Prince William Sound

Risk Assessment Overview

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Abstract

Risk assessment in marine transportation is an enterprise that has been undertaken for many years. The purpose of this document is to provide an overview of risk assessment, particularly in marine transportation, and to present recommendations for a new or updated risk assessment in Prince William Sound, Alaska. First, an overview of the current state of risk assessment science is presented, followed by a summary of maritime risk assessments that have been undertaken after 1996. Challenges associated with risk assessment in distributed, large-scale system are discussed, along with the particular challenges of risk assessment in marine transportation. Given these considerations, recommendations for a new and/or updated risk assessment in Prince William Sound are then presented. The document concludes with a summary and recommendations for next steps.

1. Introduction

The purpose of this document is to provide an overview of risk assessment, and to present recommendations for a new or updated risk assessment in Prince William Sound, Alaska. The document begins by providing an overview of the current state of risk assessment science, followed by a summary of maritime risk assessments that have been undertaken after 1996. Recommendations for a new and/or updated risk assessment are then presented, along with considerations for such a study. The document concludes with a summary and recommendations for next steps.

2. Risk Assessment in Complex Systems

Risk assessment is not a new endeavor. Formal risk assessment techniques had their origin in the insurance industry, as businesses began to make large capital investments during the industrial age. Organizations needed to understand the risks associated with such investments and to manage the risks using control measures and insurance. Insurance companies thus calculate risks associated with insured activities. In more recent times, governments have become involved in risk assessment in order to protect their citizens and natural resources. Governments have required that corporations employ risk-reducing measures, secure certain types of insurance, and in some cases, demonstrate that they can operate with an acceptable level of risk (1, 55).

Risk may be defined as the measure of the probability and severity of an unwanted event. An unwanted event is an occurrence that has an associated undesirable outcome. There are typically a number of potential outcomes from any one initial event that may range in severity from trivial to catastrophic, depending on conditions. Risk is therefore defined as the product of the frequency with which an event is anticipated to occur and the consequence of the event's outcome:

$$Risk = Frequency \times Occurrence$$

The *frequency* of a potential undesirable event is expressed as events per unit time, often per year. The frequency can be determined from historical data, if available, if a significant number of events have occurred in the past. Often, however, risk analyses focus on events with more severe consequences and low frequencies for which little historical data exists. In such case, the event frequencies are calculated using risk assessment models.

Risk in complex systems can have its roots in a number of factors. One cause may be that activities performed in the system are inherently risky (e.g. mining, surgery, airline transportation); another may be that technology used in the system is inherently risky, or exacerbates risks in the system (e.g. heavy equipment, lasers, and aircraft). Individuals and organizations executing tasks, using technology, or coordinating also cause risk. Organizational structures in a system may also unintentionally encourage risky practices (e.g. the lack of formal safety reporting systems in organizations, or organizational standards that are impossible to meet without some amount of risk taking). Finally, organizational cultures may support risk taking, or fail to sufficiently encourage risk aversion (16-19, 26, 50, 52, 53, 60, 66).

Risk events occur for a variety of reasons, as seen in Figure 1 (23, 52). Sometimes risk events are the result of *basic or root causes*, such as inadequate operator knowledge, skills or abilities, or the lack of a safety management system in an organization. Risk events could also result from *immediate causes*, such as a failure to apply basic knowledge, skills, or abilities, or an operator impaired by drugs or alcohol. *Incidents* are unwanted events that may or may not result in accidents; *accidents* are unwanted events that have either *immediate* or *delayed consequences.* Immediate consequences could include injuries, loss of life, property damage, and persons in peril; delayed consequences could include further loss of life, environmental damage, and financial costs. In the following sections, the process of risk assessment in marine transportation is described.

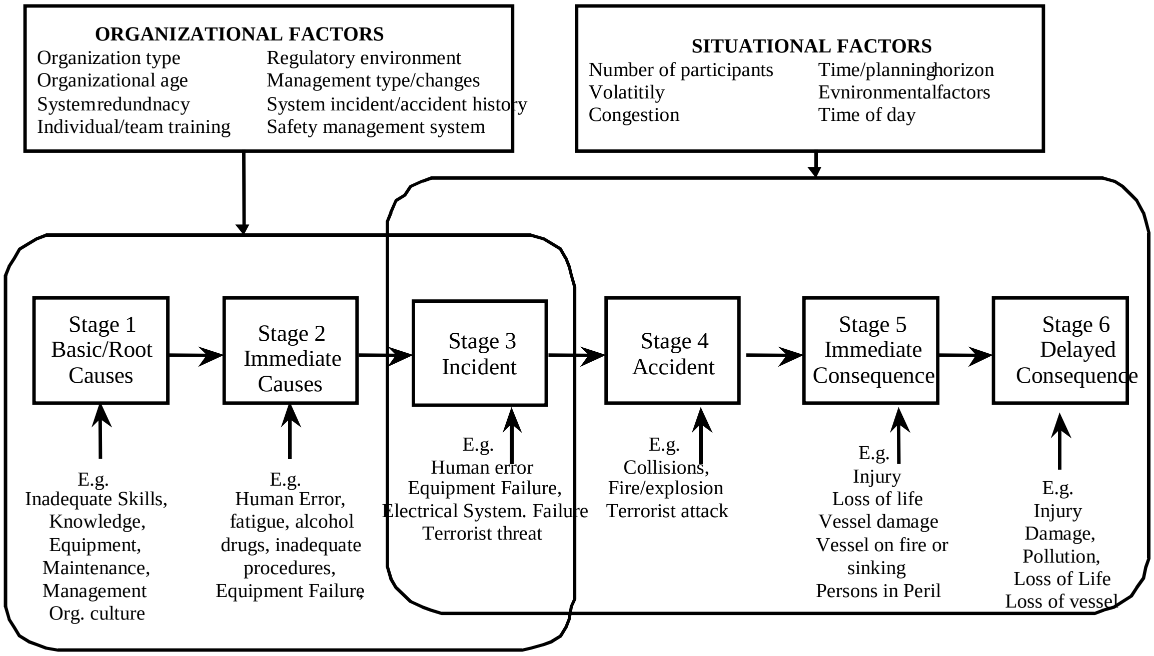


Figure 1. The risk event error chain.

2.1 Risk Assessment in Marine Transportation

Risk assessment has been utilized in marine transportation for many years. Early marine transportation risk assessments concentrated on assessing the safety of individual vessels or marine structures, such as nuclear powered vessels (51), vessels transporting liquefied natural gas (59) and offshore oil and gas platforms (48). The next type of risk assessments to be conducted included scenario-based assessments, which considered the relative risks of different conditions, scenarios and events. More recently, Probabilistic Risk Assessment (3) has been introduced in maritime risk assessment (19, 25, 54, 57, 61, 67), along with system simulations that consider the broader impacts of events, conditions and scenarios on risk in the marine transportation system under study. Such simulations provide analysis and visualization of the system, geographical and temporal impacts and risks of conditions under study, as well as tools for sensitivity and contingency (what if) analyses. The Prince William Sound (PWS) Risk Assessment (30, 31), Washington State Ferries (WSF) Risk Assessment (64) and an exposure assessment for fast ferries in San Francisco Bay (28) are three examples of risk studies in marine transportation that combine system simulation with probabilistic risk assessment techniques. Risk analyses incorporating scenario-based analyses have also been used in a recent study of tug escorts in Puget Sound (12).

