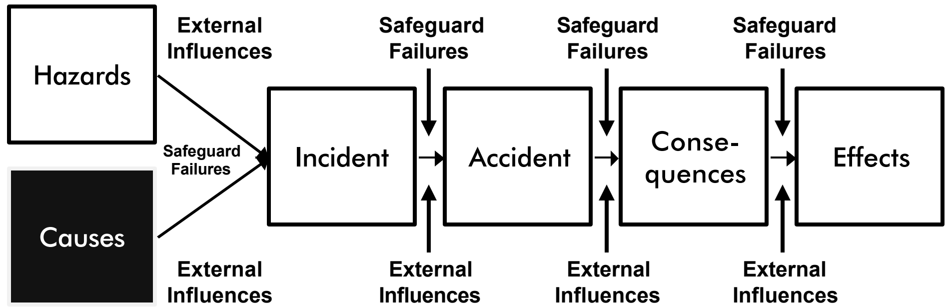


1.2.6 Elements of a marine casualty: Safeguards

Safeguards can be engineered systems, human monitoring and response, or administrative policies and programs for (1) reducing hazards, (2) preventing incidents, (3) interrupting chains of events before casualties occur, (4) reducing consequences, or (5) reducing effects. Safeguards, especially administrative safeguards, also help eliminate the underlying causes of the events in the accident chain.

Examples:

- Preventive maintenance for the steering system and relief valves
- Policy requiring a safety supervisor for all deck operations
- Personnel qualification programs for a key position
- Vessel classification
- Coast Guard inspections (dry-dock inspections)
- Coast Guard presence at port marine events



1.2.7 Elements of a marine casualty: Causes

The chain of events leading to an accident typically involves a series of human errors, equipment failures, and external influences. However, these are seldom the true causes of the accidents. Organizational issues, often referred to as management system weaknesses, are really the root causes of most accidents. Examples of these root causes include, but are certainly not limited to, the following:

For equipment failures:

- Inappropriate design or application
- Lack of predictive or preventive maintenance
- Erroneous repairs
- Unrecognized or ill-advised equipment changes

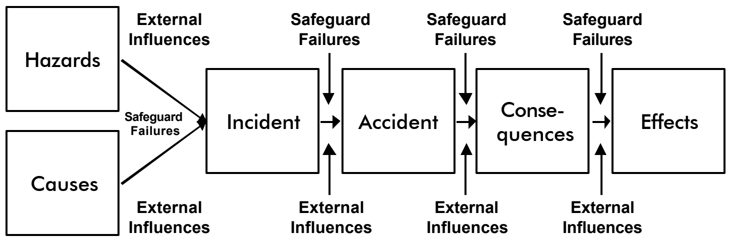
For human errors:

- Wrong, confusing, or missing procedures
- Lack of, wrong, or incomplete training
- Poor human/system interfaces
- Poor work conditions
- Excessive workload
- Lack of or deficient communication systems or processes
- Lack of or deficient supervision
- Poor workplace culture and motivational issues

For external influences

- Failing to anticipate and protect against reasonably foreseeable external conditions such as poor weather

Case study: The Exxon Valdez accident



1.3 Case study: The Exxon Valdez accident

In 1989, a major oil spill occurred in Prince William Sound, Alaska, when the Exxon Valdez ran aground while leaving the Aleyeska Marine Terminal. The following sections describe the chain of events involved in this catastrophic loss.

Hazards

- Oil (environmental pollutant and toxin)
- Kinetic energy of vessel

Incident (initiating event)

- The captain ordered the helmsman to leave the shipping lanes to steer around icebergs

Accident

- Vessel ran aground

Consequences

- 600-foot hole ripped in the bottom of the tanker
- 240,000 barrels (10,000,000 gallons) of oil spilled, causing catastrophic damage to the local environment

Effects

- Major environmental damage, including many dead animals
  - 1,000+ otters
  - 35,000+ birds
- $1 billion+ in cleanup costs

Long-range impacts

- Environmental damage to Prince William Sound
- Fishing fleet in area affected
- Increased public concern about transportation accidents, especially in ship traffic in Prince William Sound

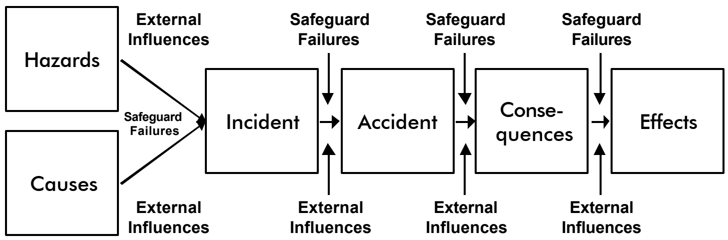
Failed safeguards and external influences

- The captain left orders with the third mate to turn back into the shipping lanes at a certain point, and the captain then left the bridge
- The third mate failed to order the new helmsman to turn back into the shipping lanes at the point prescribed by the captain
- Captain not on bridge
- Experienced mate not in charge of critical turn
- First cleanup team did not arrive until 14 hours after the spill
  - *dedicated* recovery barge had been in dry dock for repairs for the last 2 months
  - booms and skimmer equipment had to be located and loaded onto barge
  - once loaded, the barge was unloaded to transport pumps needed to transfer oil from the Exxon Valdez to another ship
- Dispersants to be used on spill
  - worldwide supply was not large enough for this size of spill
  - authorization to use dispersants was not given for 3 days
- Response was disorganized because of lack of planning; 48 hours after the spill, only 3,000 of 240,000 barrels of oil were recovered

Safeguards not provided

- Double hull tanker
  - double hull may not have prevented the spill, but could have reduced the consequences and effects
- Effective Coast Guard monitoring capability

Case study: The NASA Challenger accident



1.4 Case study: The NASA Challenger accident

In 1986, the space shuttle Challenger exploded 73 seconds after lift-off from the Kennedy Space Center in Florida. The following sections describe the chain of events involved in this catastrophic loss.

Hazard

- Fire and explosion hazards of fuels (liquid hydrogen and liquid oxygen)

Incident (initiating event)

- Lift-off of a shuttle when the ambient temperature was low

Accident

- Flight 51-L explodes 73 seconds after lift-off

Consequences

- Loss of seven astronauts
- Loss of a multi-billion-dollar shuttle

Effects

- Seven fatalities
- Multi-billion dollar economic loss
- Major impact on shuttle program

Long-range impacts

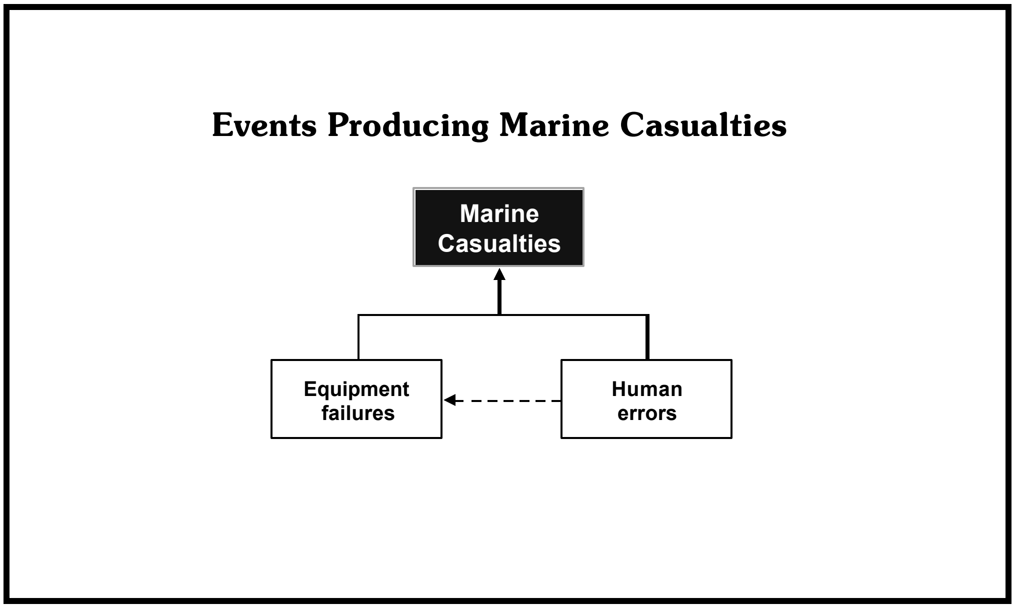
- Suspension of the shuttle program for almost three years
- Safety culture of NASA considered suspect

Failed safeguards and external influences

- Solid rocket motor rubber O-ring failed to seal properly because of its reduced pliability from sitting at a low temperature prior to launch
- Heavy wind shear during the last 45 seconds of the flight caused higher than normal bending of the joints of the solid rocket motor sealed by the rubber O-ring
- High-pressure hot exhaust gases from the solid rocket motor eroded through the cold rubber O-ring (aided by the higher-than-normal bending of the joint) and contacted the external fuel tank
- Ineffective management assessment of identified issues
  - temperature effects on O-rings not well understood by launch safety personnel
  - no definite operating envelope was set for O-rings
  - design specification did not include a temperature range
- Prior evidence of O-ring problems was not viewed as a problem
  - O-ring damage was observed on 15 of 25 missions
  - eventually, O-ring damage was viewed as acceptable

Safeguards not provided

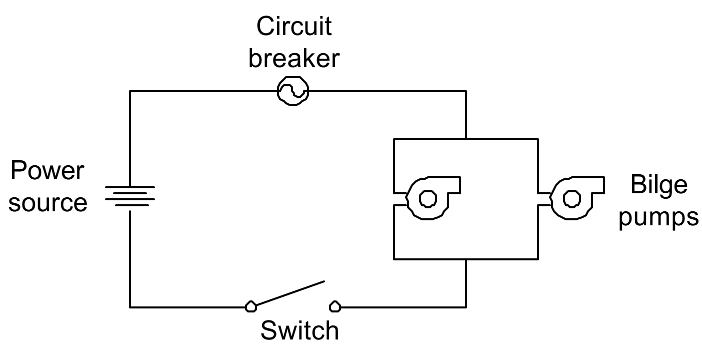
- Effective O-ring design
- Timely communication of temperature limit for O-rings in this service



2.0 Events Producing Marine Casualties

A marine casualty is caused by a combination of one or more equipment failures or human errors.

Example



Assume a bilge pumping system has a single power supply and two pumps in parallel. The entire circuit is protected by a single breaker and controlled by a single switch. The following are events contributing to a lack of bilge pumping:

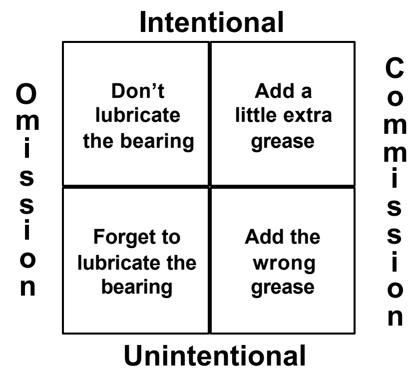
- Power supply fails off
- Wiring fails
- Circuit breaker fails open
- Switch fails open
- Operator unintentionally opens switch
- Pump #1 fails off; pump #2 fails off

The keys to preventing accidents are (1) understanding the combinations of events leading to an accident and (2) knowing how to make the equipment failures and human errors less likely.

There is an entire science dedicated to forensic analysis of equipment failures, which is more than could be addressed in these *Guidelines*. However, a good technical knowledge of equipment failure mechanisms is often important for identifying and managing risks. Straightforward texts such as Donald Wulpi's *Understanding How Components Fail* and ASM International's *Principles of Failure Analysis* are good references for developing a more in-depth knowledge in this area.

Often overlooked is the importance of human error prevention in risk management. In fact, human error is also the underlying cause of most equipment failures. After all, who designs, builds, manufactures, installs, operates, and maintains the equipment? People! Because of the importance of human error in marine risk management, section 3 of this chapter explores human error in more detail. Of course, there is also a whole field of study dedicated to preventing human errors and improving human performance.

Human Error Categories



3.0 What is Human Error?

The term "human error" refers to human actions or inactions outside the tolerances established by a system, even if no immediate consequences occur. Systems within every industry are almost always subject to failure as a result of human error.

Human error includes the following:

- Personnel not following procedures or neglecting routine duties
- Improper or inadequate training of workers or crew
- Errors in writing operating instructions
- Equipment or system design, construction, or installation errors
- Improper or inadequate inspection, testing, or repair of equipment
- Lack of management oversight

Human error excludes *deliberate actions performed with harmful intentions (i.e., sabotage).*

A human error is typically characterized by the following descriptions:

Error of omission. Failure to perform a task or step

Error of commission. Performing a task or step incorrectly, as in the following:

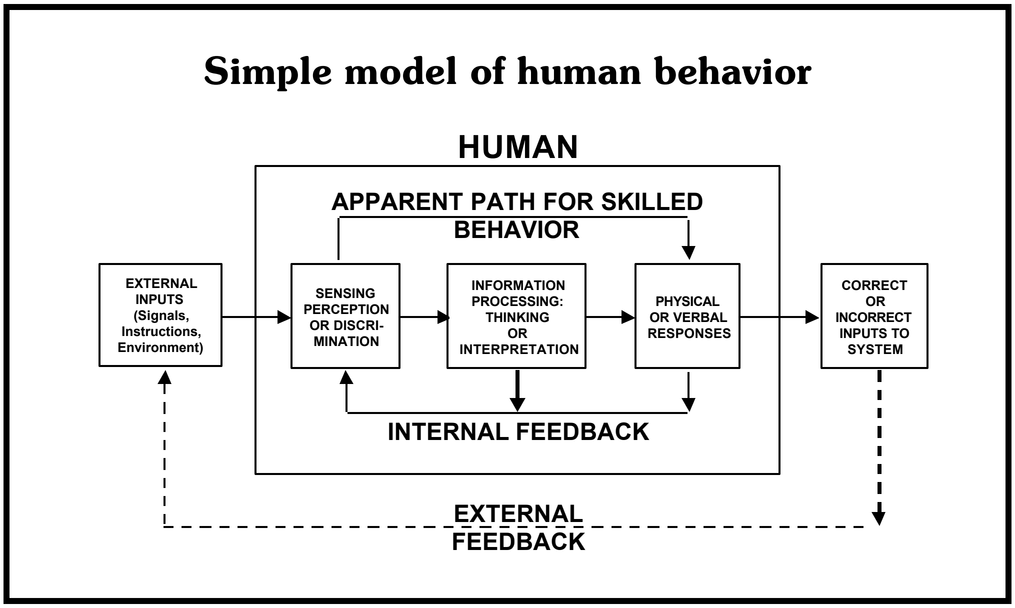
- Selection error
  - selects wrong display or device
  - mispositions device
  - issues wrong command or information
  - too slow
- Extraneous act
- Sequence error
  - too soon
  - too late
- Time error
  - too long
  - too short
- Quantitative error
  - too little
  - too much
  - too fast

Unintentional error. An action committed or omitted *accidentally*, with no prior thought

Intentional errors. An intentional error does *not* include sabotage. The difference is in the *motive*. This error includes the following:

- An action committed or omitted deliberately, because of a perception that there is a better or equally effective way to perform the task or step. This is often a *shortcut* that may not be recognized as a mistake until other conditions arise that result in a noticeable problem.
- An action committed or omitted because the worker *misdiagnosed* the system's problem or need. At best, such an action delays the correct response; at worst, it compounds the problem.

For more information on human error in the Coast Guard, see the document entitled "Human Error and Marine Safety" in the General Resources Directory in Volume 4.



3.1 Simple model of human behavior

Human interaction with a system can be modeled as a component with three distinct functions. The rest of the system continuously provides information that enters the human through one of our five senses.

1. **Sensor, perception, or discrimination.** The brain filters out most external inputs as irrelevant information. The first task of the human "component" is to recognize important information and discriminate it from background noise.
2. **Information processing: thinking or interpretation.** The human must then process the input to determine its meaning and to select an appropriate response. When people practice the same response to a given input, they eventually appear to bypass this function (i.e., the apparent path for skilled behavior). This is when actions become second nature and explains why simply retraining and improving procedures often does not improve human performance.
3. **Physical or verbal responses.** Finally, the human physically responds based on the perceived or processed information. Lack of action is also a response.

The response in turn provides new inputs to the human who can sense his or her own actions (internal feedback) and sense how the system is responding (external feedback). Well-designed systems react perceptibly to the new input and provide feedback to the human by altering the external inputs.

Application of the model of human behavior

Suppose a ferry is transitioning across a bay and a small craft begins to cross its path. The crew of the ferry must alter course to avoid a collision.

External inputs

The presence of the small craft should provide an input to the ferry's crew. Other inputs might be radar contacts, radio messages, horns, etc. Without their other inputs, the crew might not recognize the small craft in their course soon enough. Diverse, reliable, and recognizable inputs are important for good human performance.

Sensing, perception, and discrimination

Even if the inputs exist, the crew must be able to recognize the inputs. Impaired visibility, distractions, too many messages or contacts, and various other situations can keep the crew from accurately sensing the key inputs.

Information processing

Once the crew recognizes that the small craft is crossing its path, it must decide what action to take. The proper response probably depends on many factors, such as other vessel traffic, weather and sea conditions, position in the bay, etc. In most cases, we would hope for a well-reasoned choice of what actions to take. However, if this happens often or if little time to react is available, the crew may largely omit this step, reacting by experience and instinct.

Physical or verbal responses

Next, the crew would take actions such as powering down the vessel, making an evasive maneuver, alerting the small craft to the danger, etc. As members of the crew take these actions, they will be able to sense their own actions and adjust the magnitude of the response.

Correct or incorrect inputs to systems

The crew's actions will cause the ferry to respond by slowing or turning. The response of the ferry, and possibly the small craft, will create a whole new set of inputs for the crew.

This process is continually occurring for all of us!

Results of error-likely situations

- **Lack of external input**
- **Failure to sense input**
- **Misinterpretation of input**
- **Inappropriate response**
- **Lack of feedback**

3.2 Results of error-likely situations

Error-likely situations can exist at any element of the human performance model. Examples of such deficiencies related to the example application in section 3.1 include the following:

Lack of external input such as signals or instructions. The person doesn't know that he or she should act because there is no signal provided to the user.

- Crew does not receive a radar contact warning because the radar is malfunctioning
- No traffic control system is in place to warn the crew
- The small craft does not have the proper navigation lights for nighttime operation

Failure to sense input. An input signal is provided but is not sensed because of information overload, insufficient discrimination, or poorly organized information.

