RISK-BASED DECISION-MAKING GUIDELINES

Volume 3
Procedures for Assessing Risks

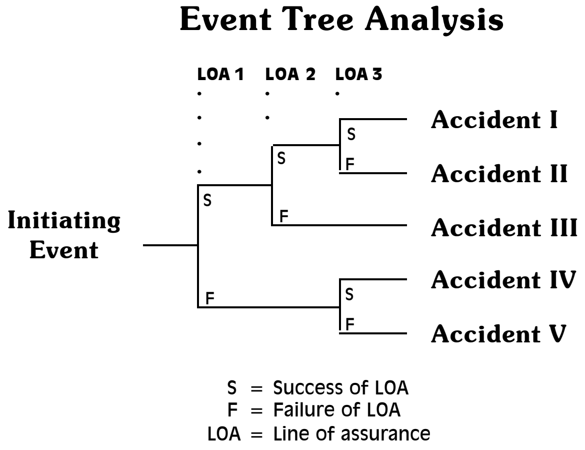
Applying Risk Assessment Tools

Chapter 12 — Event Tree Analysis (ETA)

Chapter Contents

This chapter provides a basic overview of the event tree analysis technique. It includes fundamental step-by-step instructions for using the methodology to graphically model the possible outcomes from an initiating event capable of producing an accident. Following are the major topics in this chapter:

See an example of an event tree analysis in Volume 4 in the Event Tree Analysis directory under Tool-specific Resources.



Summary of Event Tree Analysis

Event tree analysis (ETA) is a technique that logically develops visual models of the possible outcomes of an initiating event. As illustrated above, event tree analysis uses decision trees to create the models. The models explore how safeguards and external influences, called lines of assurance, affect the path of accident chains.

Event tree terminology

The following terms are commonly used in an event tree analysis:

Initiating event. The occurrence of some failure with the potential to produce an undesired consequence. An initiating event is sometimes called an incident.

Line of assurance (LOA). A protective system or human action that may respond to the initiating event

Branch point. Graphical illustration of (usually) two potential outcomes when a line of assurance is challenged; physical phenomena, such as ignition, may also be represented as branch points

Accident sequence or scenario. One specific pathway through the event tree from the initiating event to an undesired consequence

Brief summary of characteristics

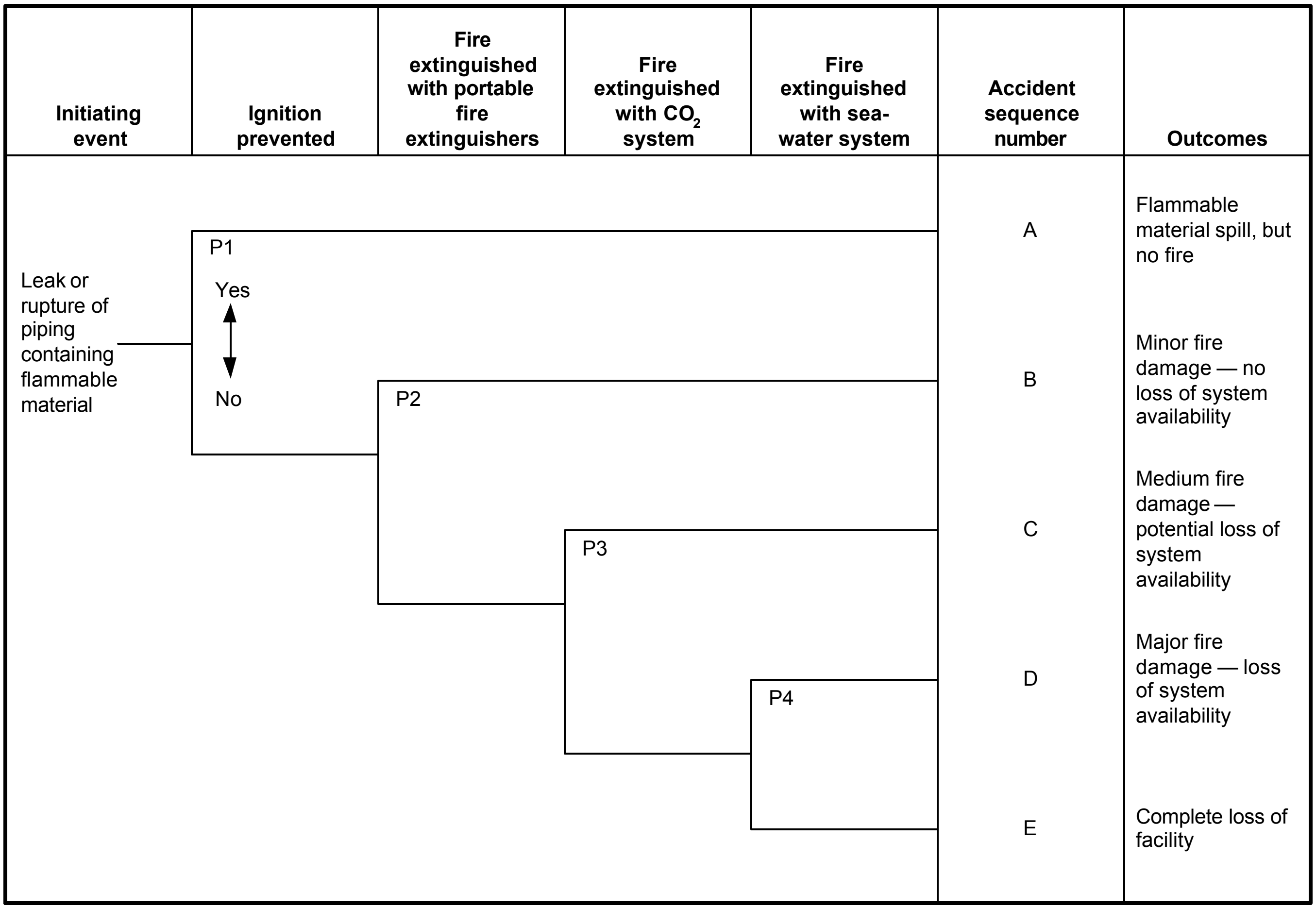
- Models the range of possible accidents resulting from an initiating event or category of initiating events
- A risk assessment technique that effectively accounts for timing, dependence, and domino effects among various accident contributors that are cumbersome to model in fault trees
- Performed primarily by an individual working with subject matter experts through interviews and field inspections
- An analysis technique that generates the following:
  - qualitative descriptions of potential problems as combinations of events producing various types of problems (range of outcomes) from initiating events
  - quantitative estimates of event frequencies or likelihoods and relative importances of various failure sequences and contributing events
  - lists of recommendations for reducing risks
  - quantitative evaluations of recommendation effectiveness

Most common uses

Generally applicable for almost any type of risk assessment application, but used most effectively to model accidents where multiple safeguards are in place as protective features

Example

The following event tree illustrates the various outcomes resulting from a leak or rupture of fuel oil piping in a vessel's engine room. The first branch depicts the two potential paths forward, depending on whether or not the release contacts an ignition source and starts a fire. If the spill ignites (shown on the downward path of the first branch), three systems are available to extinguish the fire: handheld fire extinguishers, a CO_2 system, and a seawater system. Successive branch points depict the success or failure of each system. Note that the upper branch in each case extends directly to the outcome because, once the fire is extinguished, there is no need for the remaining systems to operate.