Globally, risk assessment has also played an important role in marine transportation decision-making in coastal European waters (10), in individual port risk analyses (19, 61), in assessing shipboard risk (67), and in assessing pilot fatigue on the Great Barrier Reef in Australia (9). Risk-based decision making is of great interest in the U.S. domestic and international regulation of marine transportation, with the International Maritime Organization (IMO) and the U.S. Coast Guard issuing guidelines and procedures for risk-based decision making, analysis and management (55, 62). A summary of recent maritime risk assessments conducted in the United States and globally is provided in Table 1.

Table 1
Recent Risk Assessments in Marine Transportation

Location	Investigators	Topic of Interest	Dates	References
Puget Sound	Glosten Associates Herbert Engineering Rensselaer Polytechnic Institute Environmental Research Consulting	Tug escorts	2004 – 2005	(12)
Western Europe	Bulk carrier collisions	Bulk carrier damage assessment	2003-2004	(56)
San Francisco Bay	National Science Foundation George Washington University Virginia Commonwealth University	Uncertainty analysis	2003-2004	(29, 32)
Western Europe	Passenger vessel evacuation	Ship evacuation simulator	2003	(65)
San Francisco Bay	George Washington University Virginia Commonwealth University	Fast ferry traffic	2001	(28, 29, 32)
European Community	DNV, et al.	Waterborne commerce risk	2000	(8)
Worldwide	Guedes, et al.	Maritime risk analysis	2000	(19)
Worldwide	Wang, et al.	Shipboard risk analysis	1999	(67)
Port risk analysis	EQE International (UK) Trbojevic, et al.	Port risk analysis	1999	(61)

Location	Investigators	Topic of Interest	Dates	References
Great Barrier Reef	DNV	Pilotage risk assessment	1999	(9)
Puget Sound	Rensselaer Polytechnic Institute George Washington University Virginia Commonwealth University	Washington State Ferry risk analysis	1997 – 1999	(15, 64)
Houston	Rensselaer Polytechnic Institute	Passenger vessel traffic	1997	(13)
Inland waterways	Slob, et al.	Inland waterways	1996	(57)
European Community	SAFECO partners (10 European industry partners)	Coastal shipping risk analysis	1995-1998	(10)
Prince William Sound, Alaska	DNV George Washington University Rensselaer Polytechnic Institute/LeMoyne College	Oil transportation	1995-1997	(23, 30, 31)
Marine transportation (General)	Woods Hole Oceanographic Institute	Ship transit risk	1995	(25)
Lower Mississippi River	Rensselaer Polytechnic Institute George Washington University	Gaming vessel risk	1994	(22)
Inland waterways	Roeleven, et al.	Inland waterways	1994	(54)
Puget Sound	Rensselaer Polytechnic Institute George Washington University	Oil transportation risk	1993	(21)
Offshore oil and gas platforms		Offshore oil and gas platforms	1989	(48)
Worldwide		LNG vessels	1975	(59)
Worldwide		Nuclear powered vessels	1964	(51)

2.2 Challenges in Risk Assessment

Risk assessment in marine transportation presents a number of challenges. First, because the system is distributed, risk in the system can *migrate*, making risk identification and mitigation difficult. Risk migrates when the introduction of a risk mitigation measure to address one problem in the system introduces other, unintended consequences in another part of the system. An example of risk migration can be seen when weather-related delays cause vessels to remain in port until the weather clears. During such times, the risk of collision decreases, but the risk of collisions increases when the weather clears. The same phenomenon is observed when aircraft are held on the ground until weather clears. During such times, the risk of collisions on takeoffs and landings decreases, but the risk of ground-based collisions on runways jammed with waiting aircraft increases (68).

Risk assessment in marine transportation is also difficult because incidents and accidents in the system can have *long incubation periods* due to poor information flow between distributed sub-systems, making risk analysis and identification of leading error chains difficult. When systems have long incubation periods, precipitating factors may lie dormant for long periods of time, until catalyzed by the right combination of triggering events (i.e., a pharmaceutical that provides the right chemical catalyst, interacting personalities that cause dysfunctional organizational and behavioral reactions, or technologies that are utilized in pathological ways). Long incubation periods provide particular challenges for risk managers observing short-term changes in a dynamic system (52).

Finally, risk assessment in marine transportation is difficult because the system has organizational structures with *limited physical oversight,* which makes the process of identifying and addressing human and organizational error complicated. In a distributed system with limited physical oversight, the normal antidotes to human and organizational error—checks and balances, redundancy, and training—may be defeated by the size and scope of the system or by subcultures which can develop in the system. In medicine, for instance, the operating room and the intensive care units can be "hotbeds" for human error (4, 35) because of the tempo of operations, volume of information, criticality of decisions and actions, and complexity of interactions. As medicine moves in an increasingly distributed, electronic direction, with fewer opportunities for physical oversight, checks and balances, and redundancy, medical systems may have difficulty trying to assess and identify the role of human and organizational error, and its impact on levels of risk in the system (4, 35, 52). In marine transportation, with smaller crews, increasing automation and limited opportunities for physical oversight, the role of human and organizational error is also of particular interest.

3. Guidelines for Risk Assessment

The observations in the preceding section have implications for conducting risk assessments. To counter the problem of risk migration, dynamic risk assessment models can be used to capture the dynamics of a complex system, as well as patterns of risk migration. Long incubation periods for pathogens in a system suggest the importance of historical analyses of system performance in order to establish performance benchmarks in the system, and to identify patterns of triggering events, which may require long periods of time to develop and detect. Finally, assessments of the role of human and organizational error, and its impact on levels of risk in the system, are critical in distributed, large-scale systems with limited physical oversight.

To be effective, however, risk assessment requires more than models and analysis. The major element of an effective risk assessment is a *process* that follows generally accepted guidelines, which can establish credibility for the results of the risk modeling and enhance the success of the risk assessment (15). An effective risk assessment process should include steps for:

- Risk identification,
- Risk quantification and measurement,
- Risk evaluation, and
- Risk mitigation.

Risk identification involves developing a framework for understanding the manner in which accidents, their initiating events and their consequences occur. Thus, in addition to a process, a *risk framework* (15, 20, 33) can provide a context within which risk modeling can take place. To measure and evaluate risk, a set of *risk models* is required that capture the historical performance of the system, the dynamic complexity of the system, including risk migration; the role of human and organizational error in the system; and the particular characteristics of the system under study. Effective risk assessments, therefore, incorporate three elements: a risk framework, risk models, and a process that adheres to guidelines for effective risk assessment (40) (Figure 2).