- Weather conditions prevent the crew from seeing the small craft
- The crew is distracted with some other problem aboard the ferry
- Too much radio traffic or garbled messages confuse the crew
- The bridge of the ferry has a blind spot

Information presented to the user must be organized and prioritized. Important and urgent inputs must stand out from others.

Training and experience can increase the likelihood that appropriate signals are identified, but system design is the key to correcting these issues.

Misinterpretation of input. The input signal is clearly noted, but the meaning of the signal is misinterpreted.

- The crew believed that the vessels would pass without taking an action
- The crew mistakenly thought that the small craft was taking evasive action

Systems should provide unambiguous indications of their status and the required action. Training and experience can increase the probability of correct interpretations.

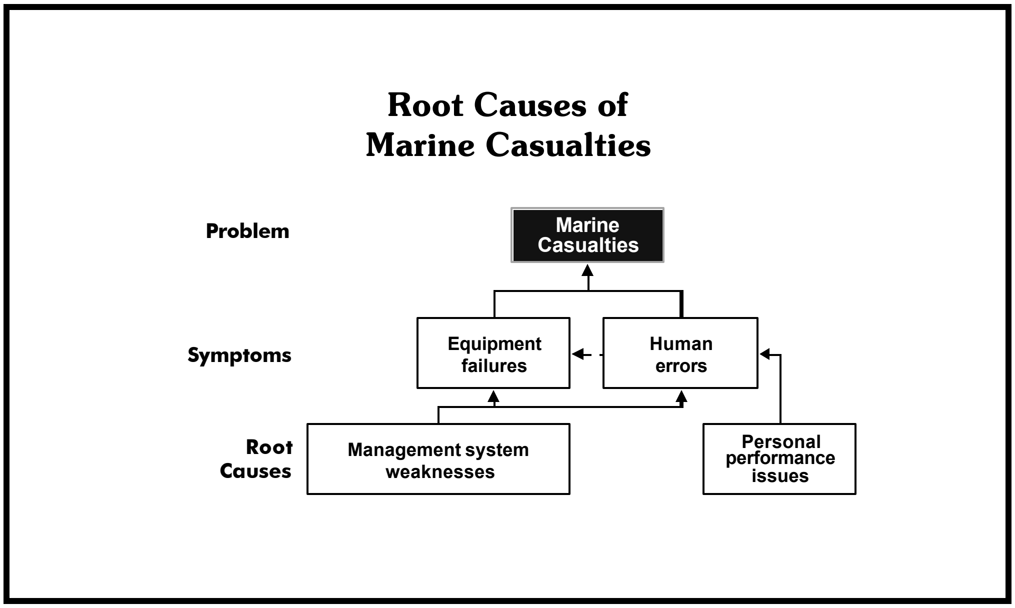
Inappropriate or insufficient physical or verbal response. The user knows what to do and how to do it, but he or she takes inappropriate action.

- The crew fails to maneuver the vessel appropriately
- The crew fails to alert the small craft
- The sea state or current makes the evasive maneuver ineffective

A system may require a high level of skill or physical strength to get an acceptable response. Examples of this fact are surgeons and athletes. Practicing the skill or better matching the person to the task can increase the likelihood of the appropriate response.

Lack of feedback. There is no indication that the user did the previous steps (sensing, interpreting, responding) correctly, or feedback is too vague or not timely.

- The small craft does not respond to warning messages or signals
- The ferry responds too slowly to control adjustments, and the crew does not have a chance to refine the adjustments



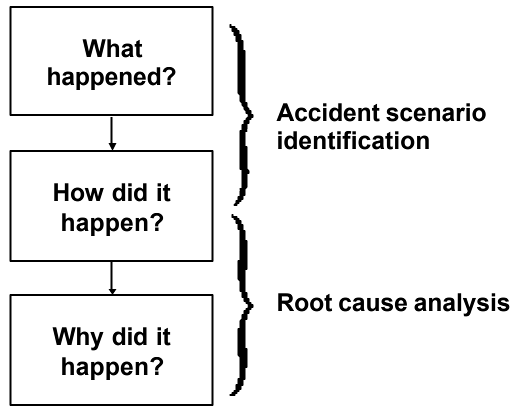
4.0 Introduction to Root Causes

Marine casualties are caused by combinations of equipment failure and human error. Sometimes the underlying causes result from personal performance errors; that is, all practical measures for preventing the errors had been tried. Humans will eventually make mistakes with even the most error-proofed systems. However, the underlying causes can usually be traced to weaknesses in an organization's management systems; that is, its programs and policies. These management system weaknesses lead to conditions for equipment failure and error-likely situations for individuals. These are the underlying root causes of most marine casualties and other unwanted situations, such as inspection deficiencies.

What is a root cause?

- Root causes are the most basic causes of an event that meet the following conditions:
  - they can be reasonably identified
  - management has the ability to fix or influence them
- Typically, root causes are the absence, neglect, or deficiencies of management systems that control human actions and equipment performance

For any event leading to a marine casualty, there may be more than one underlying root cause. It is not uncommon for a marine casualty to have many underlying root causes. If these root causes are not found and corrected, the underlying management system weaknesses will lead to marine casualties.



4.1 What is root cause analysis?

Root cause analysis provides a means to determine how and why something occurred. Understanding the accident scenario is not enough. Scenarios tell us what happened, not why it happened. Events in accident scenarios are generally only symptoms of underlying problems in the administrative controls that are supposed to keep those events from occurring. Understanding only the scenario addresses the outward symptoms, but not the underlying problems. More investigation of the underlying problems is needed to find and correct those that will contribute to future accidents. Root cause analysis provides a means to investigate underlying problems.

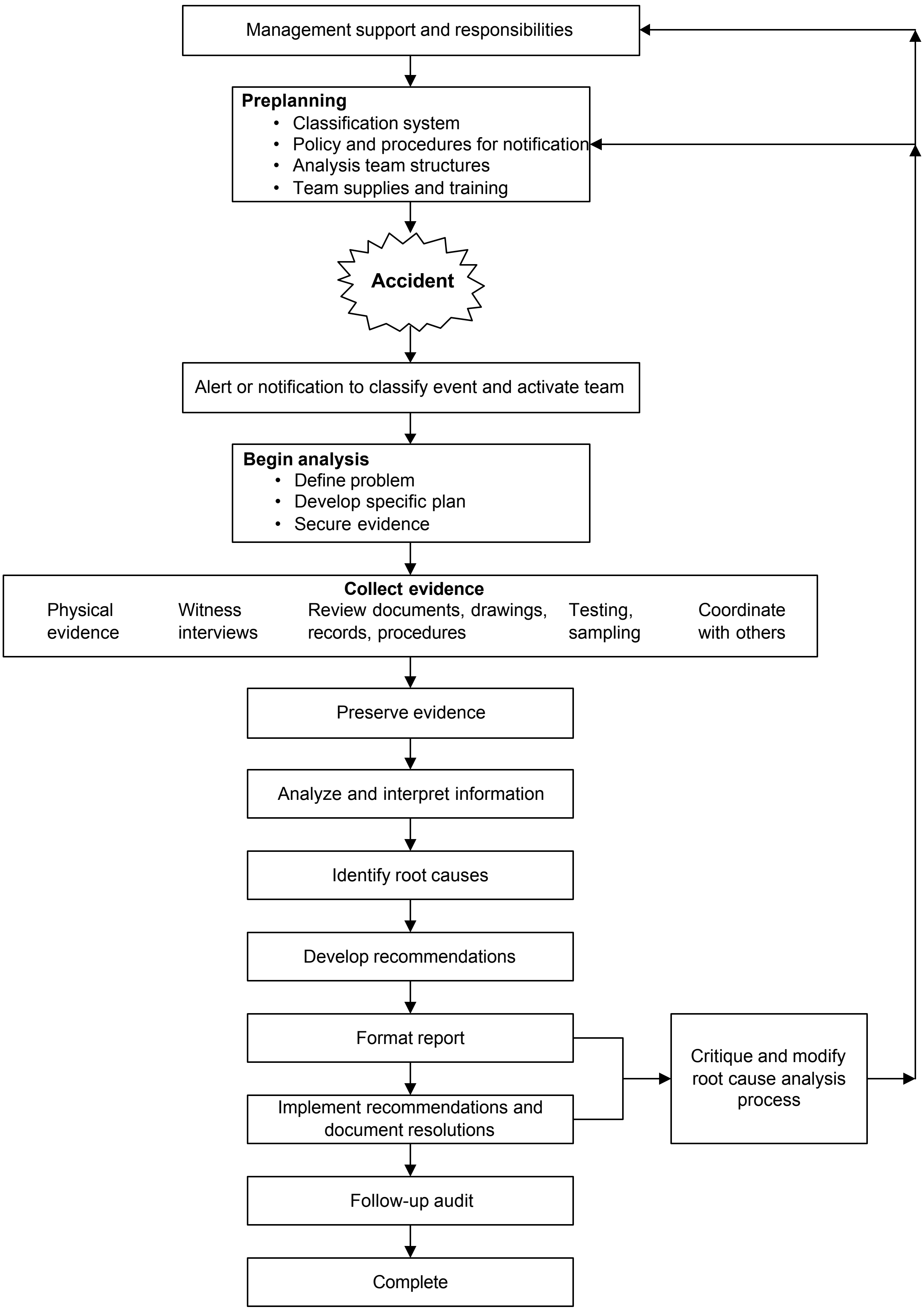
Key features of root cause analysis

- Understanding how an accident event occurred
- Discovering the underlying root causes (management system weaknesses) of the key contributors (causal factors)
- Developing and implementing practical and effective recommendations for preventing future accidents

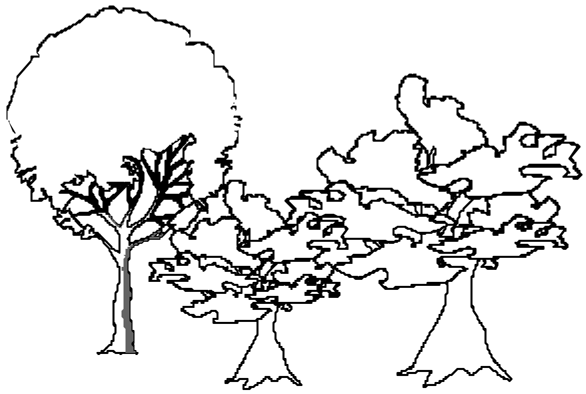
Key differences from traditional problem solving

- Logical reasoning through cause-effect relationships
- Rigorous focus on factual data versus supposition
- Range of possibilities considered
- Management system perspective
- Multiple root causes identified
- Systematic processes and tools make effective data trending possible

The flowchart on the following page is modeled after the American Institute of Chemical Engineers' process for conducting incident investigations. It illustrates the complete process of performing root cause analysis.


Management support and responsibilities
Preplanning
Classification system
Policy and procedures for notification
Analysis team structures
Team supplies and training
Accident
Alert or notification to classify event and activate team
Begin analysis
Define problem
Develop specific plan
Secure evidence
Collect evidence
Physical evidence
Witness interviews
Review documents, drawings, records, procedures
Testing, sampling
Coordinate with others
Preserve evidence
Analyze and interpret information
Identify root causes
Develop recommendations
Format report
Implement recommendations and document resolutions
Critique and modify root cause analysis process
Follow-up audit
Complete

Trending analysis results



4.2 Trending analysis results

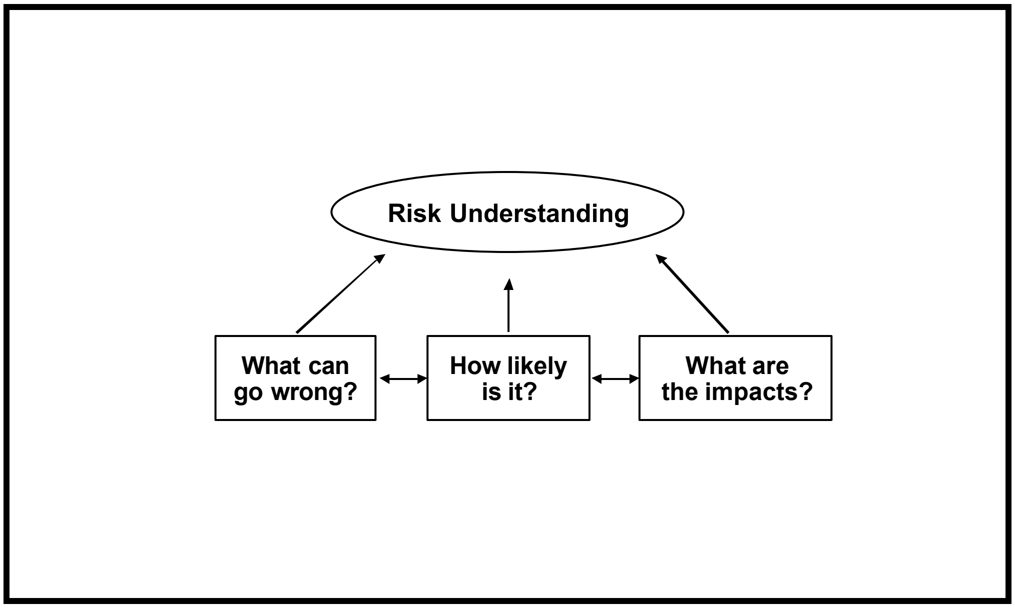
Root cause analysis results can be trended to identify persistent problem areas. Analysis teams focus on one specific event and reasonable methods for preventing recurrence. Organizations should identify systemic problems that contribute to groups of events. Trending provides the ability to associate related events.

Trending is performed by sorting various characteristics of events of interest. Trending can provide correlation of events to:

- — country of operation
- — division
- — industry sector
- — facility or vessel
- — operating areas
- — types of accidents
- — job positions
- — operating modes
- — timing (seasons, days, time of day, etc.)
- — environmental conditions
- — contributing events
- — event sequences
- — root causes

Benefits of trending

- Facilitates performance assessments and projections
- Identifies persistent management deficiencies (root causes)
- Highlights unique, unrecognized, or improperly defined risks
- Identifies misallocated management resources
- Flags sudden changes in performance, either positive or negative
- Provides correlation of changes in performance to events producing such changes
- Highlights risk assessment weaknesses



5.0 Characterizing Risk

Understanding risk requires answers to the following questions:

What can go wrong?

Risk assessment methods are used to identify combinations of events that can create marine casualties. These can include equipment failures, human errors, and external events. Based on the quantity and types of events that may occur, an analyst gains a good understanding of the risk associated with an issue of concern.

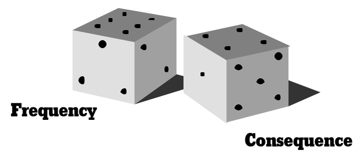
How likely is it?

Likelihood is usually expressed as the probability or frequency of an accident occurring. If the likelihood is low enough, analysts may conclude that a possible accident scenario is not credible, not of concern, or of extremely low risk. But, the criteria for making such judgments often change with the type and severity of the consequence related to the possible accident.

What are the impacts?

An accident can affect many areas of concern with different degrees of negative results. For example, a ship's boiler that is lit without proper purging can explode, causing major equipment damage and personnel injury. However, this accident may not cause environmental damage or public injury. The type and severity of consequences related to an accident help an analyst understand and judge risk.

Elements of risk



- **Risk is the combination of frequency (F) and consequence (C), often expressed as F x C**
- **Two categories of risk**
  - **risks that can be reduced or eliminated**
  - **remaining risks**

5.1 Elements of risk

Frequency. The frequency of events is often expressed as events per year. However, other bases for expressing how frequently an event will occur are also used. These include events per mile traveled, events per transit, events per ton of material moved, etc.

The frequency should be determined from past data if a large number of events have occurred. However, we usually focus on accidents with severe consequences for which few data records exist. For these events, frequency is calculated using risk assessment models.

The frequency of any event is based on (1) how often the hazard is present (i.e., how many times an operation is performed) and (2) the probability of experiencing the accident during any exposure to the hazard. Some descriptions of risk will explicitly describe frequency as the number of exposures to the hazard, multiplied by the probability of an accident during each exposure.

Consequence. Consequence is measured by the magnitude of its effects. Consequence is expressed as the number of people injured or killed, area affected, outage time, mission delay, dollars lost, etc.

Risk. The risk of a potential accident is often calculated as the combination of the frequency and consequence. This way, we can compare the risks of different operations and potential accidents. However, you should also compare the two *consequences,* because we often judge risk with a higher priority given to high-consequence events.

For example, suppose Potential Accident #1 has a frequency of once in 100 years and a consequence of $10,000. Potential Accident #2 has a frequency of once in 10,000 years and a consequence of $1 million. The risk of either potential accident is $100/yr ($10,000 x 1/100 yr or $1 million x 1/10,000 yr), but you might be more concerned about Potential Accident #2 than Potential Accident #1 based on the severity of the consequence.

Risk acceptance criteria. Any operation has risks. Once these risks are known, we can take steps to reduce them (e.g., insulate hot surfaces to reduce the chance of getting burned) or eliminate them (e.g., switching to nonflammable cleaning materials to eliminate a fire hazard). However, some known risks are accepted as the *cost of doing business*. These remaining risks, known as residual risks, should be within an organization's risk acceptance criteria.

Risk characterization methods

- **Quantitative**
  - **point risk estimate**
  - **categorization**
  - **probability distributions**
- **Qualitative**
  - **subjective prioritization**
  - **basic scenario ranking**
  - **criteria-based scenario ranking**

5.2 Risk characterization methods

Risk assessment involves processing a large quantity of data: Often hundreds or even thousands of accident scenarios must be evaluated to estimate the risk of an operation. An analyst should consider the level of detail needed in the risk results before starting the risk assessment process. Qualitative methods, as well as coarse and detailed quantitative methods, can characterize risk. Qualitative methods may suffice when focusing on the *big picture* and identifying general operations where higher risk exists. However, in other situations, a more detailed risk assessment is needed.

Quantitative risk characterization

- **Point risk estimate**
- **Categorization**
- **Probability distributions**

5.2.1 Quantitative risk characterization

Quantitative risk characterization methods provide decision makers with precise descriptions of risk; however, these methods often involve detailed studies that are very resource intensive. Also, be careful not to confuse precise descriptions of risk with the accuracy or certainty of those descriptions. Applying quantitative risk characterization methods generally requires a substantial level of experience and expertise among analysis team members. Two common forms of quantitative risk characterization are the following:

Point risk estimates. An analysis team uses historical data from directly related operational experience, expert judgment, and data published from other applications of similar equipment or human activities to estimate (1) the frequency of initiating events for various accident scenarios and (2) the probability of failure for each safeguard. The effect of the consequence, often measured in cost or injuries and deaths, is also estimated.