Initiating event
Ignition prevented
Fire extinguished with portable fire extinguishers
Fire extinguished with CO_2 system
Fire extinguished with sea-water system
Accident sequence number
Outcomes
Leak or rupture of piping containing flammable material
P1
Yes
No
P2
P3
P4
A
B
C
D
E
Flammable material spill, but no fire
Minor fire damage — no loss of system availability
Medium fire damage — potential loss of system availability
Major fire damage — loss of system availability
Complete loss of facility

Limitations of Event Tree Analysis

- **Limited to one initiating event**
- **Can overlook subtle system dependencies**

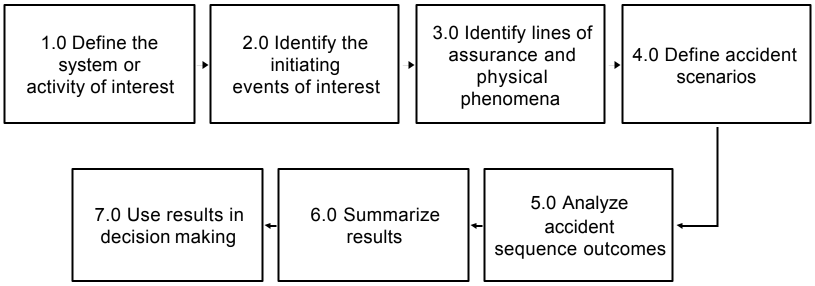
Limitations of Event Tree Analysis

Although event tree analysis is highly effective in determining how various initiating events can result in accidents of interest, this technique has two limitations.

Limited to one initiating event. An event tree is not an exhaustive approach for identifying various causes that can result in an accident. Other analysis techniques, such as HAZOP, what-if, checklist, or FMEA, should be considered if the objective of the analysis is to identify the causes of potential accidents.

Can overlook subtle system dependencies. The paths at each branch point in an event tree are conditioned on the events that occurred at previous branch points along the path. For example, if ignition of a flammable release does not occur, there is no fire for subsequent lines of assurance (e.g., fire protection systems) to fight. In this way, many dependencies among lines of assurance are addressed. However, lines of assurance can have subtle dependencies, such as common components, utility systems, operators, etc. These subtle dependencies can be easily overlooked in event tree analysis, leading to overly optimistic estimates of risk.

Procedure for Event Tree Analysis



Procedure for Event Tree Analysis

The procedure for performing an event tree analysis consists of the following seven steps:

1.0 Define the system or activity of interest. Specify and clearly define the boundaries of the system or activity for which event tree analyses will be performed.

2.0 Identify the initiating events of interest. Conduct a screening-level risk assessment to identify the events of interest or categories of events that the analysis will address. Categories include such things as groundings, collisions, fires, explosions, and toxic releases.

3.0 Identify lines of assurance and physical phenomena. Identify the various safeguards (lines of assurance) that will help mitigate the consequences of the initiating event. These lines of assurance include both engineered systems and human actions. Also, identify physical phenomena, such as ignition or meteorological conditions, that will affect the outcome of the initiating event.

4.0 Define accident scenarios. For each initiating event, define the various accident scenarios that can occur.

5.0 Analyze accident sequence outcomes. For each outcome of the event tree, determine the appropriate frequency and consequence that characterize the specific outcome.

6.0 Summarize results. Event tree analysis can generate numerous accident sequences that must be evaluated in the overall analysis. Summarizing the results in a separate table or chart will help organize the data for evaluation.

7.0 **Use the results in decision making.** Evaluate the recommendations from the analysis and the benefits they are intended to achieve. Benefits can include improved safety and environmental performance, cost savings, or additional output. Determine implementation criteria and plans. The results of the event tree may also provide the basis for decisions about whether to perform additional analysis on a selected subset of accident scenarios.

The following pages describe each of these steps in detail.

1.0 Define the system or activity of interest

- **Intended functions**
- **Physical boundaries**
- **Analytical boundaries**
- **Initial conditions**

1.0 Define the system or activity of interest

Intended functions. Event tree analyses focus on ways in which initiating events can progress to accidents through the failures of various safeguards, or lines of assurance. Clearly defining the function of safeguards is, therefore, an important first step in identifying their effectiveness as a line of assurance.

Physical boundaries. Few systems operate in isolation. Most are connected to or interact with other systems. By clearly defining the boundaries, especially boundaries with support systems such as electric power and compressed air, analysts can avoid (1) overlooking key elements of a system at interfaces and (2) penalizing a system by associating other equipment with the subject of the study.

Analytical boundaries. Conceptually, event tree analyses can include all of the events and conditions that can contribute to initiating events or can provide some level of protection (line of assurance) against accidents of interest. However, it is not practical to include all possible contributors. Many analyses define analytical boundaries that do the following:

- Limit the level of analysis resolution. For example, the analyst may decide not to analyze in detail all electrical distribution system problems when studying a navigation system.
- Explicitly exclude certain types of events or conditions, such as sabotage, from the analysis

Initial conditions. The initial state of a system, including equipment assumed to be out of service initially, affects the combinations of events necessary to produce subsequent problems. For example, if a protective interlock is routinely removed from service, the risk of certain types of problems will be greater and will, therefore, affect how the event tree is drawn and evaluated.

Example related to high-capacity passenger vessels

Two high-capacity passenger vessels (used for offshore gaming) operate to points at least three miles from shore. These vessels are individually rated for 600 people, operate year-round during the day and at night, and have limited onboard rescue equipment beyond personal flotation devices. The vessel crews are trained to retrieve people from the water. The vessels are regularly inspected by MSO personnel; however, the Coast Guard is concerned about the risk to passengers and crew if everyone must abandon ship while at least three miles from shore.

In perfect weather conditions during the day, the nearest floating asset requires 45 to 60 minutes to respond to the likely location of a distressed gaming vessel. The nearest air assets require 45 minutes to respond, weather permitting. The Coast Guard is concerned that its current response capabilities might be inadequate, given a catastrophic event in this location. Therefore, the Coast Guard is interested in exploring the following:

- Other types of response strategies to a catastrophic gaming vessel event
- Outcomes of these alternative response strategies and the level of loss associated with each

The analysis team generated the following risk-based questions:

- Are the existing Coast Guard resources and other safeguards adequate?
- What is the benefit of requiring inflatable buoyancy apparatuses (IBAs) on the gaming vessels?
- What is the benefit of requiring the gaming vessels to be within 20 minutes of each other?