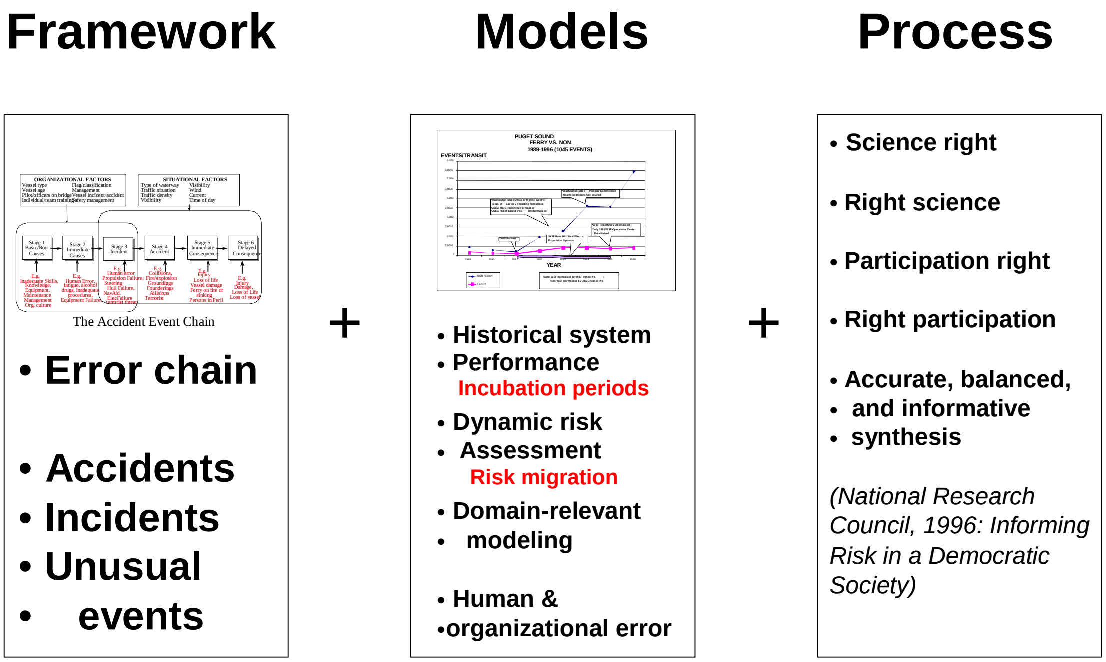


Figure 2. Elements of effective risk assessment

4. Applying the
Guidelines for Effective Risk Assessment

As just described, the National Research Council (40) in 1996 developed guidelines for effective risk assessment that incorporated three elements: a risk framework to guide decision making, the use of risk models to conduct thorough what-if analyses, and a process that promotes accurate, thorough and inclusive participation by interested parties. These elements are summarized in the following section.

4.1 Risk Framework

A risk framework is an important component of effective risk assessment. It provides organizing and orienting definitions, domain-meaningful context, and a structure around which to organize data gathering and analysis. A robust risk framework should provide:

- a definition of risk in the domain under study,
- definitions and examples for components of the error chain in the domain (e.g., basic/root causes, immediate causes, incidents, accidents, consequences, and delayed consequences),
- descriptions of accidents, incidents, and unusual events in the system, and
- identification of risk mitigation measures in the system, categorized by their impact on the error chain (40).

Thus, effective risk assessments should include a domain-meaningful framework within which to assess the risk questions of interest.

4.2 Models

The second element of effective risk assessment is the use of risk models, many of which have been proposed over the past fifty years. The requirements of distributed, large-scale systems, and the challenges of risk in marine transportation outlined in Section 2, however, suggest the need for specific types of risk models:

- *dynamic risk models* to capture the dynamic nature of risk in complex systems, and to capture risk migration in the system,
- *historical analyses of system performance over appropriately long periods of time* in order to develop benchmarks of system performance and to capture latent pathogens that may have long incubation periods,
- *assessments of the role of human and organizational performance,* and its impact on levels of risk in the system, in order to understand the role of human and organizational performance in systems with limited physical oversight, and
- *domain-appropriate models and analyses* to address any special risk requirements in the domain.

Each of these modeling elements makes an important contribution to risk modeling. Dynamic models can capture fluidity and change in a large-scale system. With these models, dynamics in the system can be modeled, a variety of risk mitigation measures can be tested, and tradeoffs between different measures, or combinations of measures, can be evaluated. In addition, changes in levels of risk in the system can be assessed under different scenarios, and "what if" analyses incorporating different risk mitigation measures can be conducted. Finally, risk migration in the system can be identified and analyzed.

System performance benchmarks can ensure that risk mitigation measures reflect historical risk patterns in the system, and can ensure that incubation periods and catalysts in the system can be appropriately identified and managed. Performance and trend analysis of machinery, equipment, and personnel can be helpful in assessing the utility of different risk reduction measures.

Formal assessments of human and organizational performance can capture important performance parameters and ensure that risk mitigation measures attend to the impact that human and organizational performance can have on levels of risk in the system. For human and organizational performance questions of interest, simulations or expert judgment studies can be undertaken to provide the required analysis.

Finally, domain-appropriate models can focus risk modeling on the salient characteristics of the system under study. Each of these modeling elements can also inform the other: historical performance assessments can provide critical input to dynamic risk models, and should highlight the role of human and organizational performance in the system. Similarly, the need for domain-appropriate models and analyses should be derived from the historical performance assessments, and the results of dynamic risk modeling. Finally, the dynamic risk models, the historical performance analyses, and the human and organizational performance assessments should all highlight the needed risk mitigation measures in the system. Following Weick's notion of requisite variety (69), the risk models should be as complex and varied as the system in which they are used.

4.3 Process

The final component in effective risk assessments is a process that adheres to commonly accepted guidelines for effective risk assessment. The National Research Council's (NRC's) Committee on Risk Assessment identified five general objectives for effective risk assessment:

- Get the science right,
- Get the right science,
- Get the participation right,
- Get the right participation, and
- Develop an accurate, balanced, and informative synthesis (40).

Getting the science right implies that the risk analysis meets high scientific standards in terms of measurement, analytic methods, data bases used, plausibility of assumptions, and respectfulness of the both the magnitude and character of uncertainty, taking into consideration limitations that may have been placed on the analysis because of the level of effort judged appropriate for informing the decision. In practical terms, this means utilizing a scientifically accepted risk assessment methodology, with careful attention to measurement, analysis, data, assumptions, and the importance of uncertain, incomplete, and unreliable information, and its impact on risk assessment.

Getting the right science means that the risk analysis addresses the significant risk-related concerns of public officials and the spectrum of interested parties and affected parties, such as risks to health, safety, economic well-being, and ecological and social values, with analytic priorities having been set so as to emphasize the issues most relevant to the decision. In marine transportation, this means that the risk-related concerns of marine transportation system members, members of the port and waterway community, public officials, regulators, scientists and other specialists, and a variety of interested and affected parties are considered. Those priorities can be determined in a variety of ways: by consulting with the applicable Port and Harbor Safety Committees; through analytic deliberation with agency, public, industry, and environmental parties; and through listening sessions, to name a few. Risk priorities should be articulated early in the assessment process, and refined as required.