Categorizations. A risk assessment team assigns accident scenarios to appropriate likelihood and consequence categories. The combination of likelihood and consequence category is used to assign a risk level to the scenario.

Probability distributions. A risk assessment team assigns probability distributions to reflect the possible range of event frequencies, probabilities, and consequences that may be applicable for a specific assessment. This method is more robust than simply selecting point estimates as described above because the uncertainty associated with each key frequency, probability, or consequence number is modeled. However, this method is considerably more complicated to apply and will not be discussed further in these *Guidelines*.

Point risk estimate characterization

$$Risk_{\substack{\text{Accident}\\\text{scenario}}} = F_{\substack{\text{Accident}\\\text{scenario}}} \times C_{\substack{\text{Accident}\\\text{scenario}}}$$

Where

$$F_{\substack{\text{Accident}\\\text{scenario}}} = F_{\text{Incident}} \times P_{\substack{\text{Safeguard \#1}\\\text{being}\\\text{undependable}}} \times P_{\substack{\text{Safeguard \#2}\\\text{being}\\\text{undependable}}} \times \cdots$$

and

F = frequency of occurrence
C = consequence
P = probability of occurrence

5.2.2 Point risk estimate characterization

Point estimates of risk provide decision makers with very precise information about the absolute magnitude of risk associated with specific activities. These precise estimates are particularly useful when decisions will be sensitive to small, subtle differences in risk.

Example for oil spill scenarios

Scenarios	Incident		Failed Safeguards			Scenario Frequencies
Scenario 1	Valve leaks (1/y)	x	Flow not stopped (0.1)	x	Oil enters water (0.01)	= 0.001/y
Scenario 2	Hose leaks (0.1/y)	x	Flow not stopped (0.1)	x	Oil enters water (0.1)	= 0.001/y
Scenario 3	Hose ruptures (0.01/y)	x	Flow not stopped (1.0)		Oil enters water (1.0)	= 0.01/y
					$F_{accident}$	= 0.012/y

Risk = 0.012/y x $10,000 = $120/y

As you can see from the table above, three different scenarios have been identified that could cause the same accident, which has an associated consequence of $10,000. The accident frequency is the sum of the scenario frequencies. Knowing the accident frequency, consequence, and risk, management can now determine if the accident risk is acceptable. If not, these same results help us focus on areas where additional control efforts may be needed.

Limitations of point risk estimate

- Accuracy depends on accuracy and completeness of scenario models and specific likelihood and consequence data for each event
- Very resource intensive for detailed studies
- Point estimate choices are often based on subjective choices

Risk characterization using categorization

- Can provide most types of risk-based information
- Generally efficient to apply
- Often an excellent screening approach

5.2.3 Risk characterization using categorization

The risk assessment process changes very little if risk is to be characterized using categories instead of point estimates. In this case, the analyst must (1) define the likelihood and consequence categories to be used in evaluating accident scenario risk acceptability and (2) define the level of risk associated with each likelihood and consequence category combination. In defining categories, be careful to provide enough so that meaningful results are obtained, but not so many that risk assessment teams have difficulty assigning category values to scenarios.

For example, using too few categories may cause analysts to assign all the accident scenarios to the same risk level. In this case, very little is learned in the risk assessment process and no direction is given as to where to focus management controls. Too many categories, on the other hand, will consume excessive amounts of the risk assessment team's time in determining the *right* category assignment for each accident scenario.

Frequency and consequence categories

The following tables are the basis for a scenario-based risk categorization system. Multiple consequence classification criteria may be required to address safety, environmental, operability, and other types of consequences.

Example criteria for consequences

This table is an example of a scheme for estimating the effects of a specific accident scenario. The most applicable category would be chosen for the scenario using the definitions provided.

Example Types of Effects*				
Severity	**Safety Impact**	**Environmental Impact**	**Economic Impact**	**Mission Impact**
Major (1)	One or more deaths or permanent disability	Releases that result in long-term disruption of the ecosystem or long-term exposure to chronic health risks	≥ $3M	≥ $3M
Moderate (2)	Injury that requires hospitalization or lost work days	Releases that result in short-term disruption of the ecosystem	≥$10K and <$3M	≥$10K and <$3M
Minor (3)	Injury that requires first aid	Pollution with minimal acute environmental or public health impact	≥ $100 and <$10K	≥ $100 and <$10K

* Losses in these categories result from both immediate and long-term effects (e.g., considering both acute and chronic effects when evaluating safety and health).

Example criteria for frequency

This table is an example of a scheme for scoring frequencies of accident scenarios. The most applicable score would be chosen for each scenario using the descriptions provided.

Frequency Category	Description
Very Frequent	**From 10 to 100 events per year in the port**
Frequent	**From 1 to 10 events per year in the port**
Occasional	**From 1 event every 10 years to 1 event per year in the port**
Infrequent	**Less than 1 event every 10 years in the port**
Rare	**Not expected to occur in the port**

Example risk matrix

The following matrix provides a mechanism for assigning risk, and making risk acceptance decisions, using a risk categorization approach. Each cell in the matrix corresponds to a specific combination of likelihood and consequence. Thus, each cell indicates the risk of a scenario having that combination of likelihood and consequence. Each cell in the matrix can be assigned a priority number or some other risk descriptor, as shown in the matrix below. An organization must define the categories it will use to score risks and, more importantly, how it will prioritize and respond to the various levels of risk associated with cells in the matrix.

Frequency of occurrence	3	2	1
Very Frequent	M	U	U
Frequent	A	U	U
Occasional	A	M	U
Infrequent	A	A	M
Rare	A	A	A

Severity of consequence

A = acceptable
M = marginal
U = unacceptable

Example Risk Acceptability for Oil Spills Throughout a Port

Scenario	Frequency and Severity Estimates			Risk Acceptability
	Level 3 Severity	Level 2 Severity	Level 1 Severity	
Scenario 1: Hose leak or rupture during a transfer	Very frequent (Risk: M)	Infrequent (Risk: A)	Rare (Risk: A)	M
Scenario 2: Tank rupture during a grounding	Occasional (Risk: A)	Occasional (Risk: M)	Infrequent (Risk: M)	M
Scenario 3: Tank overfill during a transfer	Frequent (Risk: A)	Infrequent (Risk: A)	Rare (Risk: A)	A

Example loss estimates

The significance of a risk matrix can be further understood by generating the estimated losses associated with it. In the table below, the risk assessment team estimated how often each scenario will occur and how often it will result in consequences in each of these severity levels. For example, the team determined that Scenario #3 will result in a Level 3 severity 1 to 10 times per year and essentially never result in a Level 1 severity. You can add the ranges of the frequency estimates for all scenarios to determine the Frequency Summary of each severity level. To get the range of Expected Losses for each severity level, multiply the upper and lower bounds of the Frequency Summary with the average consequence for the severity level. The total expected range of annual losses presented below the table is the sum of the Expected Losses for all severity levels.

Example Loss Estimates for Oil Spills Throughout a Port

Scenario	Frequency and Severity Estimates		
	3 ($100 to $10K) Average Consequence: $3K	**2** ($10K to $3M) Average Consequence: $300K	**1** (>$3M) Average Consequence: $5M
Scenario #1 Hose leak or rupture during a transfer	**Very Frequent** 10/yr to 100/yr	**Infrequent** 0/yr to 0.1/yr	**Rare** 0/yr
Scenario #2 Tank damage during a grounding	**Occasional** 0.1/yr to 1/yr	**Occasional** 0.1/yr to 1/yr	**Infrequent** 0/yr to 0.1/yr
Scenario #3 Tank overfill during a transfer	**Frequent** 1/yr to 10/yr	**Infrequent** 0/yr to 0.1/yr	**Rare** 0/yr
Frequency Summary (by Severity Level)	11.1/yr to 111/yr	0.1/yr to 1.2/yr	0/yr to 0.1/yr
Expected Losses (by Severity Level)	Using the Average Consequence: ~$33K/yr to $333K/yr	Using the Average Consequence: ~$30K/yr to $360K/yr	Using the Average Consequence: ~$0K/yr to $500K/yr

Total Expected Annual Losses: ~$63K/yr to ~$1.2M/yr

Limitations of risk characterization using categorization

- Less precise than point estimates
- Accuracy depends on
  - accuracy of scenario models
  - judgment and experience of those assigning scores for scenarios
  - quality of available scenario data
- Results are often subjective, especially for rare scenarios

Qualitative risk characterization

- **Subjective prioritization**
- **Basic scenario ranking**
- **Criteria-based scenario ranking**

5.2.4 Qualitative risk characterization

As you would expect, qualitative methods are easier and faster to use in characterizing risk than quantitative methods. These methods generally require less experience and expertise among risk assessment team members as well.

Subjective prioritization — A risk assessment team assigns accident scenario risk (i.e., priority) based on its collective judgment of the likelihood and severity of the failures involved in the scenario

Basic scenario ranking — A risk assessment team assigns points to each failure in a accident scenario based on the type of each failure. The points are summed to get the scenario risk. Higher scores indicate lower risks because more failures, or failures of more reliable safeguards, are required to complete the sequence.

Criteria-based scenario ranking — A risk assessment team determines if accident scenario risk is acceptable or unacceptable based on the number and type of failures described in the accident scenario. Scenarios with unacceptable risks are subject to further control measures.

Subjective prioritization

- **Identify potential accident scenarios using structured hazard assessment techniques**
- **Subjectively categorize scenarios according to their perceived level of risk**

5.2.5 Subjective prioritization

Subjective prioritization identifies potential accident scenarios using structured hazard assessment techniques. This technique subjectively assigns each scenario to a priority category based on the perceived level of risk. Priority categories can be the following:

- low, medium, high
- numerical assignments
- priority levels

Of course, the results from this technique are highly dependent on the experience of the team performing the prioritization.

Example of subjective prioritization of 20 scenarios:

- **Priority 1** → **Scenarios 3, 7, 15**
- **Priority 2** → **Scenarios 1, 5, 16, 18, 19**
- **Priority 3** → **Scenarios 2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 17, 20**

Limitations of subjective prioritization

- Very subjective: Results are highly dependent on the analyst's perception of risk
- Provides only general prioritization of scenarios
- Provides limited direction to management on where to focus control efforts

Basic scenario ranking

- **Identify potential accident scenarios**
- **Score scenarios based on types and numbers of events**
- **Prioritize based on scores**

5.2.6 Basic scenario ranking

The basic scenario ranking technique allows an analyst to systematically prioritize various accident scenarios of interest. Scores are assigned to each failure in an accident scenario, and the values are totaled to yield a scenario risk score. Similarly, the risk scores for all scenarios that have the same outcome can be totaled to estimate risk. Thus, this method allows analysts to screen various types of accidents as well as scenarios that contribute to accidents.

Example

The table on the next page presents a set of accident scenarios that were evaluated using a scenario ranking methodology. The scoring guidelines used to rank these scenarios are as follows:

- 1 point for any event (operating conditions, environmental conditions, human actions, equipment actions, etc.) expected to occur regularly (EE)
- 2 points for each human error (HE)
- 3 points for each active equipment failure (AEF)
- 4 points for each infrequent external event (IEE)
- 5 points for each passive equipment failure (PEF)

Low scores indicate that the scenario is a high risk. In this method, additional safeguards that reduce risk by adding layers of protection produce larger ranking numbers.

Note that in the example below, the scenario that is ranked highest does not have the lowest score. This is because of the strong dependencies among the human errors associated with the highest-ranked scenario. Common-cause failures can be difficult to factor explicitly into qualitative risk-based schemes.

Some ranked accident scenarios for catastrophic rupture of cargo tank A

Rank	Accident Scenario	Types of Events	Score Based on Types and Numbers of Events
1*	Operator leaves valve A open, operator leaves valve B open, and operator fails to verify that valves A and B are closed before introducing hazardous material into the tank	HE, HE, HE	6
2	Major external impact	IEE	4
3	Mechanic improperly calibrates the relief valve on cargo tank A, and pressure control valve for cargo tank A sticks closed	HE, AEF	5
4	Catastrophic rupture of cargo tank A	PEF	5
5	Operator fails to open the isolation valve under the relief valve on cargo tank A after maintenance of the relief valve, operator fails to detect improperly positioned valve during monthly status checks of special valves, operator inadvertently misdirects a high-pressure feed stream into cargo tank A, and operator fails to detect and mitigate rising pressure (based on other pressure indications)	HE, HE, HE, HE	8
6	Operator fails to open the isolation valve under the relief valve on cargo tank A after maintenance of the relief valve, operator fails to detect improperly positioned valve during monthly status checks of special valves, pressure controller erroneously commands pressure control for cargo tank A to close, and operator fails to detect and mitigate rising pressure (based on other pressure indications)	HE, HE, AEF, HE	9

*This scenario is ranked as more important than three other scenarios with lower scores because the analyst identified strong dependencies among the three human errors associated with this scenario.

Limitations of basic scenario ranking

- Provides only general prioritization of scenarios
- Basis of scoring has inherent limitations and inaccuracies

Criteria-based scenario evaluation

- **Derived from the basic scenario ranking method**
- **Efficient to implement**
- **Effective screening tool**

5.2.7 Criteria-based scenario evaluation

The criteria-based ranking is a derivative of the basic scenario ranking method. The two key differences are that numerical scores are not used and the scenario risk results are binary (i.e., pass or fail). Specific recommendations are made based on failure to meet the acceptance criteria.

Preestablished criteria

Preestablished criteria are listed in the table below. The left-hand column of this table shows the type of evaluation criteria illustrated by the actual criteria in the right-hand column. The specific scenario can now be evaluated based on how well it meets these specific preestablished criteria.

Type of Criteria	Examples
Number of safeguards that must fail before a specific accident of interest occurs (i.e., the number of events in each scenario)	There may not be any one-event scenarios capable of causing a major explosion in an engine room Two safeguards must be in place to prevent a release of oil from entering the water
Types of safeguards that must fail before a specific accident of interest occurs (i.e., the types of events in each scenario)	There may not be a situation in which a high pressure excursion in a boiler could occur without at least one equipment failure in addition to the equipment failure or human error that initiated the high pressure (i.e., no complete dependence on human response to the upset condition) An active and a passive equipment protection, or two passive equipment protections, are required for any scenario capable of causing a catastrophic consequence
Combinations of the number and types of safeguards that must fail before a specific accident of interest occurs (i.e., the numbers and types of events in each scenario)	Single-event scenarios are only acceptable if the event is a passive equipment failure **and** the worst-case effect would not be catastrophic Scenarios involving multiple passive equipment failures are considered practically impossible unless there is some dependency (i.e., common cause) between the failures

Scenario evaluation

This table presents some accident scenarios evaluated against preestablished criteria. Recommendations are made when the evaluation criteria are not met.

Item	Accident Scenario	Types of Events	Acceptable?	Recommendation
1	Operator leaves valve A open, operator leaves valve B open, and operator fails to verify that valves A and B are closed before introducing hazardous material into the tank	HE, HE, HE	No	Needs equipment protection
2	Major external impact	IEE	Yes	None
3	Mechanic improperly calibrates the relief valve on cargo tank A, and pressure control valve for cargo tank A sticks closed	HE, AEF	Yes	None
4	Catastrophic rupture of cargo tank A	PEF	Yes	None
5	Operator fails to open the isolation valve under the relief valve on cargo tank A after maintenance of the relief valve, operator fails to detect improperly positioned valve during monthly status checks of special valves, operator inadvertently misdirects a high-pressure feed stream into cargo tank A, and operator fails to detect and mitigate rising pressure (based on other pressure indications)	HE, HE, HE, HE	No	Needs equipment protection
6	Operator fails to open the isolation valve under the relief valve on cargo tank A after maintenance of the relief valve, operator fails to detect improperly positioned valve during monthly status checks of special valves, pressure controller erroneously commands pressure control for cargo tank A to close, and operator fails to detect and mitigate rising pressure (based on other pressure indications)	HE, HE, AEF, HE	Yes	None

Limitations of criteria-based scenario evaluation

- Basis of criteria has inherent limitations and inaccuracies

Risk reduction methods

- **Point estimates**
- **Categorization**

5.3 Risk reduction methods

As presented earlier in this section, risk assessment involves processing a large quantity of data to characterize the risk of a system or activity. The next step is understanding what changes will reduce the risk to acceptable levels. Point estimates and categorization methods can be used to assess the impact of change.

Point estimates. Point estimates provide precise calculations of the risk associated with a particular activity. When recommending change, the same point estimate process can be applied to the activity, considering the frequency of initiating events and the failure of safeguards both before and after the proposed change. Comparing the point estimates after the change to those before provides an assessment of the impact of the change.

Categorization. Using likelihood and consequence categories, the outcomes of each applicable scenario are evaluated both before and after the change. Results are generally presented in a tabular or matrix form to provide the analyst with an overall assessment of the change for all affected scenarios.

Example risk reduction using point risk estimate

Similar to the example shown earlier in this section, a risk assessment team identified three scenarios that could cause the same accident, which has an associated consequence of $10,000. The accident frequency is the sum of the scenario frequencies.

Scenarios	Incident	Failed Safeguards		Scenario Frequencies
Scenario 1	Valve leaks (1/y)	x Flow not stopped (0.1)	x Oil enters water (0.01)	= 0.001/y
Scenario 2	Hose leaks (0.1/y)	x Flow not stopped (0.1)	x Oil enters water (0.1)	= 0.001/y
Scenario 3	Hose ruptures (0.01/y)	x Flow not stopped (1.0)	Oil enters water (1.0)	= 0.01/y
			$F_{accident}$	= 0.012/y

Risk = 0.012/y x $10,000 = $120/y

After evaluating the three scenarios and reviewing the equipment associated with the accidents and the safeguards, the team noted that providing greater containment capacity under the hose would add an additional barrier against oil entering the water from a hose rupture. The following table illustrates the expected risk level after implementing this modification.

Scenarios	Incident	Failed Safeguards		Scenario Frequencies
Scenario 1	Valve leaks (1/y)	x Flow not stopped (0.1)	x Oil enters water (0.01)	= 0.001/y
Scenario 2	Hose leaks (0.1/y)	x Flow not stopped (0.1)	x Oil enters water (0.1)	= 0.001/y
Scenario 3	Hose ruptures (0.01/y)	x Flow not stopped (1.0)	Containment not effective (0.1)	= 0.001/y
			$F_{accident}$	= 0.003/y

Risk = 0.003/y x $10,000 = $30/y

These point estimate calculations indicate a savings of $90 per year as a result of implementing this single change.