These questions are designed so that their answers will provide the risk-based information judged by the analysis team to be most needed for decision making. In addressing these questions, the analysis team considered the potential influence of air support, fishing vessels, and recreational boaters.

Example related to high-capacity passenger vessels (continued)

The analysis team believed the likelihood of successful rescue would vary depending upon (1) whether all those on board or 93% of those on board must be rescued to consider the rescue operation a success and (2) whether the gaming vessel has 600 people (maximum capacity) or 250 people (average complement) on board. The following table presents the information identified by the analysis team as potentially useful in addressing each question and designates the information selected for analysis with an S.

Question	**Risk-based Information**			
	Likelihood that all on board are rescued (no hypothermia deaths)		**Likelihood that 93% of all on board are rescued (not more than 7% hypothermia deaths)**	
	CASE I 600 on board	**CASE II 250 on board**	**CASE III 600 on board**	**CASE IV 250 on board**
1. Are the existing Coast Guard resources and other safeguards adequate?	S	S	*	S
2. What is the benefit of requiring IBAs on the gaming vessels?	S	*	*	*
3. What is the benefit of requiring the gaming vessels to be within 20 minutes of each other?	S	*	*	*

S: Selected
*Case was not selected

Note: The U.S. Coast Guard's SAR Program objective, as described on its Web site at www.uscg.mil/hq/g-o/g-opr/sar_program.htm#objectives, is to "save at least 93% of those people at risk of death on waters over which the Coast Guard has SAR responsibility."

2.0 Identify the initiating events of interest

- **Identify hazards**
- **Screen hazards**
- **Categorize initiating events**

2.0 Identify the initiating events of interest

Event tree analyses are often more detailed risk assessments or reliability analyses. They follow simpler screening analyses that determine which potential accidents warrant further investigation.

Identify hazards. The first step usually applies a broad hazard identification technique, such as what-if, preliminary risk assessment, or preliminary hazard analysis, to systematically evaluate all activities within the scope of the study. This step helps identify the hazards and the events that can be involved with those hazards. These identification tools (1) broadly consider all operations within the scope of the study and (2) seek to identify the full range of potential initiating events and the range of consequences associated with the events. The outcome of these identification processes is usually an extensive list of potential events and their expected consequences.

Screen hazards. After identifying the entire spectrum of events within the scope of the analysis that can occur, the analysts apply a screening criteria to identify the events of most interest that will be analyzed with the event trees. This step helps identify those events that must be analyzed further to understand the complex interactions of systems.

Categorize initiating events. After the initial list of events is identified and screened, the remaining list of initiating events includes those that will be analyzed with event trees. These are the events that, upon examination by the subject matter experts, are complex enough to require additional analysis to illustrate the various system and personnel interaction that cause different outcomes from the initiating event. If there are many events that will be analyzed with the event trees, the initiating events should usually be grouped into various categories, such as groundings, collisions, fires, explosions, and toxic releases. In some cases, this categorizing of events may not be applicable. For example, if the intent of the study is to identify the range of consequences associated only with fires, then the screening analysis performed in the previous step should have screened out all events that are not related to fires, and this final step of categorizing the events is not necessary.

Example related to high-capacity passenger vessels

For the scope of analysis described in the example for Step 1, the initiating event could be any type of catastrophic event — from a vessel fire to a collision — that results in all people on board the vessel abandoning ship into the water. The frequency of these catastrophic events actually occurring was beyond the scope of analysis.

3.0 Identify lines of assurance and physical phenomena

- **Identify functional responses**
- **Identify physical phenomena**
- **Group initiating events**

3.0 Identify lines of assurance and physical phenomena

Identify functional responses. Identify the various safeguards (lines of assurance) that will help mitigate the consequences of the initiating event. These are the detection and mitigation systems that are designed to respond to the initiating events. They consist of (1) engineered systems, such as alarms, interlocks, and automatic valves, and (2) administrative or personnel systems, such as fire brigade, emergency response, and human detection through sight, sound, or smell.

Identify physical phenomena. Physical phenomena, sometimes referred to as phenomenological events, will also influence the eventual outcome of an initiating event. For example, if a flammable liquid is released, there may be engineered safeguards (lines of assurance) to isolate the leak; however, if the leak is not isolated, the ultimate outcome of the release will be affected by different physical responses, such as immediate ignition, delayed ignition, or dispersion characteristics. These physical responses are also modeled as branch points on the event trees.

Group initiating events. For an analysis with multiple initiating events requiring multiple event trees, the effort of drawing these event trees can be simplified if the events are categorized according to the lines of assurance. This will allow the same event tree logic (i.e., the same lines of assurance with the same failure or success) to be repeated for different events of interest. Or, if the lines of assurance will respond in an identical manner to various events, then the frequencies of the individual events can usually be summed to arrive at a representative frequency for all events of that type.

Example related to high-capacity passenger vessels

This is the step in which the subject matter experts identify the operational safeguards as well as the specific physical phenomena affecting this scenario. Physical phenomena can include weather conditions, time of day, water temperature, etc. It is essential that the analyst understand the chronology of safeguard use and the times for which the physical phenomena are important.

In this analysis, subject matter experts suggested several lines of assurance and physical phenomena. An event tree begins with the initiating event and branches at each line of assurance or physical phenomenon. The upward branch reflects the success of the line of assurance or the existence of the specified physical phenomenon. For example, one of the first relevant physical phenomena identified was water temperature of 60 °F. The upward branch for this physical phenomenon indicates that the water temperature is greater than 60 °F, and higher water temperatures ultimately reduce the risk of hypothermia. The lines of assurance and physical phenomena considered in the event tree analysis included the following:

- Warm water
- Daytime
- Second gaming vessel on site within 20 minutes
- Other vessels on site within 20 minutes
- Other vessels, including Coast Guard vessels, on site within 60 minutes
- People successfully into IBAs
- Successful rescue prior to hypothermia

If IBAs are not available, the largest factor in determining the success of the rescue is the response time needed for rescuers to arrive at the scene of the event, find all of the drifting victims, and pull the victims into the rescue craft. The rescue craft could be the other gaming vessel, vessels of opportunity in the area, and Coast Guard assets in the area or responding from the nearest stations. Because few other vessels operate in this area, the analysis team expected the best chance for rescue to come from the other gaming vessel operating nearby. If the other gaming vessel were not nearby, the next best chance of rescue is from a Coast Guard floating asset.

4.0 Define accident scenarios

- **Determine accident progression**
- **Identify system dependencies**
- **Understand conditional responses**
- **Construct event tree logic**

4.0 Define accident scenarios

At this point, the analyst has sufficient information to begin developing the event trees. As noted earlier, one of the strengths of the event tree analysis technique is its ability to model the timing and interaction of various systems that respond to the initiating event. To adequately account for these interactions, the analyst must (1) determine the logical progression of the accident as it moves through the various lines of assurance, (2) identify dependencies between the lines of assurance, (3) account for conditional responses of one system, given the action of the previous system, and (4) construct the event tree to illustrate these issues.