Getting the right participation means that the risk analysis has sufficiently broad participation to ensure that important, decision-relevant information enters the process, that important perspectives are considered, and that legitimate concerns about inclusiveness and openness are met. The NRC Committee specifically recommended using a variety of activities and incorporating broad participation in risk assessment activities, even though these activities are potentially time-consuming and cumbersome. The NRC Committee advised that it is often wiser to err on the side of too broad rather than too narrow participation in order to ensure the acceptance of the assessment's findings, and to enhance the likelihood of implementation of recommendations. Practically, in marine transportation, this means ensuring that participation is sought and garnered from a variety of sources: from shipping and towing company employees and operators; from state, federal, and local regulators; from ship's pilot organizations; from ship's agents and representatives; from insurers, brokers and financiers; from maritime interest groups representing all segments and types of waterway users and managers; from the U.S. Navy; from environmental and legal groups and representatives; and from other interested and affected parties.

Getting the participation right means that the risk assessment satisfies the decision makers and interested and affected parties that the risk assessment process is responsive to their needs: that information, view points, and concerns have been adequately represented and taken into account; that all parties have been adequately consulted; and that participation has been able to affect the way risk problems are defined and characterized. Practically, in marine transportation, this can mean that members of the marine transportation system, including ships' officers and pilots, are included in the process--observed and consulted in their natural work setting, where problems and issues can be observed and demonstrated. This also means that shore-based management, operations, engineering, maintenance, and safety personnel should be consulted in their places of work. A similar process should be followed with other stakeholders and interested parties: with regulators; insurers; agents; brokers, shippers; environmental, legal, and special interest groups, and other interested and affected parties. The goals for the interactions with the interested and affected parties should be to consult with the parties; to seek data and information from them; to strive to understand the viewpoints, concerns, and information provided; and to provide feedback as to how the gathered information and viewpoints can be incorporated into the risk assessment. Where appropriate, preliminary data analyses and results could also be reviewed with interested and affected parties.

Developing an accurate, balanced, and informative synthesis was the final guideline for effective risk assessment articulated by the NRC. This guideline focuses on risk characterization—presenting the state of knowledge, uncertainty, and disagreement about the risk situation to reflect the range of relevant knowledge and perspectives, and satisfying the parties to a decision that they have been adequately informed within the limits of available knowledge. An accurate and balanced synthesis treats the limits of scientific knowledge (i.e., the various kinds of uncertainty, indeterminacy, and ignorance) with an appropriate mixture of analytic and deliberative techniques.

The five process guidelines are related. To be decision-driven, a risk assessment must be accurate, balanced, and informative. This requires getting the science right and getting the right science. Participation helps ask the right questions of the science, checks the plausibility of assumptions, and ensures that any synthesis is both balanced and informative. Thus, each of the steps provides important input to an effective risk assessment.

5. Risk Analysis Considerations

In addition to a sound process, effective models and a robust risk framework, there are other considerations that should factor into the design of an effective risk assessment process. These items include the use and availability of data, the need to address human factors topics of interest, and approaches to treating uncertainty in risk analysis. These topics are addressed in this section.

5.1 Data Considerations

Large-scale modeling is critically dependent on good data, available statistics, and, when necessary, carefully encoded expert opinions (29). However, difficulties with data to support risk analyses in the marine environment have been identified by a variety of agencies (36, 37, 39). Considerable marine safety data are collected under protocols established by the Coast Guard. Although these data are useful, they do not provide the resources necessary to address trends related to vessel construction, outfitting, manning, technical systems, and maintenance, or to develop a full understanding of all safety needs (37, 39). In addition, a large number of small-scale, localized incidents occur that, with few exceptions, are not tracked by marine safety authorities. The potential for small-scale incidents to develop into marine casualties is neither well understood nor addressed in most waterways management activities, although recently the American Bureau of Shipping has begun an effort to identify precursors or leading indicators of safety in marine transportation (14).

A few reports are available that examine task performance problems and situational factors in marine accidents. Some found that different task performance problems are associated with different types of marine accidents (5, 6, 11, 34, 46, 58). Limited information for risk assessment is available in reliable, and especially electronic, form on traffic flows, seasonal variations, daily variations, trouble spots, trouble conditions, problem vessels, commodity flows, effectiveness and the utility of navigation support systems such as vessel traffic services (VTS) and on-board electronic equipment, causal factors, and other information essential to refinement of operations and system planning. Some of this information is collected in varying degrees but is not widely available for risk assessments (39).

Reliable data on a range of identified risk factors is needed to support complete risk assessments. Alternatives for development of data on risk and exposure in the absence of reliable data include the establishment of near-miss reporting systems, establishment of an exposure database, and establishment of a comprehensive risk assessment program (39).

The use of available accident data for comparing performance in operational contexts is a problem that plagues many domains. The National Transportation Safety Board has noted that flight crew performance during accidents is subject to the simultaneous influences of many operational context variables. Because of data limitations—a small number of accidents (due to their rarity), and missing data (due to the nature of the evidence in accident investigations)—the interactions between operational context variables and human performance is difficult to analyze (45, p. 84). These types of problems also plague marine transportation, and make difficult complete analyses of the impact of human error on safety in large-scale systems. The United States General Accounting Office and Congress are currently exploring methods to improve the collection, representation, integration and sharing of accident and incident data in marine transportation, but this effort is just recently underway (63).

In the 1996 Prince William Sound Risk Assessment, several uncertainties about the available data were identified, which continue as data uncertainties today (42):

- *The problem of good reporters vs. poor reporters.* In accident-incident databases, shipping companies with robust reporting systems have failure rates higher than those companies with poor reporting systems; thus, failure, incident and near-miss rates are proportionally higher for good reporters vs. poor reporters.

- *Not all members of a marine transportation system community may participated in a risk assessment.* For instance, in the 1996 Prince William Sound risk assessment, although all TAPS trade tanker owners and operators participated in the study, as did SERVS, the Southwest Alaska Pilots Association, and fishermen in the Sound, several key participants who interacted with tankers on a daily basis in the Sound, did not: ferry operators, passenger vessel operators, tour and recreational boating operators, and tug/barge operators. Thus, data reflecting their activities came from observations of other participants in the Sound about their activities, rather than data from the organizations themselves. To counter this problem, the non-participating organizations were contacted during the study; representatives from their organizations were interviewed during the system requirements part of the study; and project team members rode their vessels (with the exception of coastal tug/barges) in order to more fully understand their operations and perspectives. However, participation of all marine transportation system members is a critical data need in maritime risk assessment.

- *The absence of an accessible, independent, reliable source of failure, incident, or near miss data.* To counter this difficulty, an accident-incident database that described failures, incidents, and near misses that occurred in Prince William Sound or to TAPS trade tankers was constructed in 1996. The data used was a mix of publicly available data and company confidential data, each item of which was verified twice as to source and particulars of the incident (i.e., two independent data sources were required for inclusion of items in the database).