Risk Reduction = $120/y – $30/y = $90/y

Example risk reduction using categorization

Using risk categories (i.e., categories for frequency and severity) to assess change is an effective means for getting a high-level view of the overall risk associated with a system or activity and provides the analyst with a framework for recommending change. In the risk matrix below, the numbers in each box represent the number of scenarios that have the associated frequency and severity pairs. For example, when analyzing a particular vessel, the team identified 175 scenarios having an "Occasional" frequency with a "C" severity. Similarly, the team identified four scenarios having a "Frequent" frequency with a "B" severity.

Before Implementing Changes to Reduce Risk

Frequency of occurrence	D	C	B	A
Continuous		1		
Very Frequent	2	14		
Frequent	143	110	4	
Occasional	200	175	10	1

Severity of consequence

These types of risk matrices can be used in two ways: (1) to assess where the risks are in a system or activity and thus identify what areas should be considered for change, and (2) to illustrate the impact of change by showing how the numbers shift to other regions in the matrix.

After recommending change to a system, the team revisited the affected scenarios and reassessed the associated frequency and severity categories. The following matrix illustrates the results.

After Implementing Changes to Reduce Risk

Frequency of occurrence	D	C	B	A
Continuous				
Very Frequent	1	14		
Frequent	143	113	2	
Occasional	202	175	10	

Severity of consequence

As shown, both of the single high-risk events (i.e., the event with the high frequency and the event with the catastrophic severity) as well as some of the lower-risk issues have been reduced to lower risk categories. This revised matrix illustrates the new characterization of the risk as a result of the changes.

Once the “before” and “after” risk matrices are developed, the risk reduction impact can be determined. The following two tables show the same “before” and “after” risk matrices slightly reconfigured to aid in determining the estimated impact of the changes to the system.

Both tables summarize the frequency and severity of all loss scenarios evaluated in an analysis. For example, in the first table the team determined that there were 143 loss scenarios that could result in Level D losses 1 to 10 times per year. Next, multiply the 143 scenarios by their associated frequency range of 1/yr to 10/yr (giving 143 to 1,430 losses per year). Do the same for the rest of the scenarios under Level D and sum the results to determine the Frequency Summary of Level D losses. You can determine the Frequency Summary for the other three severity levels the same way. To get the range of Expected Losses for each severity level, multiply the upper and lower bounds of the Frequency Summary with the average consequence for the severity level. The total expected range of annual losses presented below the table is the sum of the Expected Losses for all severity levels.

Before Implementing Changes to Reduce Risk

Example Loss Estimates

Frequency	Severity Level			
	D ($1K to $10K) Average Consequence: $1K	**C** ($10K to $100K) Average Consequence: $30K	**B** ($100K to $1M) Average Consequence: $300K	**A** ($1M to $10M) Average Consequence: $3M
Continuous (Between 100 events every year and 1,000 events every year)		**1**		
Very Frequent (Between 10 events every year and 100 events every year)	**2**	**14**		
Frequent (Between 1 event every year and 10 events every year)	**143**	**110**	**4**	
Occasional (Between 1 event every 10 years and 1 event every year)	**200**	**175**	**10**	**1**
Frequency Summary (by Severity Level)	183 to 1,830 per year	367.5 to 3,675 per year	5 to 50 per year	0.1 to 1 per year
Expected Losses (by Severity Level)	Using the Average Consequence: $183K to $1.83M per year	Using the Average Consequence: $11.025M to $110.25M per year	Using the Average Consequence: $1.5M to $15M per year	Using the Average Consequence: $300K to $3M per year

Total Expected Annual Losses: $13.008M to $130.08M

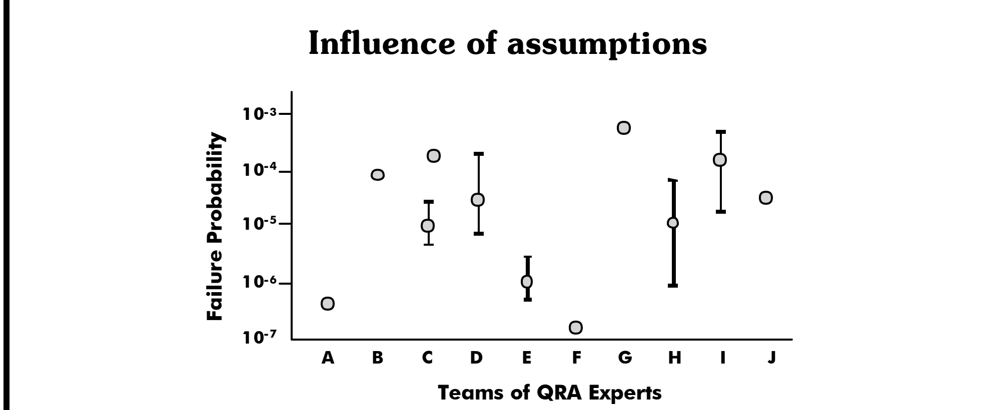
After Implementing Changes to Reduce Risk

Example Loss Estimates

Frequency	Severity Level			
	D ($1K to $10K) Average Consequence: $1K	**C** ($10K to $100K) Average Consequence: $30K	**B** ($100K to $1M) Average Consequence: $300K	**A** ($1M to $10M) Average Consequence: $3M
Continuous (Between 100 events every year and 1,000 events every year)				
Very Frequent (Between 10 events every year and 100 events every year)	**1**	**14**		
Frequent (Between 1 event every year and 10 events every year)	**143**	**113**	**2**	
Occasional (Between 1 event every 10 years and 1 event every year)	**202**	**175**	**10**	
Frequency Summary (by Severity Level)	173.2 to 1,732 per year	270.5 to 2,705 per year	3 to 30 per year	Level A losses are not expected to occur
Expected Losses (by Severity Level)	Using the Average Consequence: $173K to $1.73M per year	Using the Average Consequence: $8.115M to $81.15M per year	Using the Average Consequence: $900K to $9M per year	Level A losses are not expected to occur

Total Expected Annual Losses: $9.188M to $91.88M

The expected risk reduction after the recommended changes are made is the difference in the Total Expected Annual Losses between these two tables. In this example, the expected risk reduction is between $3.82M and $38.2M.



5.4 Influence of assumptions

When performing risk assessments, you should pay attention to any assumptions made when identifying accidents and estimating accident likelihoods and consequences. The above graph shows the results of a study in which several teams of risk experts calculated the failure probability of a system. The circles represent each team's estimated failure probability, and the bars show the uncertainty bands that some teams developed with their estimates. All the experts were given the same system design and the same failure data for the system components. The different answers were attributed to the different assumptions the experts made. When the study was repeated with the same assumptions, each team produced similar answers.

Involving the right group of stakeholders, not just one subject matter expert, and building consensus about assumptions and scope limitations will help you avoid similar problems in your own risk assessments.

Risk Assessment

Many risk assessment methods exist; however, they have common features:

- **structured**
- **predictive**
- **experience based**
- **adaptive**

6.0 Introduction to Risk Assessment Methods

There are many risk assessment methods. No one is inherently better or worse than another. They all have appropriate applications and share the following features:

Structured. Each risk assessment method has some type of structure to promote a complete examination of possible problems. Some methods have very rigid structures, while others are more flexible. More highly structured methods usually provide a more complete evaluation, but they often require much more analysis effort. Although less structured risk assessment methods require less skill to apply, they need more input from subject matter experts to make up for issues that the basic nature of the assessment might overlook.

Predictive. Some risk assessment methods can be valuable for investigating accidents that do occur. However, the main use of such methods is to characterize the possibility of future accidents. Therefore, risk assessment forecasts what is expected in the future.

Experience based. Risk assessments are predictive, but they do not ignore the past. Some of the best insight into possible accidents is based on information about the types, frequencies, and severities of past accidents in the same or similar operations. Risk assessments use this information, as well as information about corrective actions taken to address past accidents, to examine expected performance. Risk assessment methods gather this information from many sources, including records (equipment files, maintenance records, electronic databases, manufacturer information, etc.) and the opinions of subject matter experts (experienced engineers, operators, technicians, and others).

Adaptive. Most risk assessment methods can be used at various levels of detail and for many types of systems and processes. This adaptive nature makes most risk assessment methods very flexible.

Information available from risk assessments

- **Qualitative accident scenario descriptions**
- **Qualitative judgments about expected accidents**
- **Quantitative measures of factors related to loss prevention**
- **Importance of accident contributors**
- **Recommendations for improvement**

6.1 Information available from risk assessments

The information produced from risk assessments can be divided into the following categories:

Qualitative accident scenario descriptions. These descriptions define sequences of events capable of producing accidents of interest. The sequences can include equipment failures, human errors, and external influences.

Example:

- Carpenter or painter fails to wear appropriate eye protection and is injured from flying debris.

Qualitative judgments about expected accidents. Analysts often have informed opinions about whether the threat of possible accidents will exceed stated or implied loss prevention goals. These judgments are usually based on the numbers and types of events possibly leading to accidents. Judgments regarding the numbers of events would look at such things as single failures or errors versus multiple-event scenarios. Judgments regarding types of events would look at such things as equipment failures while in service, equipment failures in stand-by safety systems, mistakes made by forgetting to do something, mistakes made by doing the wrong thing, etc. These judgments are often made based on decisions made in other studies.

Example:

- The frequency and severity of injuries from personnel coming into contact with flying debris in the buoy maintenance facility will be much less when personnel are required to wear safety glasses.

Quantitative measures of factors related to loss prevention. These numeric estimates of loss prevention-related factors include measures such as reliability, availability, environmental risk, personnel or public risk, economic risk, etc. The measures are used to judge whether the threat of possible accidents exceeds numerical loss prevention goals. Sometimes these measures include studies (*what-if* scenarios) of sensitivity to changes such as implementation of recommendations, changes in operating conditions or strategies, etc.

Example:

- We expect that between one and 10 people will sustain temporarily disabling injuries leading to four or more days of lost time per person each year.

Importance of accident contributors. These results show the most important possible accidents based upon the likelihood and consequences of those accidents. Importance rankings can prioritize not only types of accidents, but also specific equipment failures and human errors.

Example:

- Failure to wear safety glasses and other personal protective equipment contributes to personnel injury at shore facilities in 50% of the identified accidents. Excessive lifting contributes to personnel injury in 35% of the accidents. The top contributors associated with the remaining 15% of the accidents are evenly divided between crew fatigue and automobile accidents.

Recommendations for improvement. Typical risk assessment results also include suggestions for reducing the frequency of accidents or preventing them altogether. These recommendations include suggestions for new or improved engineered systems, programs, policies, and items for further study. These recommendations may lessen the likelihood or consequences of an accident.

Example:

- Consider requiring personnel to wear hearing protection while using power tools such as saws and sanders. Consider enrolling these people in the formal hearing conservation program.

Life cycle approach to performing risk assessments

- Research
- Design
  - conceptual
  - preliminary
  - detailed
- Fabrication/ construction/ manufacturing
- Operation
  - startup
  - ongoing
- Decommissioning

6.2 Life cycle approach to performing risk assessments

Risk assessments can be used at every step in the life cycle of a marine system or process. The following sections discuss the use of risk assessment throughout a life cycle.

Research. Risk assessment focus at this stage is on identifying the safety and reliability of certain technologies. Assessments are performed using technical models to help us understand how failures occur over time.

Design. Risk assessment focus at this stage is on making sure that the selected operating strategy will meet overall goals. Risk managers are very interested in identifying *weak links* and opportunities for improvement in components and systems.

- **Conceptual phase.** Risk assessment focus at this stage is on deciding how overall goals can be used to define goals for individual systems. Without reviewing a lot of detail, assessments consider whether or not the system will be able to perform as expected and what changes or improvements would be needed to meet overall goals. Risk managers compare different design ideas to decide which options make the most sense based on several factors, including project risk and expected life cycle costs such as the cost of accidents and their prevention.
- **Preliminary phase.** Risk assessment focus at this stage is on how individual system goals can be used to define component goals. Assessments consider at a more detailed level whether or not the system will be able to perform as expected and what changes or improvements would be needed to meet system goals. The most favorable system performance features are based on a number of factors, including costs, loss of commerce, risk, etc.

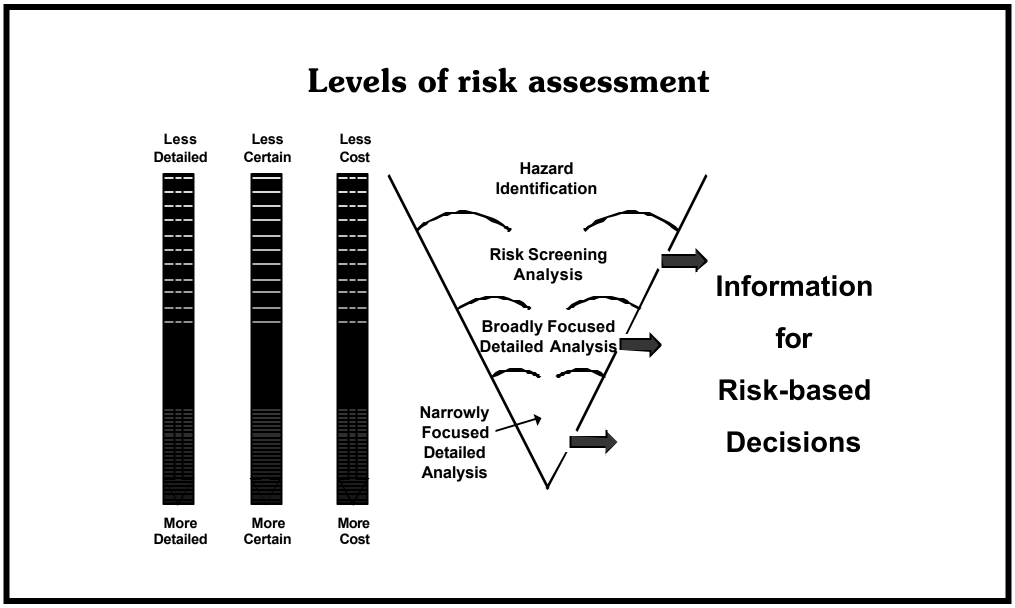
- **Detailed phase.** Risk assessment focus at this stage is on making sure the selected components work together so that the systems can meet individual component goals. Assessments consider at a component level whether or not the components will be able to perform as expected and what changes or improvements would be needed to meet component goals. The most effective component selection is based on a number of factors, including costs, loss of commerce, risk, etc. Risk managers are also interested in the following:
  - critical limits for safe and reliable fabrication, construction, and manufacturing
  - important operating limits and startup guidelines
  - appropriate preventive or predictive maintenance jobs
  - necessary spare parts and materials stores

Fabrication, construction, and manufacturing. Risk assessment focus at this stage is on making sure that specifications have been met. The assessment also tries to find any fabrication, construction, and manufacturing issues that could negatively affect the system, leading to loss. Assessments consider the importance of any identified field defects, as well as any suggested changes during fabrication, construction, and manufacturing.

Operation. Risk assessment focus at this stage is on the effectiveness of operating, maintenance, and supply strategies for reaching loss prevention goals.

- **Startup.** Risk assessment focus at this stage is on making sure that operating and maintenance plans (including programs, procedures, and training) help to achieve the safety and reliability designed into the system and are effective based on factors including costs, loss of mission, risk, etc.
- **Ongoing.** Analysis focus at this stage is on ensuring the following:
  - changes (planned, unplanned, and unintentional) do not greatly affect loss prevention performance
  - operating and maintenance plans are effective based on several factors, including costs, loss of commerce, risk, etc.

Decommissioning. Risk assessment focus at this stage is on liability issues related to removing equipment from service and what actions to take to make sure those risks stay at acceptable levels. These liability issues include safety, health, and environmental risks.



6.3 Levels of risk assessment

The goal of any risk assessment is to provide information that helps stakeholders make better decisions whenever the possibility of accidents exists. Therefore, the whole process of performing a risk assessment should focus on providing the type of risk information decision makers will need. The required types of information vary according to the following:

- The types of issues being studied
- The different stakeholders involved
- The significance of the risks
- The costs required to control the risks
- The availability of information and data related to the issue being assessed

Information needs determine how the risk assessment should be performed.

The goal is to perform the least amount of risk assessment necessary to provide information that is *barely adequate* for decision making. In other words, do as little as possible to provide the information decision makers need. Although it is not always obvious in the beginning, decision makers can often make decisions using information that has very little detail or may be uncertain. In other cases, more complicated risk assessment information is necessary. The key is always to begin risk assessments at as general a level as possible and do more detailed studies only in areas where the additional risk assessment will help the decision maker. Unnecessary risk assessment doesn't benefit the decision maker. It also uses up time and money that could have been spent solving the problem or looking at other issues.

The figure on the previous page illustrates the idea of performing different levels of risk assessment. Each level can provide more detailed and better information, but the time, money, and energy required increases at each level. The filtering effect of each level allows only the most important issues to move into the next, more detailed, level of assessment. At any point, if enough information for decision making is gathered, then the risk assessment may end at that level. Not all levels of assessment will be performed for every issue that arises. In fact, most issues will probably be resolved through risk screening or broadly focused, detailed assessments.

At each level, the risk assessment may involve qualitative or quantitative risk characterizations. The following sections briefly describe each level of risk assessment.

Hazard identification. Hazards must be understood because they are the starting point for chains of events that lead to accidents. Although hazard identification doesn't usually provide information for decision making, it is an important step. Sometimes hazard identification is specifically performed using structured techniques. Other times, usually when the hazards of interest are well known, such structured techniques are not necessary. Overall, hazard identification focuses a risk assessment on hazards of interest and the types of accidents these hazards may create.

All risk assessments begin at this level. Analysts with little risk assessment experience and some training can successfully perform these types of risk assessments.

Risk screening assessment. In most situations, there are hundreds or even thousands of ways that accidents can occur. It is usually impractical to assess each of these possibilities in detail. Risk screening assessments are very general assessments that broadly describe risk and identify the most important areas for further investigation. Sometimes this level of assessment is enough to provide all of the information decision makers need; however, more detailed assessment of important issues is most common.

Once the hazards are understood, all risk assessments should begin at this level. Generally, analysts with fairly modest risk assessment experience and some training can successfully perform these types of assessments.