Determine accident progression. Certainly not all failures result in catastrophic health and safety consequences. Similarly, not every safety feature, interlock or shutdown mechanism is called upon to respond to *every* event that occurs. There is a logical progression to an accident sequence that moves forward from the time the initiating event occurs. As the accident sequence progresses and becomes more severe, different systems respond in different ways. Understanding the progression and timing of system and physical responses is essential to developing the correct logic in the event tree. For example, if a fire ignites by spontaneous combustion in a waste receptacle, the initial response would be for personnel to extinguish the fire with handheld extinguishers, if personnel were present and there were extinguishers available. The full fire protection system and the response of the fire team would not be called upon unless the severity of the accident increased.

Identify system dependencies. Few systems operate in isolation. Most are connected to or interact with other machines and processes. These interactions, or dependencies, will influence (degrade) the level of protection offered by redundant systems that share certain equipment. In the example of the oil tanker with redundant steering and propulsion systems, the failures of each system may not be independent if the steering systems shared a common hydraulic fluid supply.

Understand conditional responses. Event trees illustrate conditional probabilities. That is, the probability of success or failure for a line of assurance is conditioned on the success or failure of the lines of assurance that precede it. In the example described above, the probability of failure for the second steering system is 1.0 (i.e., it is failed) if the reason for failure of the first system is contamination in the hydraulic fluid supply.

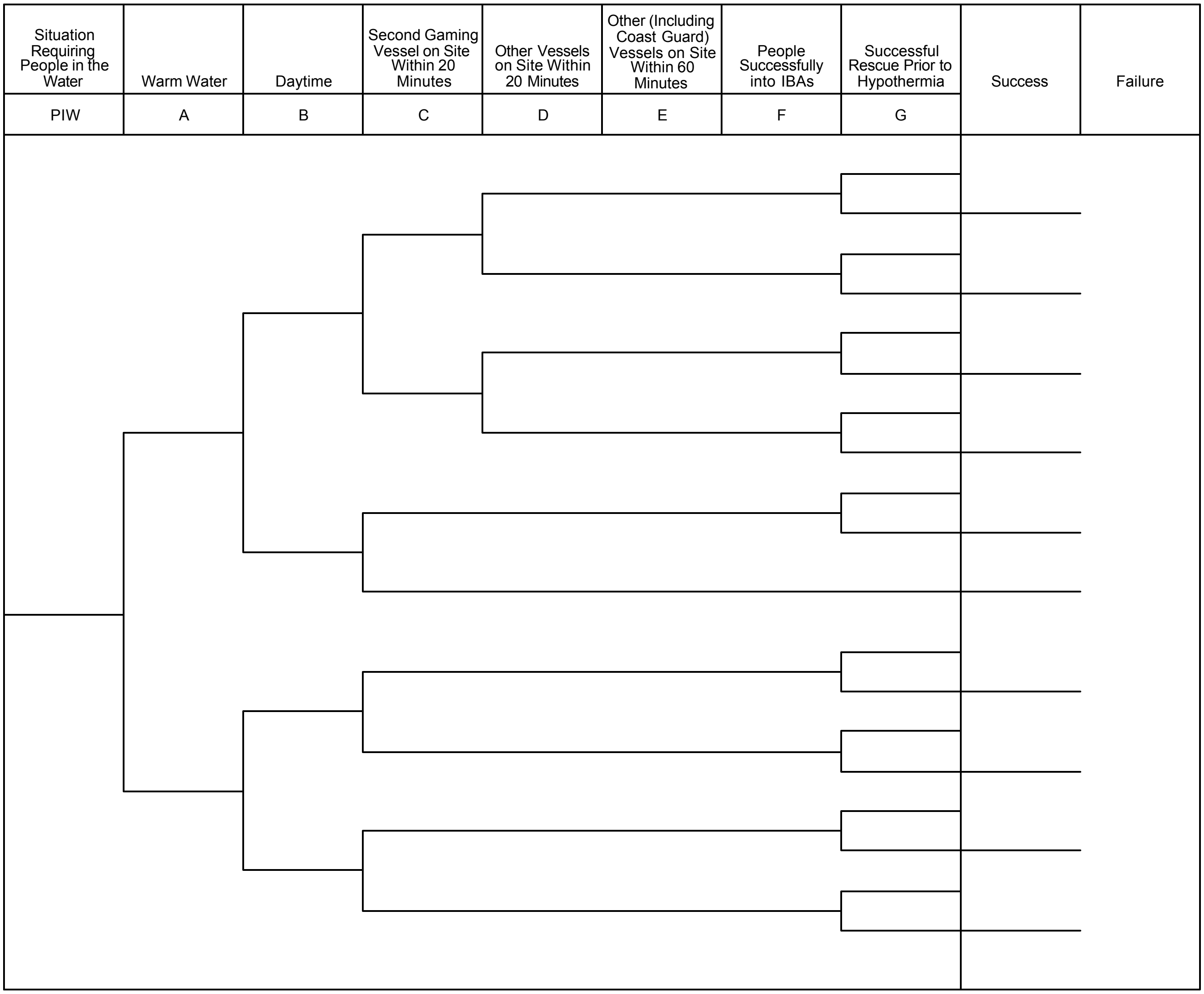
Construct event tree logic. Event tree construction consists of the following steps:

1. List the initiating event first on the left side of the tree.
2. List the lines of assurance and physical phenomena across the top of the tree in the chronological order in which they will affect the accident progression.
3. Identify success (usually displayed in the upward branch) and failure (downward branch) of each line of assurance at each branch point. Consider the following:
    - some branch points can have more than two outcomes and will be displayed with the appropriate number of branches
    - some branch points will have only one outcome; in other words, there is a straight line through that line of assurance. This will occur when the conditional probability is 1.0; the line of assurance does not affect the outcome because of some preceding success or failure of another line of assurance.

Example related to high-capacity passenger vessels

For each of the selected cases defined in the scope of analysis for our high-capacity gaming vessel example, a separate event tree was developed. Each event tree considered the same basic lines of assurance, but not all were applicable or equally effective for each case. Following is the event tree for Question I, Case I:

> 600 people on board, no sister gaming vessel accompanying the distressed vessel, no IBAs on board, and a success criteria that all passengers on the water must be rescued before hypothermia deaths occur.



5.0 Analyze accident sequence outcomes

- **Frequency**
- **Consequence**

5.0 Analyze accident sequence outcomes

After the event tree is constructed as described in the previous step, the analyst will have a clear picture of the progression of the accident to each of the various outcomes. Each outcome is uniquely represented by a frequency and consequence and can be evaluated either qualitatively or quantitatively.

Frequency

In general, the accident outcomes in an event tree, if constructed as described in the previous step, will be ordered from high frequency and low consequence to low frequency and high consequence. Each outcome has a frequency associated with it. Qualitatively, the frequency of the outcome may be determined simply by observing the number of independent lines of assurance that would have to fail in order for it to occur. For example, a catastrophic equipment failure would occur only if an operator failed to recognize the onset of the problem and three independent safety systems failed to automatically detect and shut down the equipment. At the other extreme, if only one safeguard (line of assurance) is provided for protection of a particular event, that event may be considered anticipated or likely to occur.