  Construction of the accident-incident database was a significant task, as most of the public and private data was not available in electronic form, and none of it was in a common electronic format. In addition, because of the decision to require two independent sources for all data items, data reconciliation of events in the database consumed a significant amount of time. In almost all cases, resolution of open items in the database was done manually, requiring retrieval from archival records of information relating to hundreds of incidents. Clearly this approach to data gathering is not representative of most approaches to data collection. However, absent a reliable, independent and accessible source of failure, incident, and near-miss data, or a common data format for sharing data, and given the need for trust in the data and in the risk assessment results (see below), the approach adopted offered a means of providing reliable and trustworthy data as input to the risk assessment.

- *The absence of trust in a system--between members of the system, in decisions taken between members of the system, in data used to support decisions taken. --complicates data requirements.* Approaches to collecting, assembling, and verifying data in the 1996 Prince William Sound risk assessment project reflected the needs of the participants in the study: for participants to protect confidential data from the public and their competitors; for participants to have confidence that appropriate and complete data sources were being used as the basis for the risk assessment; for participants to feel that local data that reflected the experience and operating characteristics of Prince William Sound and its calling fleet was being used as the basis of the risk assessment; and for participants to feel that all reliable data, no matter the source, was included in the data used to support the risk assessment. These dynamics led to significantly time intensive data collection and verification activities, which may not be representative of approaches chosen in other risk assessment activities.

5.2 Human Factors Modeling

In distributed, large-scale systems with limited physical oversight, assessing the role of human and organizational performance on levels of risk in the system is important, especially as such error is often cited as a primary contributor to accidents. However, data for human and organizational performance analyses are difficult to obtain. Where they are available, the data have often not been tailored to specific applications and it is difficult to quantify human factor risks or human performance in a specific context. Expert interpretation is often required to determine the applicability (41).

The most significant reason for the lack of human factors data as input into maritime risk analysis models is that human factors have not been adequately evaluated in the investigation, analysis, and coding of accidents and incidents (42, 63). This problem has been widely recognized in other modes of transportation and in other environments. However, efforts have been made in the last few decades to improve the investigation and coding of human performance factors and factors that contribute to human errors in marine transportation (42). Human performance data can be gathered in the field or in simulators, and used as input in job-task analyses, manning and crewing studies, evaluations of various technologies, and in assessments considering the risk of different scenarios, technologies, equipment, or policies (44).

Other issues can cause difficulty in the analytic use of human and organizational error data in risk assessment: uncertainty in human error probabilities, questions about the transferability of human factors data from different domains, and the compounding influence of environmental factors in accident data (2, 41). In addition, there can be difficulty integrating human factors data and analyses into models or simulations developed during a risk assessment.

These human factors considerations suggest that careful attention to the use of human factors data is warranted. Obtaining actual human performance data in the domain or in a simulator is of critical importance in many risk assessments. Use of human and organizational performance models is also important, and suggests the use of accepted performance shaping models, job task analyses, and error models (52). Finally, careful attention to the appropriate use and integration of human factors data in risk assessment models is also warranted.

5.3 Uncertainty Analyses

The presence of uncertainty in risk assessment is well recognized (49), with two types of uncertainty often discussed: aleatory uncertainty (the randomness of the system itself) and epistemic uncertainty (the lack of knowledge about the system). In a modeling sense, aleatory uncertainty is represented by probability models that give probabilistic risk analysis its name, while epistemic uncertainty is represented by lack of knowledge concerning the parameters of the model (47). In the same manner that addressing aleatory uncertainty is critical through probabilistic risk analysis, addressing epistemic uncertainty is critical to allow meaningful decision-making. Cooke (7) offers several examples of the conclusions of an analysis changing when uncertainty is correctly modeled. The following figures illustrate other examples of uncertainty challenges in risk assessment.

Figure 3 shows the results from an analysis of proposed ferry service expansions in San Francisco Bay. The estimates show the frequency of interactions between ferries and other vessels for the current ferry system (Base Case) and three alternative expansion scenarios which increase the total number of ferry transits per year.

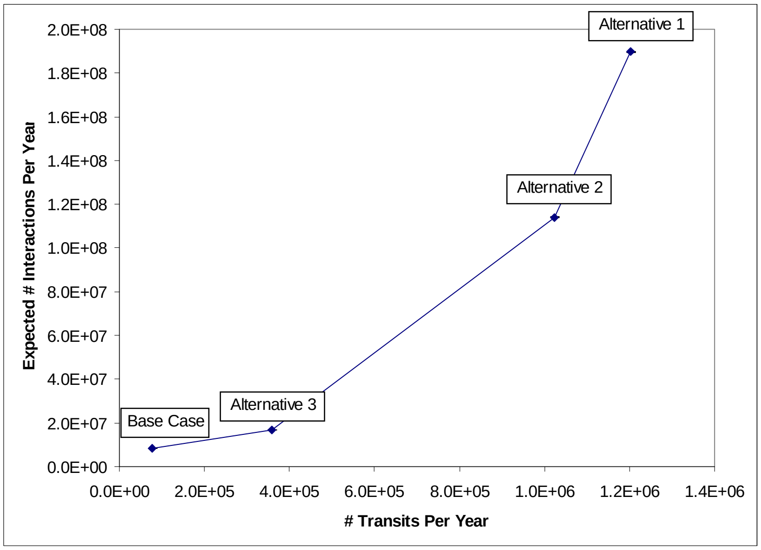


Figure 3. An assessment of alternative expansion scenarios for ferries in San Francisco Bay.

In another example, Figure 4 shows the risk intervention effectiveness estimates from a risk assessment conducted for the Washington State Ferries (32). The figure shows the total percentage reduction in collision probability for the WSF system for various risk management alternatives.

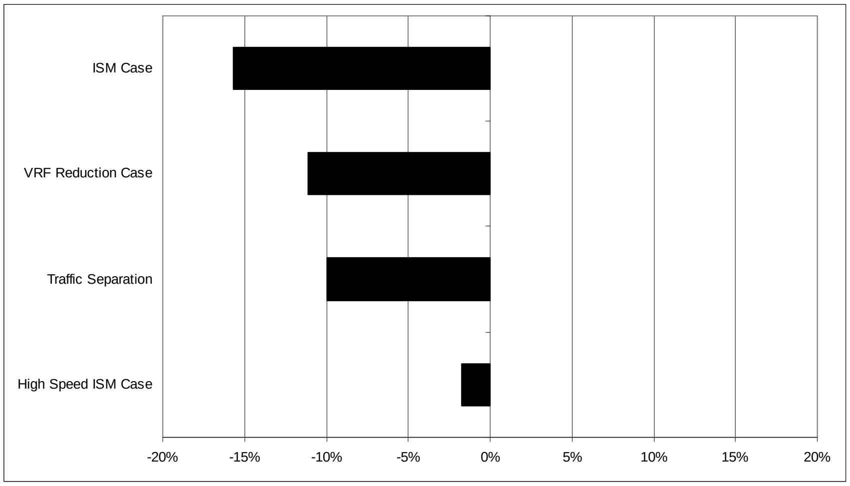


Figure 4. An assessment of risk intervention effectiveness for proposed safety improvements for the Washington State Ferries.