Broadly focused, detailed assessment. When specific activities or systems are found to have important or uncertain risks, broadly focused, detailed assessments are generally used. These assessments use structured tools for finding specific combinations of human errors, equipment failures, and external events that lead to consequences of interest. These assessments may also use qualitative or quantitative risk characterizations so that good risk management strategies can be defined.

Most risk assessments are broadly focused, detailed assessments that use qualitative risk characterizations or, at most, quantitative categorization. These risk assessments require analysts with training and experience. This is the most advanced level of assessment that someone without a specialty in risk assessment should try.

Narrowly focused, detailed analysis. When specific human errors, equipment failures, or external events are particularly important or uncertain, more narrowly focused, detailed risk assessments are needed. These assessments generally study specific issues in great detail, often involving many numeric calculations to describe the risk.

This level of assessment should be used only for those applications truly needing this level of information. Only analysts with special training and some supervised experience should try this level of risk assessment.

The following page shows a table listing the risk assessment methods discussed in this publication. The table indicates the levels of analysis for which each method is most often used.

Risk Assessment Method	Applicability to Various Levels of Risk Assessment			
	Hazard Identification	Risk Screening	Broadly Focused, Detailed Analysis	Narrowly Focused, Detailed Analysis
Pareto analysis		X		
Checklist analysis	X	X	X	X
Relative ranking/risk indexing		X	X	
Preliminary risk analysis (PrRA)		X		
Change analysis	X	X	X	X
What-if analysis	X	X	X	X
Failure modes and effects analysis (FMEA)			X	X
Hazard and operability (HAZOP) analysis			X	
Fault tree analysis (FTA)			X	X
Event tree analysis (ETA)		X	X	X
Event and causal factor charting				X
Preliminary hazard analysis (PrHA)	X	X		

RISK-BASED DECISION-MAKING GUIDELINES

Volume 2
Introduction to Risk-based Decision Making

Basic Principles

Chapter 3 — Principles of Risk Management

Chapter Contents

This chapter provides an overview of basic risk management principles that play a key role in the risk-based decision-making process. Major topics addressed in this chapter include:

1.0 Risk Goals

It is hard to control risks without knowing where to aim or how closely you have come to hitting the target. Therefore, the first step in managing risk involves establishing risk management goals.

All operations in an organization present some risk. To determine whether operations are adequately controlled, management must establish some risk acceptance criteria. The criteria usually take the form of a frequency level, a consequence severity, or a combination of these two, with an understanding that the criteria should not be exceeded. A possible system failure that violates these criteria usually results in recommendations to better control the risks.

Factors Affecting Risk Acceptance

Many factors influence our acceptance of risk:

- **Familiarity**
- **Frequency**
- **Control**
- **Media attention**
- **Consequence**
- **Suddenness of consequence**
- **Personal versus societal**
- **Benefit**
- **Dread**

2.0 Factors Affecting Risk Acceptance

In deciding how to manage risk, one key question is whether or not a risk is acceptable. Many factors affect our perception of acceptable risk. These include the following:

Familiarity — People are more comfortable and accepting of risk when they are personally familiar with the operation. For example, is a traveler more fearful of a bus accident or a plane crash? Which has the greater risk?

Frequency — Our belief in the frequency of an accident influences our risk acceptance. If we do not believe that the accident will happen, we are more likely to accept the risk.

Control — We accept more risk when we are personally in control, because we trust ourselves. For example, are you more afraid when you drive a car too fast or when you are the passenger in a speeding car?

Media attention — We fear problems that we are aware of and that we think are important and credible. Media coverage of issues increases our awareness of a problem and our belief in its credibility.

Consequence — We are not likely to accept risk for facilities that can have accidents with severe consequences. For example, an accident at a nuclear power plant could affect a large population. Therefore, we build very few such plants and we stringently regulate their safety. The risk related to coal-fired plants may be higher, but such plants are not as stringently regulated by the government.

Suddenness of consequence — The sooner we feel the impact of an event, the less likely we are to accept the risk. Would you risk your life to save your car from a carjacker? Would you risk your life by smoking cigarettes for 40 years?

Personal versus societal — We accept risk that affects only ourselves. We apply a higher standard to protect society.

Benefit — As the benefit we receive from an operation increases, we are more accepting of the risk. For example, driving a car is more risky than traveling by plane. Because of personal benefit, people are usually more accepting of driving than flying.

Dread — We have a strong fear or dread of risks whose severity we believe we cannot control. These risks are thought to be catastrophic, fatal, hard to prevent, inequitable, threatening to future generations, and involuntary. An example is the risk of cancer. People are fearful of anything that may cause cancer because of the nature of the disease, its treatment, and, in some cases, the low probability of recovery.

Issues of Acceptable Risk

- **There is no practical definition**
- **Its perception varies among industries**
- **It is very hazard specific**
- **Even government agencies are not consistent**
- **There are contemporary comparisons that can be made**

3.0 Issues of Acceptable Risk

With so many factors influencing our ideas about risk, it is nearly impossible for us to define “acceptable risk.” Many companies and the government have tried, but everyone has a different understanding of “acceptable risk.” For example, what risk is acceptable with the carcinogens benzene in gasoline and asbestos in public buildings? Even though defining acceptable risk is difficult, we should not give up on the idea. By setting a risk standard, organizations can more easily identify high-risk operations, can more appropriately allocate resources, and can measure the effectiveness of their risk reduction efforts.

The table on the next page is a summary of implied risk acceptance criteria from different government agencies for a variety of substances. Although the numbers listed are no longer valid, they show that acceptable risk is hard to determine.

Agency Interpretations of Significant Risk

Lifetime individual risks that agencies chose to regulate

Risk*	***Substance (statute)***
4×10^{-1}	Arsenic (OSHA)
2×10^{-1}	Ethylene dibromide (OSHA)
1×10^{-1}	Ethylene oxide (OSHA)
6×10^{-2}	Asbestos (OSHA)
3×10^{-2}	Arsenic from primary copper smelting (CAA)
2×10^{-2}	Coke oven emissions (CAA)
1×10^{-2}	Methylenedianiline (TSCA)
1×10^{-2}	Butadiene (TSCA)
1×10^{-2}	Uranium mines (CAA)
5×10^{-3}	Benzene from coke ovens (CAA)
2×10^{-3}	Benzene from fugitive emissions (CAA)
1×10^{-3}	Radionuclides from phosphate mines (CAA)
8×10^{-4}	Arsenic from glass manufacture (CAA)
8×10^{-4}	Radionuclides from DOE installations (CAA)
2×10^{-4}	Workers in coke ovens (OSHA)
1×10^{-4}	Radionuclides from NRC licensees (CAA)

*Probability of death given maximum regulated exposure

Risk Management Categories

S — Spread out
T — Transfer
A — Accept
A — Avoid
R — Reduce

4.0 Risk Management Categories

Risk can be managed in many different ways throughout the life cycle of the system. The following list describes the major categories of risk management strategies:

Spread out — Spread the loss exposure responsibility out among different entities, across operations, or across time

Transfer — Make others accept loss exposure responsibility

Accept — Live with the current loss exposure level or responsibility

Avoid — Cancel or delay the activity that involves the risk, or do not operate equipment that involves the risk

Reduce — Do something to reduce the accident potential

Category	Description	Example for a Possible Fishing Derby
S	Spread out	Ask local authorities to get involved in planning
T	Transfer	Make the applicants arrange safety patrols, emergency response
A	Accept	Do nothing
A	Avoid	Don't allow the derby
R	Reduce	Make the participants pass Coast Guard Auxiliary Boating Skills and Seamanship course

Accident Prevention Options

- Eliminate hazards
- Prevent initiating events (incidents)
- Add safeguards
- Make safeguards more reliable
- Reduce consequences
- Reduce effects

5.0 Accident Prevention Options

Accidents can be well controlled at any point in the chain of events producing the accident. The goal is to get the most for your money by doing the things that are most effective. The following sections describe each of the risk management options.

Eliminate hazards. Make processes inherently safer by eliminating hazards.

Examples:

- Eliminate energy sources:
  - pressure
  - heat
  - potential energy
  - kinetic energy, etc.
- Don't use hazardous materials and materials that can generate hazardous energy

Prevent initiating events (incidents). Reduce the likelihood of initiating events.

Examples:

- Eliminate error-likely situations that set people up for failure
- Perform inspections, tests, and preventive maintenance when needed
- Improve design ratings and factors of safety

Add safeguards. Provide multiple layers of safeguards, sometimes called layers of protection, in critical applications.

Examples:

- Add additional instrumentation, equipment, or safety interlocks, especially items with different design and operation
- Make the operators perform more surveillance and checks during operations

Make safeguards more reliable. Reduce the chance of safeguard failures.

Examples:

- Eliminate error-likely situations that set people up for failure
- Perform additional or more frequent inspections, tests, and preventive maintenance
- Improve design ratings and factors of safety
- Make sure that enough people are assigned to operations and maintenance departments

Reduce consequences. Make processes inherently safer by reducing the severity of consequences.

Examples:

- Reduce energy stored or generated as:
  - pressure
  - heat
  - potential energy
  - kinetic energy, etc.
- Keep only small inventories of hazardous materials and materials that can generate hazardous energy
- Use other, less hazardous, materials in place of more hazardous materials
- Provide shutdown and response systems to limit consequences. These include alarms and quick-shutoff valves.

Reduce effects. Protect people and other valuables from consequences.

Examples:

- Provide emergency response training
- Provide personal protective equipment
- Move people away from the danger zones
- Train the employees and community to find shelter in a safe place

Guidelines for choosing risk management options

We can measure how well our actions are working, or will work, to reduce risk. Three general measures of risk management success are shown in the table below.

Criterion	Description
Efficacy	How much of the risk will be eliminated or minimized by the proposed action?
Feasibility	Is the proposed action acceptable (legally, physically, politically, socially, technically, etc.)?
Efficiency	Is the proposed action cost-effective? In other words, is the cost of implementing the action low compared to the loss that could occur if no action were taken?

An effective risk management activity must strike a good balance among the three criteria in the above table.

RISK-BASED DECISION-MAKING GUIDELINES

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Basic Principles

Chapter 4 — Principles of Risk Communication

Chapter Contents

This chapter provides an overview of basic risk communication principles that play a key role in the risk-based decision-making process. Major topics in this chapter include:

Definition of Risk Communication

"The interactive process of exchanging information and opinion among individuals, groups, and institutions involving multiple messages about the nature of risk..."

The National Research Council

1.0 Definition of Risk Communication

Communicating about risk is an important and challenging part of doing business with corporations, the government, and the military. In fact, some professional communicators believe that, in modern society, all communication is risk communication. The National Research Council's definition shows what risk communication is and what it is not.

What risk communication *is:*

An interactive process. This process (1) requires an understanding of factors that affect the communication process and ways in which people think about risk and risk information, and (2) provides for ongoing response and discussion with key audiences and affected parties.

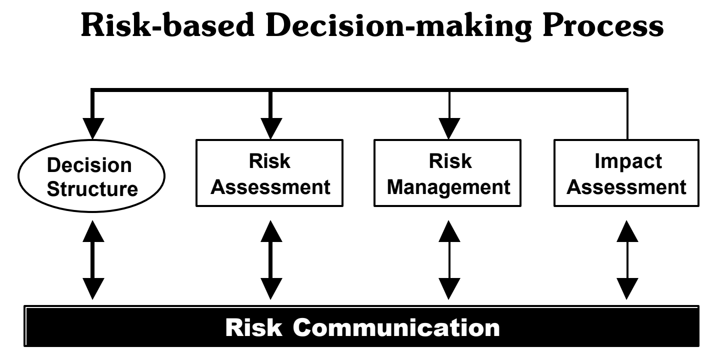
An exchange of information and opinion. The goals of this information exchange include (1) improving people's understanding and (2) changing impressions, attitudes, and behaviors.

A process that involves individuals, groups, and institutions. These participants see your communication as (1) objective (a product of research, statistics, and technical expertise) or (2) subjective (based on personal values and experience).

A process that concerns the nature of risk. The nature of risk is more than simply the frequency and consequence of an event. It involves questions such as, "What can happen to me, personally?" and "What can I do to keep from having to deal with this?" It also involves the history of the risk and the future associated with addressing it.

Risk communication is *not:*

- A set of gimmicks or techniques to avoid debate or criticism
- A collection of unclear messages
- An afterthought during the final stages of risk assessment
- A promise of general agreement or consensus about risk management actions



2.0 Risk Communication in the Risk-based Decision-making Process

Skilled risk communication must take place throughout the risk-based decision-making process. The graphic above shows that communicating about risk is a part of all phases of the process. Risk-based decisions will rarely produce the desired results if the decisions are made without considering the opinion of those who will be affected; that is, the stakeholders.

The involvement of all stakeholders in the risk-based decision-making process is essential and is consistent with the Coast Guard Marine Safety and Environmental Protection Business Plan (FY2001-2005) capability goal of partnership and stakeholder engagement. Every effort should be taken to include appropriate representatives from both internal and external organizations, as well as individuals affected by key risk-based decisions. Involving other stakeholders enhances the risk-based decision-making process in the following ways:

- It creates a sense of "buy-in" with the final decision among the stakeholders
- It allows stakeholders to understand other points of view
- It facilitates the consideration of ideas that would have been overlooked without stakeholder involvement

A balance of stakeholder involvement is required, though. Involving too many stakeholders in all aspects of the risk-based decision-making process can be overwhelming to the stakeholders and counterproductive to the decision-making objectives. At the same time, bringing in stakeholders after the decision-making process has progressed too far can also be counterproductive. These issues must be considered early in the decision-making process.

When dealing with members of the public, remember that concerned citizens feel they have fought for and won the right to have a say in environmental, health, and safety matters that may affect their lives. The standard for “successful” risk communication in this setting has risen steadily. Citizens have come to expect notification, an exchange of views, and, whenever possible, consensus on key issues. They want to weigh the benefits against the potential downsides of economic and environmental decisions. They do not want surprises.

Refer to the PTP Guide for Improving Communications sponsored by G-MSE (located in the General Resources directory of Volume 4) for more information on how to communicate with the public.

Risk Communication Cycle

- **Assess**
- **Prepare and train**
- **Broaden outreach and dialogue**
- **Plan and coordinate**
- **Communicate risk**
- **Follow up and evaluate**

3.0 Risk Communication Cycle

Risk communication activities usually follow six basic steps. Any or all may take place at any time throughout the risk-based decision-making process, and not all activities are necessary for each situation. The step you choose to take and when you choose to take it depend on the circumstances. Audiences or groups of stakeholders may choose to be involved at different levels and at different times in the process. However, all stakeholders must be genuinely given the opportunity to participate. Their opinions and concerns must be addressed, even if common ground cannot be found.

Assess

- Identify audiences. These can include mariners, industry, environmental groups, and citizen action groups, as well as local, state, and federal government
- Determine how well the community understands the risks
- Evaluate existing communication efforts
- Evaluate available communication media

Prepare and train

- Become familiar with basic principles and techniques of risk communication
- Learn and practice basic presentation skills

Broaden outreach and dialogue

- Encourage community and stakeholder involvement
- Set up ways to exchange ideas with the community
- Improve community outreach efforts

Plan and coordinate

- Set up a communication plan and timeline
- Establish a mission statement and set measurable goals
- Identify the primary concerns of each audience
- Select paths of communication for each audience
- Identify communication tools for each audience

Communicate risk

- Develop and test messages
- Create communication materials
- Arrange events to exchange ideas
- Start up dialogue with key audiences

Follow up and evaluate

Risk communication is a two-way street and an ongoing process. You must, therefore, do the following:

- Follow up and respond to stakeholder input, questions, and concerns
- Evaluate whether the communication process is effective

Refer to the PTP Guide for Improving Communications sponsored by G-MSE (located in the General Resources directory of Volume 4) for more information on how to communicate with the public.

Successful Risk Communication

- Factors influencing personal values
- Three principles of risk communication
- Seven cardinal rules of risk communication

4.0 Successful Risk Communication

Risk communication is the exchange of information, opinions, and ideas between you and the stakeholders. It is much more than communicating information and expecting stakeholders to come around to your side of the table. While you are presenting information from your point of view, so are many others. When faced with opposing views, participants in risk communication often become confused and may ignore input from one or all sides of an issue. This causes communication efforts to fail. Successful risk communication requires all stakeholders to know that their input has been heard and considered.

Successful risk communication also happens when all parties involved believe they are receiving quality information, and each person considers the values of the various participants. It is a mistake to assume that hazards, consequences, and remedies are viewed the same way by everyone.

Factors influencing personal values

These factors may include the following:

- Cultural background
- Shared interests, concerns, and fears
- Social attitudes
- Ability to understand technical language
- A personal stake in the process or outcome

Three principles of risk communication

Perception = Reality
Goal = Trust + Credibility
Communication = Skill

4.1 Three principles of risk communication

Understanding the values of your stakeholders and how their values influence opinions and beliefs is only one factor in a successful risk communication program. Research into risk communication offers other guidelines that affect your communication efforts. These principles fall into three general categories:

Perception = Reality

Even if the stakeholder's perception is not based on fact, it cannot be dismissed. In risk communication, you must deal with expected or known perceptions that may disagree with your technical understanding. These perceptions are still real to the person who holds them and must be respected as that individual's reality.

Goal = Trust + Credibility

The goal of successful risk communication is reached through the development of a basic trust with the stakeholders, often influenced by past experience, and the soundness of the information communicated. Low-trust, high-risk situations require more care in developing the risk messages.

Communication = Skill

Even when trust is earned, results are positive, and leaders are sincere, the success of risk communication depends on the communication skills of those involved. Factors that affect how risk messages are understood include the following:

- Sincerity of the source (YOU)
- Content of the message (WHAT you say)
- Delivery of the message (HOW you say it)
- Planning (WHERE you say it)

Seven cardinal rules of risk communication

1. **Accept and involve the public (actually, all of the stakeholders) as a partner**
2. **Plan carefully and evaluate your efforts**
3. **Listen to your audience**
4. **Be honest and open**
5. **Plan and work with other reliable sources**
6. **Meet the needs of the media**
7. **Speak clearly and with understanding**

4.2 Seven cardinal rules of risk communication

Even if you establish a trusting relationship with your stakeholders, risk communication can provide a tangled web of information. Though this may be the information age, *more* information is not always *better* information. Information coming from many sources may contain opposing messages. Therefore, it is up to you to make sure that the messages you communicate are clear, accurate, and understood (if not accepted). You must also provide ways to accept the same kind of messages from your stakeholders. While the three principles of risk communication will guide you through the beginning of your risk communication efforts, the following seven cardinal rules of risk communication will help you carry out an effective program.