Quantitative evaluation of accident frequencies is accomplished by multiplying together the initiating event frequency and all of the probabilities from the various branch points. These probabilities may be based on historical data for the specific components being evaluated, relevant generic data, or subjective judgment from subject matter experts. Since the objective is to forecast the expected frequency and probability values that will be experienced, these values should reflect any changes in systems, personnel, or organizational factors.

Consequence

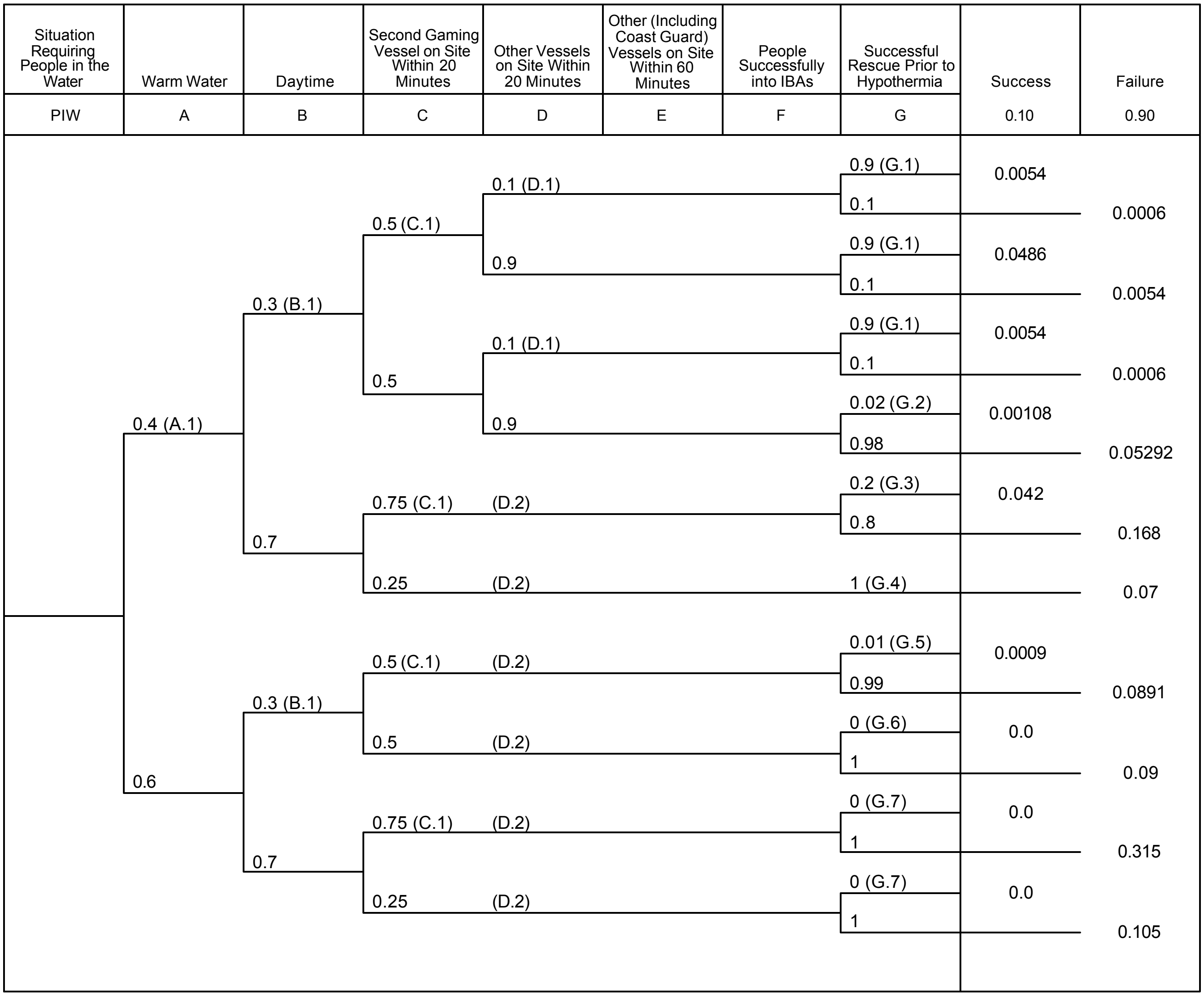
Each outcome has a consequence associated with it. Quantitative evaluation of accident consequences involves various forms of consequence and effects modeling applicable to the type of accident scenarios being analyzed. For example, an event tree may describe the accident sequence for a medium-sized release of a toxic material that occurs during cargo unloading. The release continues for one hour before operators isolate the release. Quantitative evaluation of the consequences of this scenario would involve the following:

- Release rate modeling to determine the rate at which material escapes from the equipment
- Atmospheric dispersion modeling to estimate the downwind concentrations of the toxic material
- Demographic data around the port to estimate the number of people exposed to the specific concentrations calculated by the dispersion models

There are other types of consequence modeling for other types of accidents. These include models for assessing ship damage during a grounding or collision, models of hazardous exposure effects on people, etc. Of course, simple, subjective estimates of accident consequences can also be made, avoiding the time and effort of detailed consequence modeling.

Example related to high-capacity passenger vessels

In our high-capacity gaming vessel example, the only measure of interest is the likelihood of meeting the successful rescue criteria (either 100% or 93% of persons in the water), given that the initiating event occurs. The following event tree shows this result for Question 1, Case I and includes notes defending the quantitative analysis.



Notes for Question 1, Case I: 600 on board, second gaming vessel not required, no IBAs, and must rescue all

A.1 Warm Water: Have warm water 40% of the time (i.e., 60 °F or higher) based on local SAR team experience.

B.1 Daytime: One of the vessels does not go out on Monday, Wednesday, and Friday during the daytime. Also, there is a possibility of cancellation due to low customer demand, which mostly occurs during the day.

C.1 Second Gaming Vessel on Site Within 20 Minutes: Variation in vessel schedules and the possibility of cancellation are higher during the day. Therefore, the team chose a probability of 0.5 for a second gaming vessel being on site during the day and a probability of 0.75 for a second gaming vessel being on site during the night.

D.1 Other Vessels on Site Within 20 Minutes: Expectation that other vessels (certificated passenger vessels, commercial fishing vessels, and recreational craft) will be coming and going with seasonal variations.

D.2 Other Vessels on Site Within 20 Minutes: During the night and during seasonal cold weather, other vessels in sufficient numbers are not expected to be on site within 20 minutes.

E.1 Other (Including Coast Guard) Vessels on Site Within 60 Minutes: Not expected because vessels at their ports would require travel times > 60 minutes.

F.1 People successfully into IBAs: None available.