One problem with the representations in Figures 3 and 4 is the apparent finality of the results. The decision-maker is led to believe that the results are definitive and are in no way uncertain. In fact, the National Research Council's peer review of the PWS Risk Assessment concluded that the underlying methodology showed "promise" to serve as a systematic approach for making risk management decisions for marine systems (42), but cautioned that in order to represent risk in a balanced manner, the degree of uncertainty needed to be communicated (27, 42). *"Risk management … should answer whether evidence is sufficient to prove specific risks and benefits"* (43).

The National Science Foundation has recently funded research that addresses uncertainty in maritime risk assessment (27, 29, 32). As a result of this research, more robust means of representing and communicating uncertainty have been developed, a critical need in maritime risk assessment (42). Developing an accurate, balance and informative risk synthesis requires presenting the state of knowledge, uncertainty, and disagreement about the risk situation, and treating the various kinds of uncertainty in the system with an appropriate mixture of analytic and deliberative techniques (40). Thus, although progress has been made in representing and characterizing uncertainty in risk analyses, and more robust uncertainty tools have been developed, attention to the characterization of uncertainty in maritime risk assessment is important, and additional work in uncertainty in risk assessment will be required in the future.

6. Recommendations

Following the guidelines for effective risk assessment outlined in Sections 3 and 4, and mindful of the human factors, data, and uncertainty considerations highlighted in the previous section, a risk assessment process to consider the impacts of changes in tug escort policies in Prince William Sound, Alaska can be considered. Figure 5 illustrates a Gantt chart of activities along a timeline; Table 2 provides a descriptive narrative of tasks and activities suggested for a new or updated risk assessment. Figure 5 follows the elements described in Sections 3 and 4, providing a framework, models and process for risk assessment in Prince William Sound. A discussion of the data requirements and limitations of such a risk assessment is also contained in this section.

As can be seen in Figure 5, the risk assessment process begins with a *Project Scope and Objectives* task that establishes the scope and objectives for the risk assessment, including a draft project plan, deliverables and schedule, and a set of governing assumptions for the risk assessment. Following the initial Project Scope and Objectives task, a *System Requirements task* follows, during which the initial 1996 Prince William Sound system description can be updated, which defines the domain, context and environment for the study, along with key constructs of the risk assessment—people, organizations, roles, technology and equipment, organizational and system culture, organizational and system structure, as well as key definitions and assumptions. Vessel rides on TAPS trade tankers can be completed, and a TAPS tanker background questionnaire as well as the TAPS escort survey questionnaire can be administered, both of which address procedures, practices and assumptions aboard the tankers and the tug escorts.

Data Assessment is the next task. During this task, the sources of data for the risk assessment can be identified, and a data analysis plan can be prepared. A *Simulation Analysis* task follows; the traffic, weather, ice and VTS data to be utilized can be collected; expert judgment elicitation sessions can be scheduled; the baseline Prince William Sound traffic and weather simulation can be updated, and an initial 2006 baseline risk evaluation can be prepared. The 2006 initial risk baseline can be compared to the initial 1996 baseline, and evaluation of an initial set of scenarios of interest can begin. A revised simulation analysis is conducted following the HF analysis, in order to incorporate the human factors results.

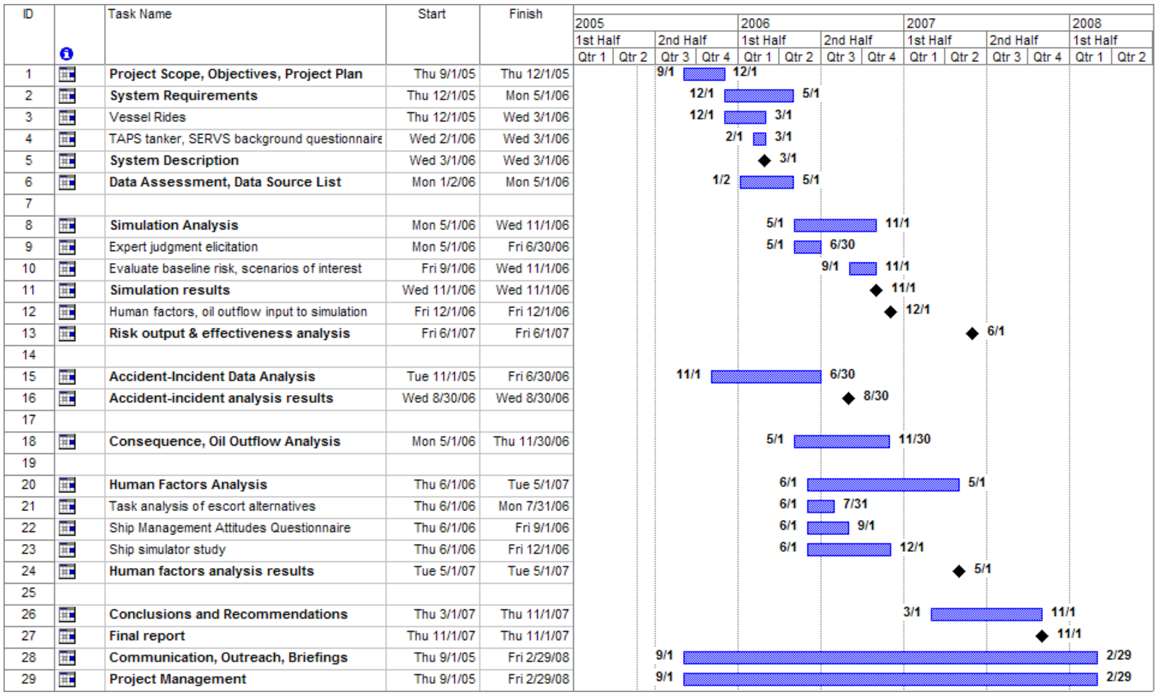
Earlier, work on an *Accident-Incident Data Analysis* can begin; data collection can be performed, and a historical accident-incident database from 1996-2006 can be constructed, and a comparison between 1996 and 2006 baselines completed. An *Oil Outflow Analysis*, or *Consequence Analysis* can follow, during which consequence analyses can be undertaken.

A separate *Human Factors Analysis* is suggested, given the importance of human and organizational performance questions in the tug escort system. Initially, a task analysis of the escort system can be developed, evaluating a baseline escort scenario, and comparing the baseline to a set of scenarios of interest. Timelines, roles, and response scenarios can be examined. A redundancy, critical path, and slack analysis can be performed, as input to the system simulation. At the same time, a safety culture questionnaire (the Ship Management Attitudes Questionnaire), which assesses organizational and vessel safety culture and climate, can be administered to provide quantitative and qualitative input to the safety culture analysis. Finally, in order to develop the empirical human factors data so critical to risk assessments involving human performance, a ship simulator task is suggested to evaluate escorted, unescorted, and sentinel tug scenarios of interest. The results of the human factors analysis will be characterized, and provide input to the revised simulation analysis.