1. Accept and involve the public (actually, all of the stakeholders) as a partner. Paying lip service to the risk communication process is worse than having no risk communication at all.

2. Plan carefully and evaluate your efforts. If you do not know where you are going, how will you know when you get there? Set measurable goals in the beginning.

3. Listen to your audience. Act on and respond to their concerns.

4. Be honest and open. The human qualities of the person who represents you have a more lasting impact than the words of the message. You become the message.

5. Plan and work with other reliable sources. Involve reliable third parties — clergy, local elected officials, emergency responders, employees — in the risk communication process.

6. **Meet the needs of the media.** Most members of the public receive their information from the media.

7. **Speak clearly and with understanding.** Even a well-structured and well-delivered message can be lost if it is delivered by an unskilled speaker.

The following table provides a few factors affecting the ways in which risk is understood, along with situations that tend to increase and decrease public concern.

Factors Affecting Risk Perception		
Factor	**Conditions Associated with *Increased* Public Concern**	**Conditions Associated with *Decreased* Public Concern**
Disastrous potential	Deaths and injuries at the same time in the same place	Random deaths and injuries
Familiarity	Unfamiliar	Familiar
Understanding	Mechanisms or process not understood	Mechanisms or process understood
Controllability (own)	Uncontrollable	Controllable
Exposure willingness	Involuntary	Voluntary
Effects on children	Children specifically at risk	Children not specifically at risk
Effects timing	Delayed effects	Immediate effects
Future generation effects	Risk to future generations	No risk to future generations
Victim identification	Identifiable victims	Statistical victims
Dread	Effects dreaded	Effects not dreaded
Trust in institutions	Lack of trust in responsible institutions	Trust in responsible institutions
Media attention	Much media attention	Little media attention
Accident history	Major or minor accidents	No major or minor accidents
Equity	Uneven spread of risks and benefits	Even spread of risk and benefits
Benefits	Unclear benefits	Clear benefits
Reversibility	Effects irreversible	Effects reversible
Origin	Caused by human actions or failures	Caused by acts of nature of God

Developing Key Messages

- **Premise statement**
- **Support points**
- **Enhancements**

5.0 Developing Key Messages

Keeping these risk communication principles and rules in focus throughout the risk communication process helps you work toward your goal, in which all parties involved believe they have received quality information. Nowhere in the process are these principles and rules more important than in developing your key messages. Your key messages — no more than three, each of which is no more than 15 to 20 words — are the heart of the communication process. Begin by considering what is most important in the minds of your audiences. Environment? Health of their children? Job security? Knowing what kinds of information your audience wants will help you prepare messages more effectively.

Messages generally have three parts:

Premise statement. The fundamental message. The one thing you want your audiences to know or understand about you and what you do.

Support points. Develop two to four key support points for your premise statement. Use easy-to-understand facts or figures, stories or comparisons, historical data, or quotes from reliable third-party sources.

Enhancements. These are examples or sketches of your story in action, elements that give your story a human face — a person who developed a new safety process, for instance, or an end-user who benefits personally from the fact that the Coast Guard is here.

The next page provides a checklist to help you develop and present better risk communication messages.

Risk Message Checklist*

Information about the Nature of Risks	
	What are the hazards of concern?
	What is the probability of exposure to each hazard?
	What is the spread of exposure (who is exposed to the hazard)?
	How likely is it that someone will be harmed from a given exposure to each hazard?
	What are the sensitivities of different populations to each hazard?
	How do exposures interact with exposures to other hazards?
	What are the qualities of the hazard?
	What is the total population risk?
Information about the Nature of Benefits	
	What are the benefits associated with the hazard?
	What is the probability that the expected benefit will actually follow the activity?
	What are the qualities of the benefits?
	Who benefits and in what ways?
	How many people benefit and how long do benefits last?
	Which groups get an unequal share of the benefits?
	What is the total benefit?
Information on Options	
	What are the options regarding the hazards in question?
	What is the effectiveness of each option?
	What are the risks and benefits of other actions and of not acting?
	What are the costs and benefits of each option and how are they spread out?
Uncertainties in Knowledge about Risks	
	What are the weaknesses of available data?
	What are the assumptions on which estimates are based?
	How sensitive are the estimates to changes in the assumptions?
	How sensitive is the decision to changes in the estimates?
	What other reviews have been made; what differences exist and why?
Information on Management	
	Who is responsible for the decision?
	What issues have legal importance?
	What constrains the decision?

*Improving Risk Communication, National Research Council

Dealing with an Angry Public

- **Why is the public angry?**
- **Develop a mutual gains approach to dealing with an angry public**

6.0 Dealing with an Angry Public

Risk communication often takes place among parties who are on opposite sides of an issue. One or all of the parties, particularly *the public*, may be angry.

Why is the public angry?

Members of the public may be angry for any of several reasons:

- Because they have been negatively affected by something
- Because they are fearful of being negatively affected by something
- Because they disagree in principle with something that is happening

Traditional responses to an angry public have included (1) proving that the public has not been negatively affected by something, (2) attempting to put aside public fears, and (3) downplaying differences in values. In addition, many organizations find well-known supporters for their point of view.

Develop a mutual gains approach to dealing with an angry public

The traditional approach does not work, because a public that prefers not to take any additional risk does not trust the supporters. In addition, advocacy groups sometimes take advantage of conflict for their own ends. Often, the media increase distrust, and the public does not understand that the differing interests are valid. The mutual gains approach to dealing with an angry public is more effective when you do the following:

- Accept concerns of the other side
- Encourage joint fact finding

- Offer commitments to reduce impacts if they do occur; promise to make up for unintended effects
- Accept responsibility, admit mistakes, and share power
- Act in a trustworthy way at all times
- Focus on building long-term relationships

The mutual gains approach to dealing with an angry public has, at its core, effective risk communication. During this process, you must do the following:

- **Take the initiative** — do not wait until you are on the defensive
- **Seek agreement** — do not try to convince people they are wrong; give them a reason to do what you want them to do
- **Emphasize outcomes** — do not lose sight of your long-term objectives
- **Maintain credibility** — do not say anything that you know is not true; do not make promises you cannot keep
- **Enhance legitimacy** — act as you want others to act

Working with the Media

Three keys to success with the media:
- **use conflict creatively**
- **put substance in a sound bite**
- **present the story visually**

7.0 Working with the Media

Many stakeholders affected by your issues, whether angry or not, get most of their information from the media. The media are essentially the pipeline through which information to the public must ultimately pass. Therefore, the media are vital to the success of any risk communication program. Knowing how the media work and understanding their role in the communication process can help you communicate with this important audience and, thus, with the audiences the media reach for you.

Journalists work under tight deadlines and management constraints. They often have little technical expertise or understanding, and they cover viewpoints, not truths. Your story, whether good or bad, competes for air time or print space with many others. Remember, bad news sells, and that is what journalists are first to cover. While you cannot prevent media coverage of the bad news, you can work effectively to see that all information is fairly and accurately presented. The Coast Guard has developed several formal protocols for working with the media. Work with the appropriate Coast Guard public affairs office when you know the decision-making process will require contact with the media.

Three keys to success with the media

1. **Use conflict creatively.** Every media interview is an opportunity to show your organization's commitment to its mission. It is a chance to spread your message and improve public opinion.
2. **Put substance in a sound bite.** Most television stories are 45 to 90 seconds long; you have about 20 seconds to get your point across. Focus on your key messages, and always answer questions honestly. Do not give in to the temptation to tell the reporter more than he or she, or the audience, wants to know.

3. **Present the story visually.** Provide easy-to-understand charts, graphs, and photographs for print media, and video or audiotapes for the electronic media.

Some Interview "Dos" and "Don'ts"

Do
- speak to the physical audience
- consider the editorial process
- refer to key messages often
- state important facts first
- say you don't know if you don't
- be responsive, but maintain control
- keep answers short
- keep it simple
- assume the camera is always on
- be serious

Don't
- say "No comment"
- speculate or guess
- lie
- speak off the record

Some Interview "Dos" and "Don'ts"

The following are some important "dos" and "don'ts" to remember when talking with the media. While these suggestions are not magical formulas for success, they should help you avoid some of the most common media interview pitfalls.

Do

Speak to the physical audience. Speak to the reporter or camera crew. If addressing a gathering of people, speak to that audience.

Consider the editorial process. The reporter is looking for a 10- to 20-second sound bite containing your actions and concerns.

Refer to your key messages often. Do this at every opportunity.

State the most important facts first. Who, what, when, where, why, and how. Speak directly and simply.

Say you don't know if you don't. Do not try to snow the questioner. The questioner will have greater respect for you and your operations if you do not waste time trying to dance around the issue. Say "I don't know, but as soon as I can get that information, I'll get back to you." Then do it.

Be responsive, but maintain control. Do not lose your cool with a questioner who seems pushy or technically uninformed.

Keep your answers short. They are more easily understood and less likely to be edited by the media.

Keep it simple. Do not be technical. Remember, you are talking to people who do not share your knowledge of your organization. Do not use jargon or acronyms.

Assume that TV cameras and microphones are always on. Assume they are recording your words, actions, and expressions.

Be serious. Any attempt at humor will fail with some listeners, and may embarrass you as well.

Don't

Say "No comment." The questioner will think you are trying to hide something. If you cannot discuss something because it involves matters of a confidential nature or because you do not know, say so.

Speculate or guess. Do not allow yourself to be drawn into answering hypothetical questions or into debates with third parties who are not present.

Lie. Be honest and factual.

Speak off the record. With the media, there is no such thing. Assume that anything you say in an interview — or before or after an interview — is fair game for publication or broadcast.

RISK-BASED DECISION-MAKING GUIDELINES

Volume 2
Introduction to Risk-based Decision Making

Overview of Assessment Tools

Chapter 5 — Decision Analysis Tools

Chapter Contents

This chapter provides an overview of different decision analysis tools and includes basic instructions for using each tool. The following are the major topics in this chapter:

Summary of Decision Analysis Tools

- **Help structure the decision process**
- **Vary from informal to formal methods**
- **Provide documentation of the decision-making process**

1.0 Summary of Decision Analysis Tools

Decision analysis tools provide a structured process for making decisions. This chapter presents four types of decision analysis tools appropriate for many uses:

- Voting methods
- Weighted scoring methods
- Decision trees
- Optimization methods

The following paragraphs describe three basic features of decision analysis tools:

Help structure the decision process. Decision analysis tools have a basic structure to help you examine options and make a decision.

Vary from informal to formal methods. Some tools have very rigid structures, while others are more flexible. Typically, more highly structured tools provide more complete evaluation but often require much more effort than less structured tools. Although less structured tools usually require fewer skills, they need more input from subject matter experts to make up for issues that the decision-making process might overlook. This wide range of methods allows you to choose the proper level of effort for the complexity of the decision.

Provide documentation of the decision-making process. Decision analysis tools provide written data supporting the results of the decision-making process. This documentation can also be used to make other decisions for similar situations.

Guidelines for Selecting Decision Analysis Tools

- **Level of effort**
- **Uncertainty**
- **Qualitative or quantitative information**

2.0 Choosing Decision Analysis Tools

A few guidelines should be considered when choosing a decision analysis tool. These include the following:

Level of effort

The amount of time and money spent on decision analysis should depend on the expected results of the decision. Some tools are simple and quick, while others require a lot of effort. For example, a $10,000 decision probably does not warrant a $6,000 decision analysis.

Uncertainty

All data used in the decision-making process will have some level of uncertainty, or doubt. Medium to high levels of uncertainty in the data can produce an uncomfortable level of uncertainty in the analysis results. Some decision analysis tools specifically model uncertainty in the input data.

Qualitative or quantitative information

Most decision analysis tools accept numeric inputs. These inputs range from equipment performance specifications to numerical rankings of features or competing alternatives. Some tools handle qualitative inputs (e.g., good reliability, easy to operate, more expensive) more easily than others; however, some tools cannot handle qualitative inputs at all. Most tools provide numeric outputs, such as scoring or ranking of alternatives, for making decisions. The level of detail in the results depends on the complexity of the tool.

Voting Methods

Results for the Plurality and Ranking Voting Methods									
	Participant					Plurality		Ranking	
Option	A	B	C	D	E	No. of #1 Votes	Position	Average Rank	Position
1	1	1	4	4	5	2	2	3	1
2	8	6	1	1	1	3	1	3.4	3
3	2	4	7	8	3	0		4.8	4
4	7	5	2	7	4	0		5	5
5	3	7	3	5	7	0		5	5
6	6	3	6	6	6	0		5.4	7
7	4	2	5	3	2	0		3.2	2
8	5	8	8	2	8	0		6.2	8

3.0 Summary of Voting Methods

Voting methods for decision analysis use a team of experts to review and vote on different choices. These methods rely on the ability of the stakeholders to understand the advantages and disadvantages of each choice and to vote accordingly.

Brief summary of characteristics

- Minimal effort is required. Modeling of problems requires little information, and the models usually have little structure, with decision factors not plainly identified
- Uncertainty is not specifically modeled but is addressed informally
- Outputs are quantitative

Situations for using voting methods

- Large number of stakeholders
- Possible negative results from the decision are minimal
- Uncertainty and sensitivity analyses are not needed
- Documentation is not required

Advantages of voting methods

- Quick to perform
- Easy to use
- Can be used for almost any decision

Example

The following is a simple example demonstrating the plurality and ranking voting methods. The table below shows the plurality and ranking method used to decide on options 1-4. Each person (A-E) ranked the options in order of preference.

Plurality steps

Results for the Plurality Voting Method							
	Participant					Plurality	
Option	A	B	C	D	E	No. of #1 Votes	Position
Oil spill control system 1	1	1	2	2	2	2	2
Oil spill control system 2	4	3	1	1	1	3	1
Oil spill control system 3	2	4	3	3	3	0	
Oil spill control system 4	3	2	4	4	4	0	

Step 1. Each person ranks the alternatives. The table shows that Options 1 and 2 received all of the first phase votes.

Step 2. Select the alternative with the most #1 votes. Option 2 is selected using the plurality method.

Ranking steps

Results for the Ranking Voting Method							
	Participant					Ranking	
Option	A	B	C	D	E	Average Rank	Position
Oil spill control system 1	1	1	2	2	2	1.6	1
Oil spill control system 2	4	3	1	1	1	2.0	2
Oil spill control system 3	2	4	3	3	3	3.0	3
Oil spill control system 4	3	2	4	4	4	3.4	4

Step 1. Each participant ranks all alternatives. The rows of numbers under participants A - E show the ranking of each option by each participant.

Step 2. The rankings are summed and averaged. The average rank column shows the average ranking of each option.

Step 3. The alternative with the lowest average is selected. Option 1 is chosen using the ranking method as shown by the position column.

Disadvantages of voting methods

- When voting methods are used, there is usually very little written data to show how a decision was reached. This can lead to second-guessing of the decision, especially by individuals outside the voting group. Lack of documentation limits the ability to use the information in making other, similar decisions.
- Voting methods often do not make use of all information available to the decision-making group. For example, the plurality method does not consider the ranking of options, and neither the ranking method nor the plurality method considers the way an individual prefers one option over another.
- Strengths and weaknesses of options are unclear. The negative aspects of an alternative are usually not described, and the reasons for supporting an option are not documented.
- Typically, the issues or options are only listed and not described. This can lead to confusion as to what is really being voted on.
- The information from each expert is typically weighted equally, regardless of the actual experience of each expert.

Weighted Scoring Methods

Factor	Value (Score)					Weighted Scores			
	Weight	Pump A	Pump B	Pump C	Pump D	Pump A	Pump B	Pump C	Pump D
Safety	30%	Very High (100)	High (75)	Medium (50)	Medium (50)	30	22.5	15	15
Flowrate	20%	2.6 (73)	2.5 (72.5)	1.3 (45.5)	2.1 (70.5)	14.6	14.5	9.1	14.1
Cost	50%	$520 (48)	$270 (73)	$560 (44)	$400 (60)	24	36.5	22	30
Initial		$500	$230	$430	$350				
Operating		$20	$40	$130	$50				
					Total	68.6	**73.5**	46.1	59.1

4.0 Summary of Weighted Scoring Methods

Weighted scoring methods plainly identify decision factors, and each alternative is compared to the factors. The decision models address many factors. A numerical value is assigned to each alternative for each factor. Various factors are weighted differently. The weighted numerical values are added, and the alternative with the highest score is the best overall alternative.

Brief summary of characteristics

- Both qualitative and quantitative inputs are easily handled
- Each alternative is given an overall score

Situations for using weighted scoring methods

- Group or individual decision making
- Few alternatives (<10)
- Timing is not an issue

Example

The example on the following pages demonstrates the steps for using a weighted scoring method to make decisions. The decision involves choosing a fuel pump for an onboard system.

Weighted scoring steps

Step 1. Define the decision factors of interest. For choosing a fuel pump, the following factors could be considered:

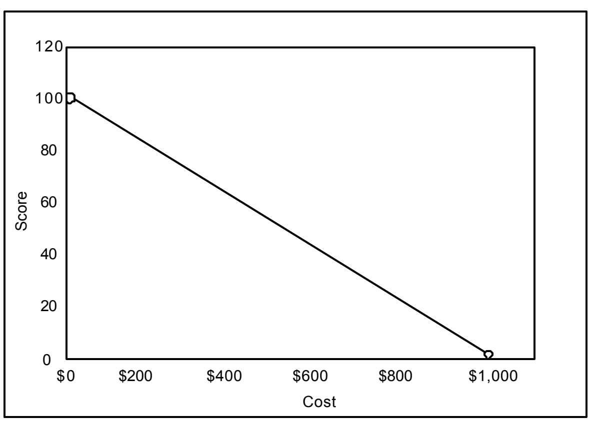
- Safety
- Flowrate (i.e., capacity)
- Cost
  - initial
  - operating

Step 2. Assign importance levels, or weights, to each decision factor. Weight each decision factor based on its importance in the decision-making process. Subject matter experts need to participate in this step.

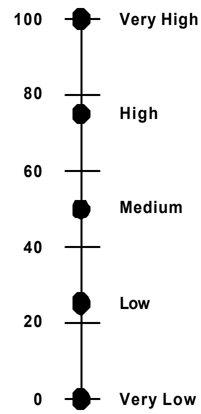
Factor	Weight
Safety	30%
Flowrate	20%
Cost	50%
	100%

Step 3. Develop scales for changing decision factor values into scores. A scale of some type allows the decision maker to rate the factors of each option. Scales can be created in a variety of forms. The following are scales for cost, safety, and flowrate.