G.1 Successful Rescue Prior to Hypothermia: Would recover all people in the water 90% of the time because sufficient vessels are immediately available; however, 10% of the time someone would die from hypothermia due to not being retrieved from the water in under two hours.

G.2 Successful Rescue Prior to Hypothermia: Sufficient assets will not be on the scene within one hour; therefore, some people will be in the water for three to four hours. While this event occurs in warm water during daylight, it is very unlikely that all 600 people would be rescued before having a hypothermia death. All people in the water would be recovered only 2% of the time.

G.3 Successful Rescue Prior to Hypothermia: Even though the other gaming vessel is on site and the water is warm, recovery of all people in the water would occur only 20% of the time. Operations would be at night, making it difficult to locate all of the people in time.

G.4 Successful Rescue Prior to Hypothermia: Even though the water is warm, sufficient assets will not be on the scene within two hours. Therefore, some people will be in the water for three to four hours, and at least one hypothermia death among 600 people is expected in this situation.

G.5 Successful Rescue Prior to Hypothermia: Even though the other gaming vessel is on site during daylight, recovery of all people in the water would occur only 1% of the time. Operations would be in cold water, which would severely limit the time to successfully rescue the people.

G.6 Successful Rescue Prior to Hypothermia: Even though the event occurs during daylight, sufficient assets will not be on the scene within two hours. Therefore, some people will be in the cold water for three to four hours, and at least one hypothermia death among 600 people is expected.

G.7 Successful Rescue Prior to Hypothermia: Because of dispersion at night and cold water, the analysis team does not expect to find everyone in time.

The quantitative analysis could be extended to estimate the following:

- The frequency of each scenario occurring. This would be done by multiplying each outcome likelihood by the initiating event frequency.
- The expected number of fatalities per initiating event. This would be done by estimating fatalities for each outcome and multiplying by outcome probabilities.

6.0 Summarize results

- **Data table**
- **Graphical illustrations**

6.0 Summarize results

Event tree analysis can generate numerous accident sequences that must be evaluated in the overall analysis. Summarizing the results in a separate table or document will help organize the data for evaluation. As an illustration, the table on the following page presents the results from four event trees. The accident sequence numbers indicate the event tree for each scenario (i.e., 1.1 is the first accident scenario from event tree 1, 3.2 is the second scenario from event tree 3, etc.), and the frequency and consequence information is summarized in the subsequent columns. For analyses where the number of accident scenarios is small, a visual examination of these data is usually sufficient to support decisions about the analysis.

Accident sequence number	Frequency (events/yr)	Consequence (gallons of oil released at sea)
1.1	0.9	4
1.2	0.0495	48
1.3	0.0505	2,190
2.1	0.5	1
2.2	0.06	24
2.3	0.01	100
2.4	0.0006	2,190
2.5	0.00003	8,760
3.1	0.6	2
3.2	0.1	1
3.3	0.04	72
4.1	0.9	3
4.2	0.2	1
4.3	0.06	36
4.4	0.02	48
4.5	0.004	2,190
4.6	0.001	2,190
4.7	0.0005	4,380
4.8	0.00004	16,920

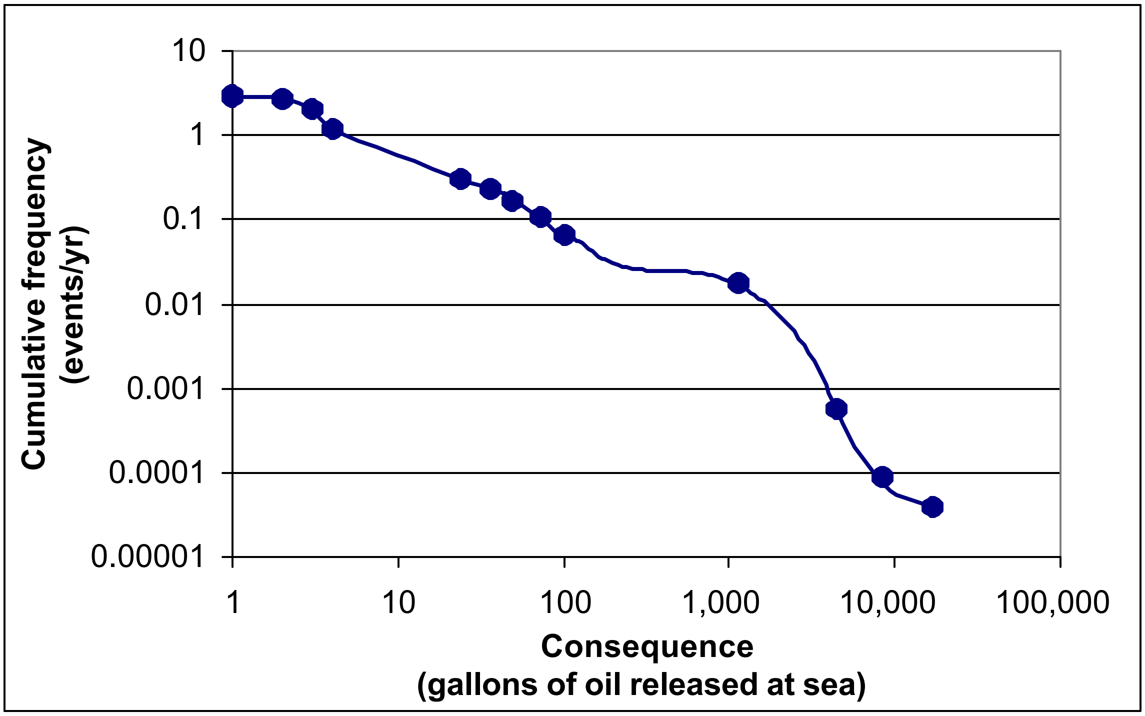
When the number of accident scenarios is large, the analyst must present the data in a format that facilitates decision making.

One example of scenario presentation for large numbers of accidents is the F-N curve, which can also be used with tools other than event tree analysis. The F-N curve plots the cumulative frequencies of events causing N or more impacts, with the number of impacts (N) shown on the horizontal axis. With the F-N curve, you can easily see the expected frequency of outcomes that are above a specific level of interest (e.g., capital dollars lost, number of spills). To generate the F-N curve, the accident scenarios are sorted from the highest to the lowest consequence. Then the frequency data are accumulated for each scenario. The x axis plots the consequence, and the y axis plots the cumulative frequency.

The following table and figure illustrate the formatted F-N data and the corresponding F-N plot.