Conclusions and Recommendations are suggested following completion of these steps. Because of the importance of communication and feedback during the risk assessment, periodic interim reports and presentations can be scheduled with the sponsor(s), in addition to outreach and briefing sessions as desired with interested parties. An attentive and responsive project management task can underscore each of the tasks just outlined.

Following Figure 2 and the NRC guidelines, the suggested tasks provide a framework, models, and a process guiding the conduct of the risk assessment. The *framework* suggested for the risk assessment process is provided in Figure 1. The *models* proposed include a real-time traffic, weather, ice and tug escort simulation model; an oil outflow model; and a model of historical accidents and incidents that serves as input to the simulation model as well as a standalone model for trend analysis. In addition, the suggested tasks include a separate human factors simulation task in order to examine the human and tug escort response timelines and performance. The use of several models that share common data and assumptions is recommended so that model results can be integrated and coordinated, and so that 'what if' analyses from one model can be used as input to, or as analysis of, another model.

Finally, the *process* ensures that the risk assessment follows generally accepted guidelines, which can establish credibility for the results of the risk modeling and enhance the success of the risk assessment. The process includes the 5 steps outlined in the NRC risk assessment report—getting the science right, getting the right science, getting the participation right, getting the right participation, and developing an accurate, balanced, and informative synthesis.



ID	Task Name	Start	Finish
1	**Project Scope, Objectives, Project Plan**	Thu 9/1/05	Thu 12/1/05
2	**System Requirements**	Thu 12/1/05	Mon 5/1/06
3	Vessel Rides	Thu 12/1/05	Wed 3/1/06
4	TAPS tanker, SERVS background questionnaire	Wed 2/1/06	Wed 3/1/06
5	**System Description**	Wed 3/1/06	Wed 3/1/06
6	**Data Assessment, Data Source List**	Mon 1/2/06	Mon 5/1/06
7			
8	**Simulation Analysis**	Mon 5/1/06	Wed 11/1/06
9	Expert judgment elicitation	Mon 5/1/06	Fri 6/30/06
10	Evaluate baseline risk, scenarios of interest	Fri 9/1/06	Wed 11/1/06
11	**Simulation results**	Wed 11/1/06	Wed 11/1/06
12	Human factors, oil outflow input to simulation	Fri 12/1/06	Fri 12/1/06
13	**Risk output & effectiveness analysis**	Fri 6/1/07	Fri 6/1/07
14			
15	**Accident-Incident Data Analysis**	Tue 11/1/05	Fri 6/30/06
16	**Accident-incident analysis results**	Wed 8/30/06	Wed 8/30/06
17			
18	**Consequence, Oil Outflow Analysis**	Mon 5/1/06	Thu 11/30/06
19			
20	**Human Factors Analysis**	Thu 6/1/06	Tue 5/1/07
21	Task analysis of escort alternatives	Thu 6/1/06	Mon 7/31/06
22	Ship Management Attitudes Questionnaire	Thu 6/1/06	Fri 9/1/06
23	Ship simulator study	Thu 6/1/06	Fri 12/1/06
24	**Human factors analysis results**	Tue 5/1/07	Tue 5/1/07
25			
26	**Conclusions and Recommendations**	Thu 3/1/07	Thu 11/1/07
27	**Final report**	Thu 11/1/07	Thu 11/1/07
28	**Communication, Outreach, Briefings**	Thu 9/1/05	Fri 2/29/08
29	**Project Management**	Thu 9/1/05	Fri 2/29/08

Figure 5
Proposed Risk Assessment Plan

6.1 Data Required

The necessary data for such a risk assessment includes information on traffic patterns, the environment (weather, sea conditions, visibility, ice), historical and current operational performance data, and human performance data. Traffic and environmental data patterns are used to develop the traffic simulation model, and operational data is also used in the system simulation, along with human performance data, as available. A more complete list of data required follows:

- Geographic data for the area under study to provide the baseline geographical representation for the simulation;
- Vessel traffic data for TAPS and non-TAPS tankers in the system, including SERVS vessel, tug and barge, and fishing vessel traffic over a period of several years;
- Weather, visibility, and ice data over a several year period;
- Historical accident, incident, and near miss data for all vessels in the system—TAPS and non-TAPS tankers, SERVS vessels, tug and barges, passenger ships, and fishing vessels over a several year period;
- TAPS tanker and non-TAPS tanker (including SERVS vessels) background surveys;
- Ship visit and survey data;

- TAPS tanker, non-TAPS tanker, and SERVS vessel failure rates over a several year period (propulsion failures, steering failures, navigational equipment failures, electrical failures, etc.);
- Human bridge and tug performance and response data over a several year period;
- Expert judgment data to supplement missing or inadequate human factors data;
- Oil outflow, consequence data;
- New TAPS trade tanker vessel performance and reliability data;
- New TAPS trade tanker vessel data characteristics; and
- Pilot and master human performance data over a several year period.

All of the models intended for use are highly dependent on appropriately selected databases that accurately represent the local situation. The effectiveness of the models, however, will reflect any data limitations. For instance, as in many other marine areas, Prince William Sound will lack some data suitable for use in the models described. As a result, creative procedures will be required to develop the requisite data and relationships by using expert judgments, worldwide data and data from other areas (e.g., the North Sea), making assumptions about the similarity of operations in the PWS and elsewhere, and making assumptions about how behavior in one aspect of operations (e.g., company management quality) and/or one parameter (e.g., loss of crew time) correlates with another area (e.g., operations safety) (42).

Care is required with the use of worldwide data, however, as much of those data are influenced by location or environmental conditions. For example, in the 1996 Prince William Sound risk assessment, it was generally assumed that certain mechanical failures were independent of location. In fact, however, mechanical failures often depend on factors like duty cycles or maintenance procedures, which, in turn, depend on the particular service in which the vessel is employed (42). Thus, the use of worldwide data to supplement local data should be undertaken with care. On the other hand, however, electronic access to worldwide casualty data such as the Paris MOU, U.K. Marine Accident Investigation Board (MAIB), and IMO Port State Detention databases makes possible access to worldwide casualty statistics that were not available in 1996.

A sparse database and a relatively large difference between real experience in PWS and the data used for the study can influence the credibility of a risk assessment's results. Worldwide data, when used to fill the gap of existing data, may not be representative of local conditions or operations. Some data, such as propulsion failure rates, should be derived from shipping company databases. But every company collects and reports data differently, which could compromise the accuracy and precision of the analysis. Weather data can be incomplete when the number and locations of collecting stations do not cover weather at the two most critical sites in the PWS, the Narrows and the Hinchinbrook Entrance, as in the 1996 risk assessment (42). Expert judgments can be used to fill gaps and augment weather data; however, even when attempts are made to minimize errors from expert judgments, the data are inherently subject to distortion and bias. Thus, even with an extensive list of required data, there are limits that available data can place on the accuracy, completeness, and uncertainty in the risk assessment results.