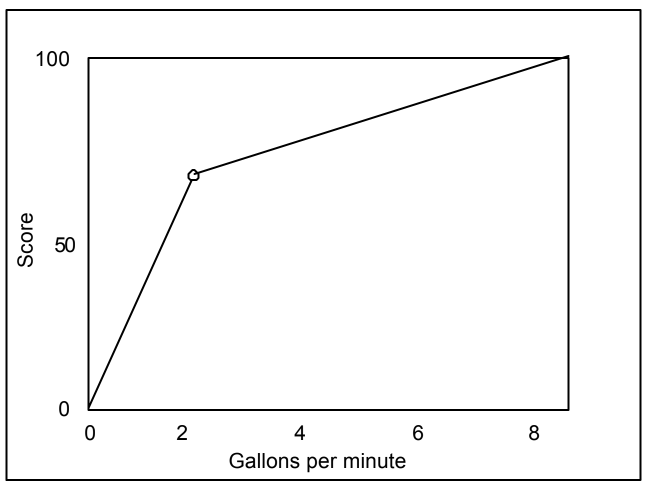
Evaluation scale for cost



Evaluation scale for safety



Evaluation scale for flowrate



Step 4. Score each decision factor for each alternative, multiply the score by its weight, and sum the weighted scores. The table below shows the ratings of four pumps. For example, Pump D has a medium safety (which translates to a 50), a flowrate of 2.1 gallons per minute (which translates to 70.5), and a cost of $400 (which translates to 60). The weighted scores are the weights of each factor multiplied by the score.

	Value (Score)					Weighted Scores			
Factor	Weight	Pump A	Pump B	Pump C	Pump D	Pump A	Pump B	Pump C	Pump D
Safety	30%	Very High (100)	High (75)	Medium (50)	Medium (50)	30	22.5	15	15
Flowrate	20%	2.6 (73)	2.5 (72.5)	1.3 (45.5)	2.1 (70.5)	14.6	14.5	9.1	14.1
Cost	50%	$520 (48)	$270 (73)	$560 (44)	$400 (60)	24	36.5	22	30
Initial		$500	$230	$430	$350				
Operating		$20	$40	$130	$50				
					Total	68.6	**73.5**	46.1	59.1

The results show that Pump B has the highest total weighted score and, therefore, would be the best choice.

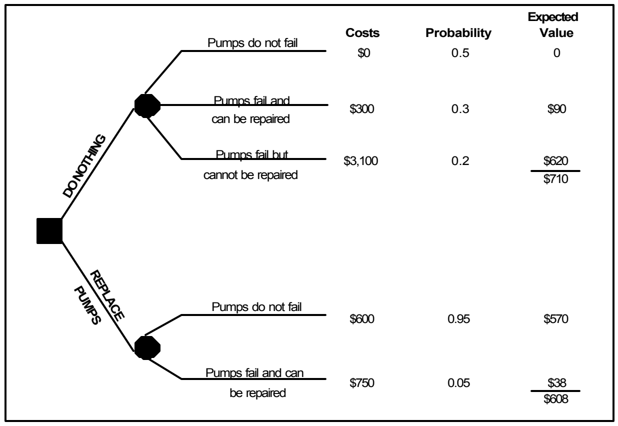
Advantages of weighted scoring methods

- Address different factors, such as the pump flow rate and the cost of the pump
- Different types of scales can be used for the various factors
- Decision factors are plainly identified and weighted so the group can reach an agreement on each item
- Can be used by individuals or groups

Disadvantages of weighted scoring methods

- Time consuming — decision factors and evaluation scales must be developed, and each alternative must be compared against each evaluation scale
- Basic scoring models do not plainly account for uncertainty
- Difficult to address future events or pending decisions
- Decision factors may be linked, which may result in double counting. For example, the age of the vessel is linked both to the number of associated accidents and the vessel's repair costs

Decision Trees



5.0 Summary of Decision Trees

The decision tree method of decision analysis uses a tree structure to illustrate the decision process. Probabilities are assigned to events, and the expected value of each alternative is determined. The alternative with the most attractive total expected value is chosen. Depending on the decision, the most attractive expected value may be the highest or lowest number.

Brief summary of characteristics

- Decision trees require (1) sequential modeling of decision points and chance events and (2) the development of probabilities and outcome values for each branch
- Uncertainty of inputs is plainly modeled in the tree branches
- Sensitivity analysis can be implemented easily but is best approached with commercial software
- Inputs and outputs are quantitative. Qualitative inputs are difficult to address.

Situations for using decision trees

- Sequential decision models
- Uncertain inputs

Example

The following example shows the steps for performing a decision tree analysis. The problem is to determine whether aging pumps should be replaced. Below are information about the pumps, the available options, and costs associated with the options.

Pumps are aging

- If pumps fail, they are difficult to repair, and some spare parts are no longer available
- Two major options
  - do nothing
  - replace pumps

Possible outcomes if "do nothing" option is selected

- Pumps do not fail (50%)
- Pumps fail and can be repaired (30%)
- Pumps fail and cannot be repaired (20%)

Possible outcomes if "replace pumps" option is selected

- New pumps may also fail (5%)
  - failure rate should be lower
  - all failures can be repaired

Costs associated with options

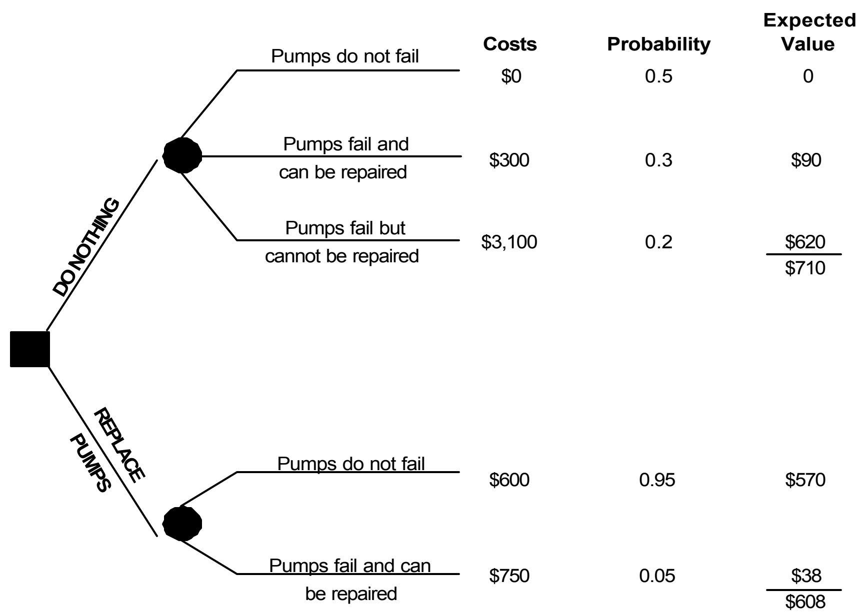
- Replacement pumps cost $500, and related labor costs for installation are $100
- There is no downtime associated with planned replacement of the pumps
- Repairing old pumps costs $200 for labor and $100 in downtime
- If old pumps fail and cannot be repaired, labor costs for installation are $100 and downtime costs are $2,500
- Repairing new pumps costs $100 for labor and $50 in downtime

Decision tree steps

Step 1. Draw a decision tree. The tree below represents the pump problem.

- Use a ■ for a decision
- Use a ● for an occurrence

Step 2. Assign probabilities to the outcomes. Use data and subject matter experts to estimate probabilities of outcomes occurring. For example, in the tree above, the estimated probability the pumps do not fail if nothing is done is 50%.



Step 3. Assign costs or benefits (opposite sign of cost) to the outcomes. If there is a cost and benefit, add them. Consider the following types of cost:

- Cost of procurement
- Cost of labor
- Cost of downtime to install
- Benefits of new pumps and control system

In the example, the cost of replacing the pumps and the pumps not failing is $600.

Step 4. Determine expected values of options. Multiply the cost or benefit by its probability to figure out the expected value at the outcome. Add the expected values of the outcomes for each alternative to arrive at the alternative's expected value.

Option	Outcome	Pumps	Costs Labor	Downtime	Total Cost	Probability	Expected Value	Notes
Do Nothing	Pumps don't fail	$0	$0	$0	$0	50%	$0	
	Pumps fail and can be repaired	$0	$200	$100	$300	30%	$90	
	Pumps fail but can't be repaired	$500	$100	$2,500	$3,100	20%	$620	1
							$710	
Replace Pumps	Pumps don't fail	$500	$100	$0	$600	95%	$570	2
	Pumps fail and can be repaired	$500	$200	$50	$750	5%	$38	3, 4
							$608	

Notes

1 - Large downtime costs are the result of procurement time ($2,500), not installation time

2 - Labor costs are for installation of the pumps ($100)

3 - Labor costs include installation of the pumps ($100) and repairs ($100)

4 - New pumps can be repaired for 50% of the downtime costs of the old pumps

The table above shows the total cost, the probability, and the expected value of each option. For example, the expected value of replacing the pumps is $570 plus $38, for a total of $608.

Step 5. Compare expected values of options benefits. Compare expected values and choose the one that meets the decision goals. In this example, the option "replace the pumps" should be chosen because the expected value (in this case a cost) is lower.

Step 6. Examine assumptions. Review assumptions made in estimating costs and probabilities to make sure the results are correct. The notes in the table above are examples of assumptions.

Advantages of decision trees

- Can be used to show a series of conditional choices
- Can be used to show the impact of time on decisions
- Can plainly model uncertainty
- Can produce quantitative results

Disadvantages of decision trees

- All decision factors must be changed into common units. Qualitative inputs may be difficult to convert (e.g., translating community goodwill to dollars, or effects on organizational reputation to dollars)
- Decision trees are harder to develop in a group setting
- Developing and reaching agreement on event probabilities may be difficult
- Qualitative methods are not easily used
- The number of possible outcomes in the model can be extremely large

Other Decision Analysis Tools

- **Optimization Methods**
- **Kepner-Tregoe Decision Analysis**
- **Benefit-cost Analysis**
- **Multiattribute Utility Analysis**

6.0 Other Decision Analysis Tools

There are other decision analysis tools available, and some are listed below. Those included in this chapter were chosen because they are well developed, widely usable, and cover a range of complexity.

Optimization Methods

- Can address many or infinite alternatives
- Accept only quantitative inputs
- Find the optimal solution to a complex problem
- Identify feasible solutions that meet all limits
- Require a great deal of effort to develop and solve equations. Reaching stakeholder agreement on the model may be difficult.
- Uncertainty is not directly addressed

Kepner-Tregoe Decision Analysis

- Similar to the weighted scoring method, but evaluation scales are not developed
- Uncertainty not directly addressed

Benefit-cost Analysis

- Tries to make decisions independent of the preferences of decision makers
- Is data driven
- Minimizes the cost/benefit ratio across the affected groups
- Group that pays for the analysis may not receive benefits
- Often used by government agencies

Multiattribute Utility Analysis

- Extension of decision analysis and decision trees to address more than one performance criterion
- Plainly addresses uncertainty and value trade-offs
- Evaluation scales much the same as weighted scoring methods developed

RISK-BASED DECISION-MAKING GUIDELINES

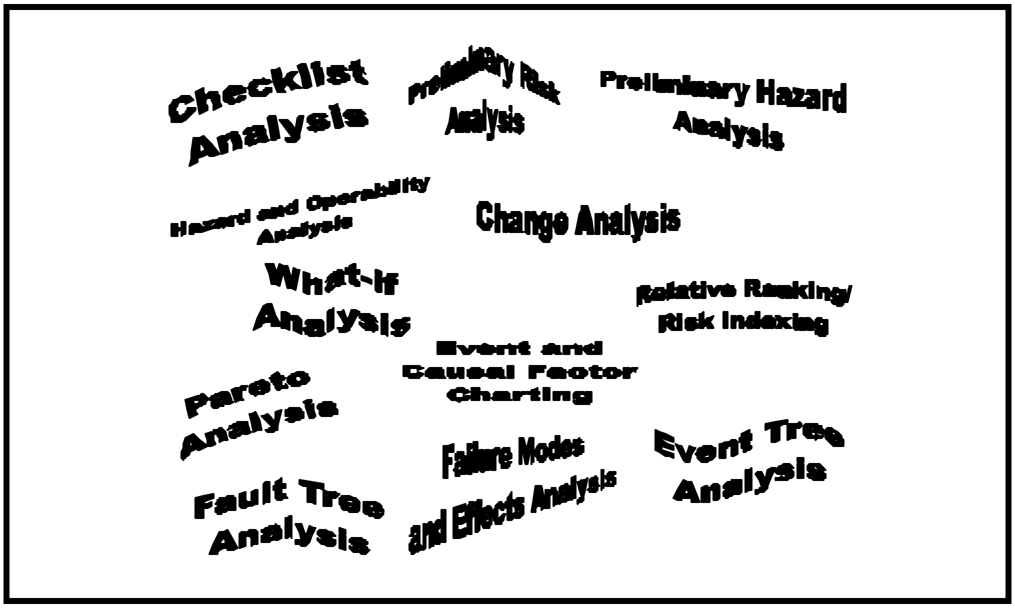
Volume 2
Introduction to Risk-based Decision Making

Overview of Assessment Tools

Chapter 6 — Risk Assessment Tools

Chapter Contents

This chapter provides an overview of some of the risk assessment tools that are used for marine systems. The brief summaries are in a tabular format and point to the specific locations in Volume 3 where additional information on these tools can be found.



Overview of Commonly Used Risk Assessment Tools

There are many hazard and risk assessment tools. The tables that follow provide a brief overview of 12 commonly used tools that are well suited to risk assessments of marine systems. They include:

1. Pareto analysis
2. Checklist analysis
3. Relative ranking/risk indexing
4. Preliminary risk analysis (PrRA)
5. Change analysis
6. What-if analysis
7. Failure modes and effects analysis (FMEA)
8. Hazard and operability (HAZOP) analysis
9. Fault tree analysis (FTA)
10. Event tree analysis (ETA)
11. Event and causal factor charting
12. Preliminary hazard analysis (PrHA)

Overview of Commonly Used Risk Analysis Tools

Hazard Risk Analysis Methods	Summary of Method	More Common Uses	Location
Pareto Analysis	Pareto analysis is a ranking technique based only on past data that identifies the most important items among many. This technique uses the 80-20 rule, which states that about 80 percent of the problems are produced by about 20 percent of the causes.	• Can be used for any type of system, process, or activity as long as enough historical data are available • Usually used to find the most important risk contributors so that more detailed risk assessments can be performed later	Volume 3, Chapter 3
Checklist Analysis	Checklist analysis is an evaluation against existing guidelines in the form of one or more checklists.	• Useful for any type of system, process, or activity, especially when suitable checklists of accident prevention requirements or best practices exist • Most often used when the use of other, more precise, methods such as FMEA and HAZOP analysis are not possible or practical • Checklist analysis is frequently combined with what-if analysis to add depth and allow for creative thinking • An error-likely situation checklist is a special type of checklist for use in human reliability analysis • A walkthrough analysis is a type of human factors checklist helpful for understanding equipment characteristics as they relate to worker actions • The Root Cause Map is a special graphical checklist used in incident investigations to determine root causes	Volume 3, Chapter 4
Relative Ranking/Risk Indexing	Relative ranking/risk indexing uses measurable features of a vessel, shore facility, port, or waterway to calculate index numbers that are useful for comparing risks of different options. These index numbers can, in some cases, be related to actual performance estimates.	• Used to set priorities for boarding and inspecting foreign-flagged vessels • Suited to any type of analysis, especially when only relative priorities are needed, as long as a proper scoring tool exists • Foreign Vessel Targeting Matrix, Waterway Evaluation Tool, Ports and Waterways Safety Assessment, and Rank Risk, Target Risk are Coast Guard methodologies using the relative ranking/risk indexing technique	Volume 3, Chapter 5
Preliminary Risk Analysis (PrRA)	PrRA is a simplified approach to accident-based risk assessment. The main goal of the technique is to define the risk related to important accident scenarios. This team-based approach relies on subject matter experts examining the issues. The team suggests possible accidents, most important contributors to accidents, and protective features. The analysis also identifies the risk of the accidents and identifies recommendations for reducing risk.	• Used for producing risk profiles across a range of activities, such as in port-wide risk assessment • Coarse risk analysis is a special type of PrRA and is deviation-based instead of accident-based	Volume 3, Chapter 6
Change Analysis	Change analysis looks logically for possible risk effects and proper risk management strategies in changing situations (e.g., when system layouts are changed, when operating practices or policies change, when new or different activities will be performed).	• Used for any situation in which change from normal setup, operations, or activities is likely to affect risks (e.g., marine events in ports or waterways) • Can be used as an effective root cause analysis method, as well as a forecasting risk assessment method	Volume 3, Chapter 7

Overview of Commonly Used Risk Analysis Tools (continued)

Hazard Risk Analysis Methods	Summary of Method	More Common Uses	Location
What-if Analysis	What-if analysis is a problem-solving approach that uses loosely structured questioning to (1) suggest upsets that may result in accidents or system performance problems and (2) make sure the proper safeguards against those problems are in place.	• Useful for any type of system, process, or activity • Most often used when the use of other, more precise, methods (e.g., FMEA and HAZOP analysis) are not possible or practical • What-if analysis is frequently combined with checklist analysis to add structure to the analysis	Volume 3, Chapter 8
Failure Modes and Effects Analysis (FMEA)	FMEA is a reasoning approach best suited to reviews of mechanical and electrical hardware systems. The FMEA technique (1) considers how the failure modes of each system component can result in system performance problems and (2) makes sure the proper safeguards are in place. A quantitative version of FMEA is known as failure modes, effects, and criticality analysis (FMECA).	• Used for reviews of mechanical and electrical systems (e.g., fire suppression systems, vessel steering and propulsion systems) • Often used to make planned maintenance and equipment inspection plans more effective • Sometimes used to gather information to help find trouble areas in systems	Volume 3, Chapter 9
Hazard and Operability (HAZOP) Analysis	The HAZOP analysis technique uses special guide words for (1) suggesting departures from design intents for sections of systems and (2) making sure that the proper safeguards are in place to help prevent system performance problems.	• Used for finding safety hazards and operability problems in continuous process systems, especially fluid and thermal systems. Also used to review procedures and other sequential or batch operations • Another type of guide word analysis technique is Worker and Instruction Safety Evaluation, which is used to understand the significance of human errors	Volume 3, Chapter 10
Fault Tree Analysis (FTA)	FTA is a technique that graphically models how logical relationships between equipment failures, human errors, and external events can combine to cause specific accidents of interest. Probabilities and frequencies can be added to the analysis to estimate risks numerically.	• Suited to almost every type of risk assessment, but best used to focus on the basic causes of specific system failures of relatively complex combinations of events • Often used for complex electronic, control, or communication systems • 5 Whys is a less complicated fault tree analysis technique used in incident investigations to determine root causes	Volume 3, Chapter 11
Event Tree Analysis (ETA)	ETA is an analysis technique that uses decision trees to model the possible outcomes of an event that can produce an accident of interest. Probabilities and frequencies can be added to the analysis to estimate risks numerically.	• Suited to almost every type of risk assessment, but best used to focus on possible results of events for which many safeguards are in place as protective features • Often used for analysis of vessel movement incidents, the spread of fires or explosions, or toxic releases • A human reliability analysis event tree is a specific and detailed method used in modeling human reliability	Volume 3, Chapter 12