Accident sequence number	Frequency (events/yr)	Cumulative frequency (events/yr)	Consequence (gallons of oil released at sea)
4.8	0.00004	0.00004	16,920
2.5	0.00003	0.00007	8,760
4.7	0.0005	0.00057	4,380
1.3	0.0505	0.05107	2,190
4.5	0.004	0.05507	2,190
4.6	0.001	0.05607	2,190
2.4	0.0006	0.05667	2,190
2.3	0.01	0.06667	100
3.3	0.04	0.10667	72
4.4	0.02	0.12667	48
1.2	0.0495	0.17617	48
4.3	0.06	0.23617	36
2.2	0.06	0.29617	24
1.1	0.9	1.19617	4
4.1	0.9	2.09617	3
3.1	0.6	2.69617	2
3.2	0.1	2.79617	1
4.2	0.2	2.99617	1
2.1	0.5	3.49617	1

Note: Data in shaded rows are not plotted. Because the data accumulate frequencies, those accident scenarios with identical consequences will generate a vertical line on the F-N curve. To eliminate the vertical lines, only the last data point for each consequence is plotted. This is the data point with the highest accumulated frequency.



Example related to high-capacity passenger vessels

The following table presents the risk-based information generated to answer each of the three risk-based questions specified in Step 1.0. The information focuses on the likelihood of rescue, given that a catastrophic event has caused all on board to enter the water. This table is the primary work product from this analysis.

Question	**Risk-based Information**			
	Likelihood that all on board are rescued (no hypothermia deaths)		**Likelihood that 93% of all on board are rescued (not more than 7% hypothermia deaths)**	
	CASE I 600 on board	**CASE II 250 on board**	**CASE III 600 on board**	**CASE IV 250 on board**
1. Are the existing Coast Guard resources and other safeguards adequate?	10%	23%	*	26%
2. What is the benefit of requiring IBAs on the gaming vessels?	73%	*	*	*
3. What is the benefit of requiring the gaming vessels to be within 20 minutes of each other?	17%	*	*	*

*Case was not selected

7.0 Use the results in decision making

- **Judge acceptability**
- **Identify improvement opportunities**
- **Make recommendations for improvement**
- **Justify allocation of resources for improvements**

7.0 Use the results in decision making

Evaluate the recommendations from the analysis and the benefits they are intended to achieve. Benefits can be in forms such as improved safety and environmental performance or cost savings. Determine implementation criteria and plans. The results of the event tree may also provide the basis for decisions to perform additional analysis on a selected subset of accident scenarios.

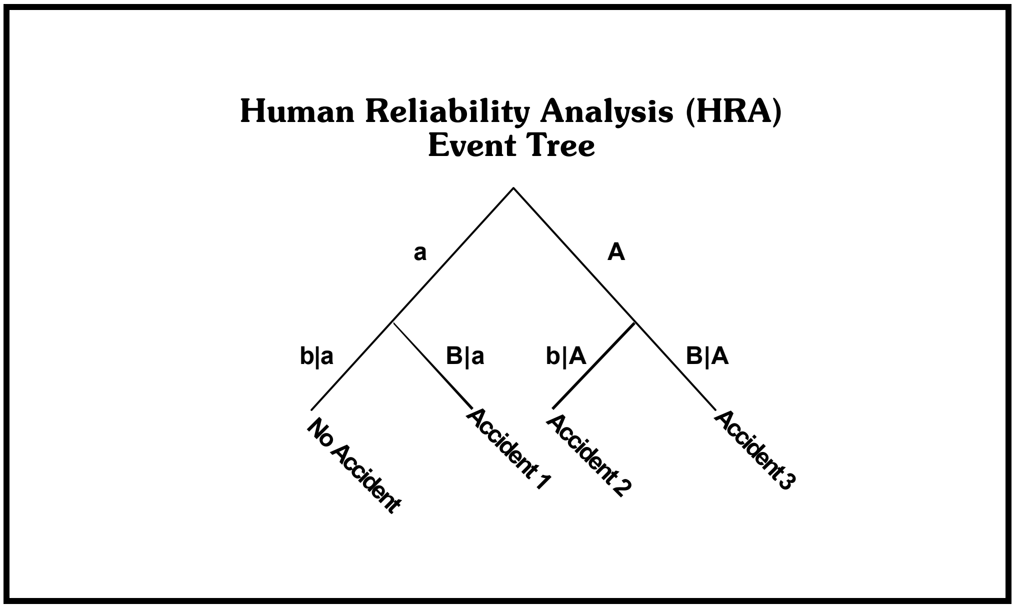
Judge acceptability. Decide whether the estimated performance for the system or activity meets an established goal or requirement.

Identify improvement opportunities. Identify the elements that are most likely to contribute to future problems. These are the items with the largest percentage contributions to the pertinent factors of merit.

Make recommendations for improvement. Develop specific suggestions for improving future performance, including any of the following:

- Equipment modifications
- Procedural changes
- Administrative policy changes such as planned maintenance tasks, personnel training, etc.

Justify allocation of resources for improvements. Estimate how implementation of expensive or controversial recommendations for improvement will affect future reliability performance. Compare the economic benefits of these improvements to the total life-cycle costs of implementing each recommendation.



A Specific Type of Event Tree Analysis – Human Reliability Analysis (HRA) Event Tree

Human reliability analysis event trees are specialized tools, similar in form to fault tree analysis and event tree analysis, designed for evaluating possible errors in procedures being performed by people. This technique accounts for various human errors and recovery actions, as well as equipment failures, by modeling the range of outcomes as a person performs a procedure. As illustrated in the above figure, each step in the procedure is represented by a letter and may be successful or unsuccessful. The lower case letters indicate successes, the upper case letters indicate errors. The HRA event tree visually illustrates the combination of errors that lead to various types of accidents.

Brief summary of characteristics

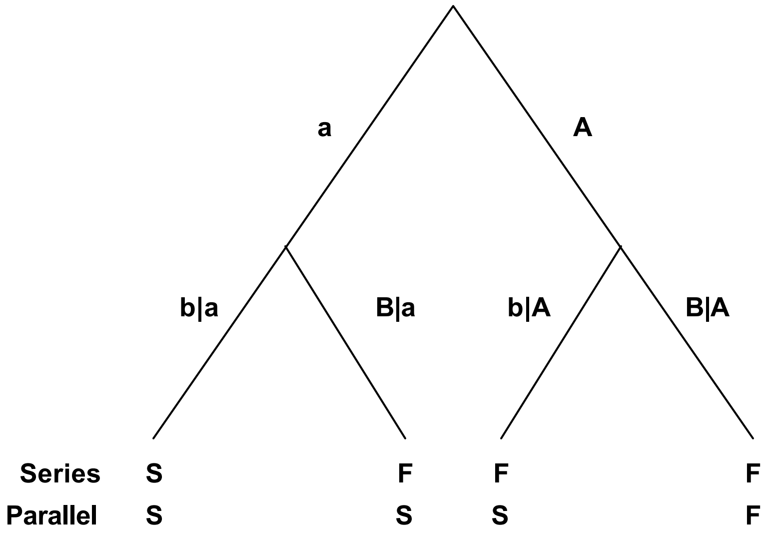
- Models the range of possible accidents that may occur while performing a procedure
- Performed primarily by an individual working with system experts through interviews and field inspections
- A technique that generates:
  - qualitative descriptions of potential undesirable events; these descriptions point to combinations of events producing various types of undesirable events as a result of human errors at various steps of a procedure
  - quantitative estimates of failure frequencies and likelihoods and relative importances of various accident sequences and contributing events
  - lists of recommendations for reducing risks
  - quantitative evaluations of recommendation effectiveness