Overview of Commonly Used Risk Analysis Tools (continued)

Hazard Risk Analysis Methods	Summary of Method	More Common Uses	Location
Event and Causal Factor Charting	Event and causal factor charting is used to understand how an accident occurred, by finding specific equipment failures, human errors, and external events contributing to the accident. Then, the analysis continues to discover the underlying root causes of the key contributors to the accident and to make recommendations for fixing the root causes.	• Used to study any accident or some selected problem • Event and causal factor charting is most commonly used when the accident scenario is complicated, involving a chain of events or a number of root causes	Volume 3, Chapter 13
Preliminary Hazard Analysis (PrHA)	The PrHA technique is a broad, basic study that focuses on (1) finding hazards, (2) assessing the severity of accidents that could occur involving the hazards, and (3) finding protective features or safeguards for reducing the risks of the hazards. This technique focuses on finding weaknesses early in the life of a system, thus saving time and money that might be needed for major redesign if the hazards are found later.	• Usually conducted early in the development of an activity or system when there is little detailed information or few operating procedures, and is often the first of further risk assessments • In any type of system or process, used to identify and rank hazards	Volume 3, Chapter 14

Summary of Key Features

Risk Analysis Method	Types of Results: Qualitative Accident Descriptions	Types of Results: Quantitative Risk Character-izations	Types of Results: Relative Importances of Accident Contributors	Types of Results: Recommendations	Types of Activities or Systems	Level of Effort/ Complexity	Level of Expertise Required for Analysis Teams
Pareto Analysis		✓	✓	✓	All	Low to medium	Low to medium
Checklist Analysis				✓	All	Low to medium	Low
Relative Ranking/Risk Indexing		✓	✓	✓	All	Low to medium	Low to medium
PrRA	✓	✓	✓	✓	All	Medium	Medium
Change Analysis	✓	✓	✓	✓	All, but generally for systems experiencing recent changes in design or operation	Low to medium	Low to medium
What-if Analysis	✓			✓	All	Medium	Low to medium
FMEA	✓	✓	✓	✓	All, especially mechanical and electrical systems	Medium to high	Medium
HAZOP Analysis	✓			✓	Cargo loading and unloading systems, especially fluid and thermal systems Sequential operations and procedures	Medium to high	Medium

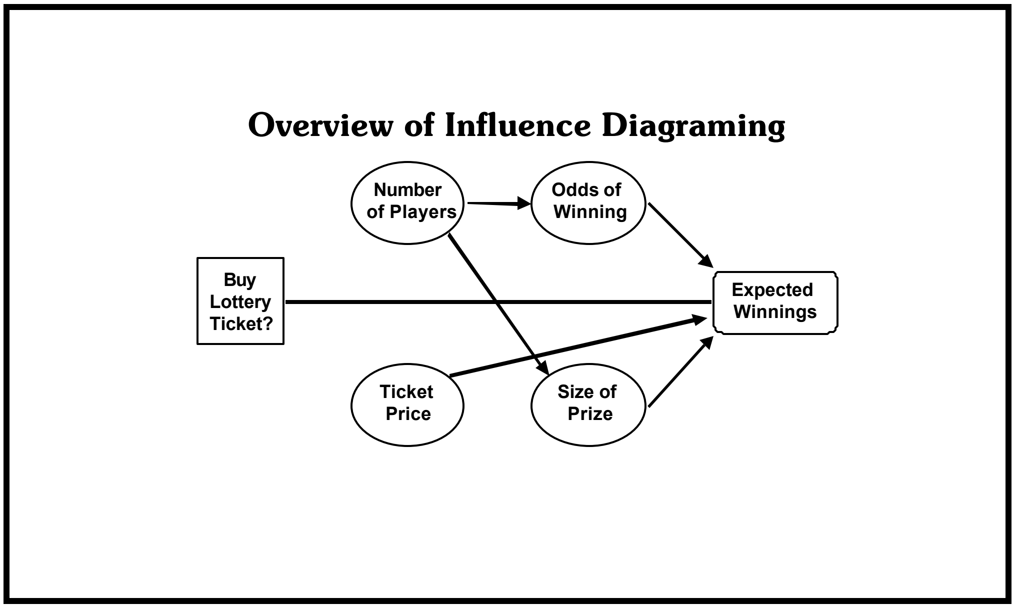
Summary of Key Features (continued)

Risk Analysis Method	Types of Results				Types of Activities or Systems	Level of Effort/ Complexity	Level of Expertise Required for Analysis Teams
	Qualitative Accident Descriptions	Quantitative Risk Character-izations	Relative Importances of Accident Contributors	Recommendations			
FTA	✓	✓	✓	✓	All	High	Medium to high
ETA	✓	✓	✓	✓	All	High	Medium to high
Event and Causal Factor Charting	✓			✓	All	Low to medium	Low to medium
PrHA	✓	✓		✓	All	Low to medium	Low to medium

Overview of Operational Risk Management

Overview of Operational Risk Management

Operational Risk Management (ORM) is another risk assessment tool used in the Coast Guard and referred to in these *Guidelines*. The ORM policies are described in COMDTINST 3500.3. ORM focuses primarily on safety and health issues, looking at Coast Guard internal risks to personnel and property arising from unit operations. It features simple models, tools, and checklists that concentrate primarily on tactical situations related to Coast Guard activities. Although internally focused, the ORM tools have some limited applicability to marine safety decisions, especially those related to preparedness and response issues. Often, the complexity of marine safety issues and the number of associated stakeholders prevent the application of ORM, but you should consider whether ORM will yield suitable information and support for the risk-based decision.



Overview of Influence Diagraming

An influence diagram is a powerful tool for identifying hazards, evaluating risk, determining risk management options, and communicating hazards. By providing a framework for the decision, influence diagrams link the real world with the analytical model. An example influence diagram is shown in the figure above.

As can be seen, influence diagrams are constructed of three elements: branches, directed arcs, and nodes. Nodes are used to capture the various stages for the problem. There are three types of nodes:

- Decision nodes (e.g., buy lottery ticket?)
- Event nodes (e.g., odds of winning)
- Value nodes representing the results of a decision process (e.g., expected winnings)

The nodes are drawn as squares, ovals, and rounded rectangles, respectively. They are typically arranged from left to right, to match the flow of time.

Branches can be used in two ways. They can show possible outcomes of random events, and they can describe possible alternatives. Branches are drawn as line segments between nodes.

Directed arcs are used to show possible conditional dependence. They are drawn as arrows connecting nodes, with the direction indicating dependence. In the example above, they are used to show the effects of the various quantities (e.g., number of players) on later quantities (e.g., odds of winning).

Though this overview is qualitative, influence diagrams can be used quantitatively by applying probabilities to model future events based on the influence of previous events.

RISK-BASED DECISION-MAKING GUIDELINES

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Chapter 7 — Acronym List and Glossary of Terms

Acronyms

AOR	Area of responsibility
CCF	Common cause failure
COTP	Captain of the port
DOI	Document of Inspection
ETA	Event tree analysis
FMEA	Failure modes and effects analysis
FMECA	Failure modes, effects, and criticality analysis
FTA	Fault tree analysis
HAZMAT	Hazardous materials
HAZOP	Hazard and operability analysis
HRA	Human reliability analysis
IBA	Inflatable buoyancy apparatus
LNG	Liquefied natural gas
LOA	Line of assurance
MSO	Marine Safety Office
MTS	Marine Transportation System
OCMI	Officer in charge of marine inspections
ORM	Operational risk management
PAWSA	Ports and Waterways Safety Assessment
PIW	Person in the water
PQS	Personnel qualification standard
PrHA	Preliminary hazard analysis
PrRA	Preliminary risk analysis
R&D Center	Research and Development Center
R2TAR	Rank Risk, Target Risk
RCM	Reliability-centered maintenance
RIN	Risk index number
SAR	Search and rescue
SEH	Safety, environmental, and health
WET	Waterway evaluation tool
WISE	Worker and instruction safety evaluation

Glossary

Accident	Possible result of a deviation; a loss of interest
Accident sequence or scenario	One pathway from an initiating event (incident) to an unwanted result
Actions	Suggestions for design changes, procedural changes, or further study
AND gate	A Boolean logic element used to develop fault trees. The output event related to this gate exists only if all of the input events exist at the same time.
Asphyxiant hazard	The potential for one or more materials to prevent organisms from using oxygen
Basic events	The lowest level of resolution in a fault tree
Branch point	A graphical illustration used when constructing an event tree, usually of two possible outcomes when a line of assurance is challenged
Causal factors	Key events or conditions, such as human error or equipment failure, that may result in an accident. Causal factors are usually (1) an initiating event for an accident, (2) a failed safeguard, or (3) a reasonable safeguard that was not provided.
Cause	An event that, if not mitigated, may result in an accident
Certainty	The confidence that the risk information generated from a risk assessment is accurate
Change analysis	A risk assessment technique that logically identifies risk impacts and risk management strategies in situations where change is occurring
Checklist analysis	An analysis technique that evaluates a situation against existing guidelines in the form of one or more checklists
Chemical asphyxiants	Materials that prevent organisms from using oxygen
Chemical reactant hazard	The potential for one or more materials to chemically combine, or to self-react, and produce unwanted consequences
Combustible or flammable hazard	The potential for one or more materials to quickly react with an oxidant, releasing energy in the form of heat and light
Common cause failure	Failures that occur because of the same root causes, thus defeating many layers of protection at the same time
Consequences	Unwanted events that can negatively affect subjects of interest
Corrosivity hazard	The potential for one or more materials to chemically burn body tissues, especially the skin and eyes, or to excessively erode or dissolve materials of construction or emergency response equipment
Coupling factors	Factors that lead to common cause failures
Data uncertainty	Lack of confidence in the information used to provide risk assessment results
Decision maker	An individual or group, such as a management team, that uses risk assessment results to make risk-based decisions

Glossary (continued)

Deficiency	The failure of a system or operation to perform as it was intended
Demanded events	One or more events that act, or should act, to interrupt the chain of events stemming from an initiating event or incident
Design intent	A planned action or function that should be performed, based on the design specifications
Deviation	An unusual condition or situation that has the possibility to result in an accident
Effects	Measurable negative impacts on subjects of interest
Electrical energy hazard	The potential for unwanted consequences resulting from contact with, or failure of, manufactured or natural sources of electrical voltage or current. Electrical energy hazards include lightning, electrical charges, short circuits, stray currents, and loss of power sources
Error-likely situation	A situation or characteristic of a system or activity that makes human errors more likely
Error-likely situation checklist analysis	An analysis technique that uses a checklist of human factors issues, either general or specific, on areas of an activity to find current strengths and weaknesses
Event tree analysis (ETA)	An analysis technique that uses decision trees to graphically model the possible results from an initiating event that is able to produce an accident of interest
Event and causal factor charting	A written or graphical description for the time sequence of contributing events of an accident
Explosion hazard	The potential for one or more substances to release energy over a short period of time, creating a pressure wave that travels away from the source
Failed safeguards	Planned protections that fail to prevent or reduce unwanted effects
Failure modes and effects analysis (FMEA)	An approach best suited to reviews of mechanical and electrical hardware systems. The FMEA technique (1) considers how the failure modes of each part of the system can cause system performance problems and (2) makes sure that appropriate safeguards against such problems are in place.
Failure modes, effects, and criticality analysis (FMECA)	A quantitative version of FMEA
Fault tree analysis (FTA)	A deductive analysis that uses Boolean logic to graphically model how logical relationships among equipment failures, human errors, and external events can combine to cause specific accidents of interest
Frequency	The expected number of occurrences, per unit time, of an accident
Frequency range	A lower and upper limit of an accident's estimated frequency of occurrence
Hazard and operability (HAZOP) analysis	An approach that uses a logical process with special guide words to suggest ways in which system sections can deviate from design intents. This approach helps ensure that safeguards are in place to help prevent system performance problems.

Glossary (continued)

Hazards	Situations, conditions, characteristics, or properties that create the potential for unwanted consequences
Human error analysis	An analysis that evaluates the possibility for human actions or inactions that are outside the limits set by a system or operating envelope
Human reliability analysis event tree	An analysis tool that is specialized and graphical, similar to event tree analyses. It is designed for evaluating series of operations that people perform. This technique considers human errors and recovery actions, as well as equipment failures.
Impact assessment	The process of tracking the effectiveness of actions taken to better manage risks. The goal is to be sure that the organization is benefiting from the actions as intended.
Indications	Visual, audible, physical, and odor clues, etc., that suggest to a crew member or some other inspector or troubleshooter that a failure mode has occurred
Initiating event	The event in an accident sequence that begins a chain of events that will result in one or more unwanted consequences unless planned demanded events are successful. Also called an incident.
Issues of concern	Consequences that have a great impact on the organization
Items of note	Unwanted events or conditions identified during an analysis that must be addressed or corrected, but did not lead to the loss event of interest
Kinetic energy hazard	The potential for unwanted consequences resulting from motion of materials, equipment, or vehicles
Line of assurance	A protective system or human action that may respond to an initiating event or incident
Loss	Any action, state, or condition in which a system is not meeting one or more of its design intents and causes unwanted consequences
Model uncertainty	Lack of confidence in the models used in both the overall decision-making structure and in risk assessments that support decision making because of the level of detail in the models and scope limits
OR gate	A Boolean logic element used to build fault trees. The output event related to this gate exists if at least one of the input events exists.
Pareto analysis	A screening assessment tool that uses historical information to identify and rank the most notable areas of interest for more evaluation
Potential energy hazard	The potential for unwanted consequences resulting from (1) high pressures other than explosions (e.g., normal operational pressures), (2) low pressures (e.g., vacuum conditions), or (3) mass, gravity, or height (e.g., lifting operations)
Preliminary hazard analysis (PrHA)	A broad study, used in the early stages of system design, that focuses on (1) identifying apparent hazards, (2) assessing the seriousness of accidents that could occur involving the hazards, and (3) identifying safeguards for lowering the risks of the hazards. The PrHA focuses on identifying weaknesses early in the life of the system, thus saving time and money that could be needed for major redesign if the hazards were found later.

Glossary (continued)

Preliminary risk analysis (PrRA)	A streamlined, accident-centered risk assessment approach. The main objective of the technique is to identify the risk of significant accident scenarios.
Qualitative	Expressible in terms of quality or kind (e.g., too much, too little, very high, very low)
Quantitative	Expressible in terms of quantity (e.g., 100 deaths)
Recommendations	Suggestions and action items for (1) reducing the risk of a deviation or (2) providing further evaluation of specific issues
Relative ranking/risk indexing	A ranking technique that uses features of a system or activity to calculate index numbers that can be used to compare different systems and activities. The numbers can, in some cases, be related to absolute risk estimates.
Risk	A measure combining an undesirable event's frequency and consequence
Risk assessment project management	Activities that ensure the success of a risk assessment project. These activities include defining the scope of the risk assessment, identifying participants, preparing for the risk assessment, directing the meetings, documenting the meetings, writing the report, and implementing recommendations.
Risk assessment	The process of understanding (1) what bad things can happen, (2) how likely they are to happen, and (3) how severe the effects may be
Risk communication	The interactive process of exchanging information and opinion among individuals, groups, and institutions about a risk or possible risk to human health or the environment
Risk index number (RIN)	A quantitative measure of risk used in many risk assessment methods
Risk management	Actions that minimize risk within acceptable limits
Risk matrix	A matrix showing the risk profile of issues analyzed; each cell in the matrix provides the number of accident sequences having that frequency and consequence
Risk-based decision making	A process that organizes information about the possibility for one or more unwanted outcomes into a broad, orderly structure that helps decision makers make better management choices
Root cause analysis	An analysis technique that defines the most basic causes of an event that can be reasonably identified and that management has control or influence to fix
Safeguards	Equipment, procedural, and administrative controls in place to help (1) prevent a situation from occurring or (2) reduce the effects if the situation does occur
Safeguards not provided	Reasonable protections that were not provided but that could have prevented or reduced unwanted effects
Screening	Determining at a general level that an item is of low risk and will not need to be assessed in detail

Glossary (continued)

Sensitivity analysis	An evaluation that determines how (1) a change in one component of a system affects the entire system or (2) a change in one aspect of a risk assessment affects overall results
Simple asphyxiants	Nontoxic gases that replace oxygen necessary to support life
Sponsor	An individual or group that determines the need for a risk assessment. The sponsor is responsible for obtaining results from the risk assessment, and usually has a specific use for the results.
Stakeholders	Individuals or groups possibly affected by the decision. Stakeholder input into the decision-making process is important for reaching the best decisions and improving acceptance for the process and its results.
Subject matter experts	Individuals or groups who take part in the risk assessment, providing expert knowledge and experience about operations, layouts, and possible problems
Successful safeguards	Planned protections that successfully prevent or reduce unwanted effects
Thermal hazard	The potential for very hot or cold temperatures to produce unwanted consequences affecting people, materials, equipment, or work areas
Toxic hazard	The potential for one or more materials to cause biological damage to surrounding organisms by being absorbed through the skin, inhaled, eaten, or injected
Undeveloped events	Events that are not further developed in a fault tree
Value tradeoff	An option that offers more value to the user by providing some important benefit while sacrificing a previously existing, less important benefit
What-if analysis	A brainstorming risk assessment approach that uses broad, loosely structured questioning to (1) suggest system upsets that may result in accidents and (2) make sure that safeguards against those accidents are in place
Worker instructor and safety evaluation (WISE)	A specialized form of HAZOP analysis for assessing human activities through the use of guide words customized for human factors issues, including issues historically addressed through job task analysis
Voting method	Use of a team of experts to review and vote on competing options