Limitations

- Quality of the analysis results depends on the quality of the documentation and the expertise of the subject matter experts
- Unavailability of reliable and applicable data for many applications
- Requires trained personnel to conduct the study

Application

The following is a basic description of the workings of a human reliability analysis event tree:



TASK "A" = THE FIRST TASK
TASK "B" = THE SECOND TASK
a = PROBABILITY OF SUCCESSFUL PERFORMANCE OF TASK "A"
A = PROBABILITY OF UNSUCCESSFUL PERFORMANCE OF TASK "A"
b|a = PROBABILITY OF SUCCESSFUL PERFORMANCE OF TASK "B" GIVEN a
B|a = PROBABILITY OF UNSUCCESSFUL PERFORMANCE OF TASK "B" GIVEN a
b|A = PROBABILITY OF SUCCESSFUL PERFORMANCE OF TASK "B" GIVEN A
B|A = PROBABILITY OF UNSUCCESSFUL PERFORMANCE OF TASK "B" GIVEN A

FOR THE SERIES SYSTEM:

$Pr[S] = a(b|a)$
$Pr[F] = 1 - a(b|a) = a(B|a) + A(b|A) + A(B|A)$

FOR THE PARALLEL SYSTEM:

$Pr[S] = 1 - A(B|A) = a(b|a) + a(B|a) + A(b|A)$
$Pr[F] = A(B|A)$

The simplest of human reliability event tree analyses produces qualitative results that highlight practical means for reducing human errors. Human reliability event tree analysis results can also be quantified, producing estimates of human error probabilities that can feed into cost/benefit analyses or quantitative risk assessments.

Most common uses

- Used exclusively for detailed evaluation of human operations, especially procedural tasks; most often used as a supplement to a broader risk assessment using another technique
- Best suited for situations in which complex combinations of errors and equipment failures are necessary for undesirable events to occur
- Often used in conjunction with checklist analyses that focus on specific human reliability issues, such as error-likely situation checklists

Example of an HRA event tree for ferry operations

While trying to resolve a request to require two licensed mariners for high-speed ferries, a unit decided to examine the risks of collisions with other vessels. The unit decided that the analysis needed to compare the risks between (1) operations with only one licensed mariner and deckhands and (2) operations with two licensed mariners and deckhands.

This analysis involved the development of four human reliability event trees that show the progression of events that can result in a collision, the conditional probabilities for each event, and the expected frequency of collision. These event trees include:

Addressing One Licensed Operator

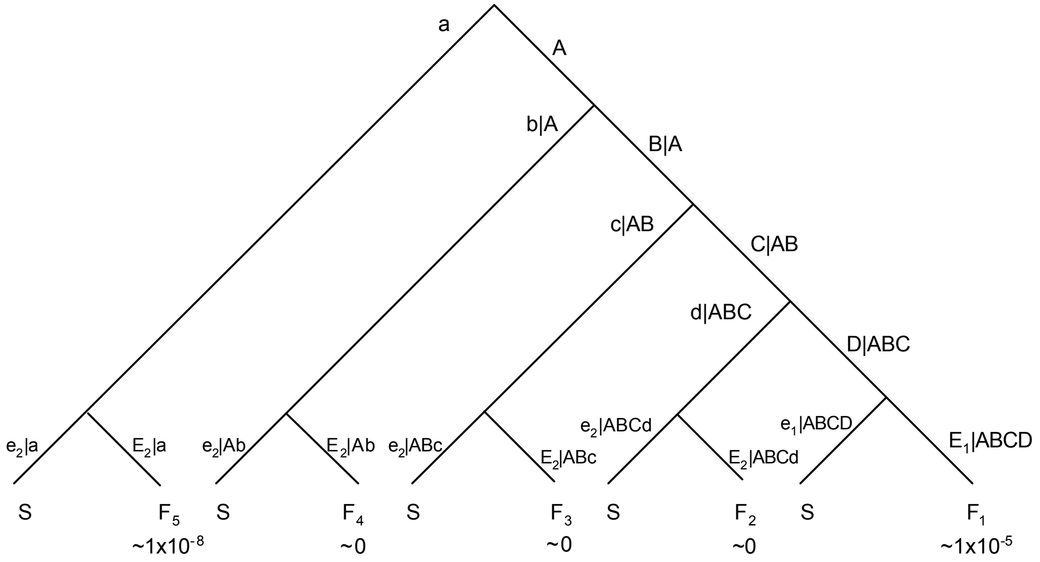
- Event Tree 1: High-speed Ferry on Collision Course with Uninspected Vessel
- Event Tree 2: High-speed Ferry on Collision Course with Inspected Vessel

Addressing Two Licensed Operators

- Event Tree 3: High-speed Ferry on Collision Course with Uninspected Vessel
- Event Tree 4: High-speed Ferry on Collision Course with Inspected Vessel

On the next page is an example of one of these human reliability event trees. Similar human reliability event trees were developed for each of the four scenarios.

Event Tree 1: High-speed Ferry on Collision Course with Uninspected Vessel (One Licensed Operator)



Collisions with an uninspected vessel – one operator $= C_1$

$= (IE_1) \times (P_{F1} + P_{F2} + P_{F3} + P_{F4} + P_{F5})$

$\approx (4 \times 10^4/\text{yr}) \times (1 \times 10^{-5})$

$\approx 0.4/\text{yr}$

Where: IE_1 is the number of times per year that a high-speed ferry is on a collision course with an uninspected vessel (4×10^4/yr)

Failure Symbol	Failure Description	Estimated Conditional Probability
A	High-speed ferry operator fails to observe uninspected vessel on radar	0.9
B	High-speed ferry operator fails to observe (see or hear) uninspected vessel	0.01
C	High-speed ferry deckhand fails to observe (see or hear) uninspected vessel	0.1
D	No communication to high-speed ferry from other vessel	0.01
E_1	High-speed ferry fails to adequately maneuver in time to avoid collision with uninspected vessel given uninspected vessel is not observed	1.0
E_2	High-speed ferry fails to adequately maneuver in time to avoid collision with uninspected vessel given uninspected vessel is observed	10^{-7}

The following table presents the annual expected number of collisions involving high-speed ferries based on the results from the four human reliability event trees analyses. These cumulative risk results provide the basis for generating the needed risk-based information.

Type of Vessel Encountered	Annual Expected Number of Collisions	
	One Licensed Operator	**Two Licensed Operators**
Uninspected vessels	0.4/yr (see Event Tree 1)	0.2/yr (see Event Tree 3)
Inspected vessels	0.0004/yr (see Event Tree 2)	0.0004/yr (see Event Tree 4)
Total	~0.4/yr	~0.2/yr