6.2 Human Factors Modeling

There is substantial work on the contributing role of human factors in accidents in fields other than marine transportation, such as aviation safety and nuclear reactor safety. Expert judgments have long been used to assess relative probabilities in studies of risk, but the usefulness of expert judgments depends on the experts' ability to make judgments and the analysts' ability to aggregate these opinions properly (42). In the 1996 Prince William Sound risk assessment, experts were asked to make judgments about the likelihood that failures would occur in specific situations. This data supplemented the paltry human performance data available at the time. Effective elicitation has become an important element in risk assessments of complex systems, such as nuclear power plants and high-level waste repositories. Thus, careful attention to expert judgment data and human factors modeling is warranted in the proposed work (42).

Because of the importance of human performance issues in the risk assessment, a separate *Human Factors Analysis* is suggested. Initially, a task analysis of the escort system can be developed, evaluating a baseline escort scenario, and comparing the baseline to a set of scenarios of interest. Timelines, roles, and response scenarios can be examined. A redundancy, critical path, and slack analysis can be performed, as input to the system simulation. At the same time, a safety culture questionnaire (the Ship Management Attitudes Questionnaire), which assesses organizational and vessel safety culture and climate, can be administered to provide quantitative and qualitative input to the safety culture analysis. Finally, in order to develop the empirical human factors data so critical to risk assessments involving human performance, a ship simulator task can be performed to evaluate escorted, unescorted, and sentinel tug scenarios of interest.

The results of the human factors modeling and analysis can be a set of response timelines for escorted and unescorted scenarios, as well as for various scenarios of interest. Analysis of the results can provide important standalone information such as bottlenecks, hazards, redundancy, and response timelines. The results can also provide important human factors input to the system simulation, an element missing from the 1996 Prince William Sound risk assessment (42).

6.3 Alternatives to Risk Assessment

As an alternative to a system-wide probabilistic risk assessment (24), scenario-based analyses of tanker-escort combinations under a variety of scenarios can be undertaken, as was recently done in Puget Sound (12). Scenario-based analyses consider the relative risks of different conditions, scenarios and events. Such analyses offer deep knowledge of escort requirements and tug performance, but the data and/or results are not linked to a system simulation that permit analysis of the system-wide impacts of various risk reduction interventions or tug escort scenarios.

For instance, when a simulation is run for a period of time (for example, 10 years), it is calibrated so that the number of accidents and incidents that have occurred over the study period are replicated. With the system simulation, however, a geographic analysis of the results is possible, meaning that it is possible to identify where (geographically) accidents and incidents are occurring. Thus, risk reduction interventions and tug escort alternatives can be considered from a geographic and system-wide perspective, an analysis not possible with a scenario-based analysis. Such a system-wide representation of risk would be quite helpful in studying risk with and without tug escorts, or in studying a pre-positioning question with varying tug response times and distances. In addition, the question of where additional risk will occur, based on the presence of returning escort vessels, can also be studied with a system-wide dynamic simulation. Scenario-based analyses do not allow such an analysis.

Finally, scenario-based analyses do not provide visibility into the risk-related impacts of system changes, into risk migration, or into the unintended system-wide consequences of the introduction of risk reduction measures. Thus, scenario-based analyses can be undertaken as an alternative to a system-wide risk assessment, but the analyses will not provide a system-wide representation of risk and the impact of various risk reduction interventions and/or tug escort scenarios on overall levels of risk in the system, particularly over a period of time.

Table 2
Prince William Sound Risk Assessment Project Plan
24 May 2005 **ARO = after receipt of order*

Task	Activity	Deliverable	Dates	Participants
Project Scope and Objectives	Develop Project Scope and Plan • **Project Objectives** • **Project Scope** • **Project Plan** • **Deliverables/Schedule** • **Assumptions**	**Project Scope, Definition, Plan**	**1-3 months ARO**	**All**
System Requirements	**Update System Description** • **Domain/Context/Setting/** Environment • **Definitions** • **Assumptions** • **Organizations, Members** • **Tasks** • **Technology** • **Organizational Structure** • **Organizational Culture**		**3-9 months ARO**	**RPI/LeMoyne lead** **All**
	Vessel Rides			**All**
	TAPS Tanker background questionnaire			**RPI/LeMoyne**
	Tug Escort Survey—procedures, practices, assumptions			**VCU**
	Draft System Description	**System Description**	**6 months ARO**	**RPI/LeMoyne lead** **All**
	Final System Description			**RPI/LeMoyne lead**

Task	Activity	Deliverable	Dates	Participants
Data Assessment	**Data source list** **Data analysis plan**		**6 months ARO** **8 months ARO**	**All** **All**
Simulation Analysis • **Traffic Patterns** • **Weather Data** • **Ice Data** • **VTS Data**	**Expert judgment elicitation** **Update simulation** **Evaluate 2006 baseline risk** **1996 baseline vs. 2006 baseline** **Evaluate scenarios of interest analysis**	**Simulation analysis results** **Risk output and effectiveness analysis**	**14 months ARO draft** **21 months ARO revised, incorporating human factors input**	**GWU/VCU lead**
Accident-Incident Data Analysis	**Historical accident – incident analysis 1996 – 2006** **1996 vs. 2006 comparison**	**Historical accident incident analysis**	**12 months ARO**	**RPI/LeMoyne lead**
Consequence Analysis	**Oil Outflow Analysis**	**Consequence analysis**	**15 months ARO**	**GWU/VCU lead**
Human Factors Analysis	**Task analysis of escort alternatives** **--baseline escort scenario** **--scenarios of interest** **--timelines, roles, response timelines** **--redundancy analysis** **--critical path analysis** **--input to OFI/RIP** **Ship Management Attitudes Questionnaire (culture)**		**9-20 months ARO** **6 – 12 months ARO**	**RPI/LeMoyne lead** **SW Alaska Pilots** **TAPS tanker crews** **Simulator** **RPI/LeMoyne lead** **SW Alaska Pilots** **TAPS tanker crews** **Simulator** **RPI**

Task	Activity	Deliverable	Dates	Participants
Human Factors Analysis, continued	**Ship simulator study:** **SH escorted** **DH unescorted** **DH sentinel tug** • **Baseline scenarios** • **Scenarios of interest**	 **Human factors analysis**	**9 - 15 months ARO** **20 months ARO**	**RPI lead** **RPI lead**
Conclusions and Recommendations	**Prepare findings and conclusions** **Prepare final report**	 **Draft final report** **Final report**	**18 – 26 months ARO** **22 months ARO** **26 months ARO**	**All** **All** **All**
Communications, Meetings, Briefings, Outreach	**Meetings** **Briefings** **Outreach** **Publication**	**Presentations and materials as required**	**0 – 30 months ARO**	**All**
Project Management	**Project Management**		**0 – 30 months ARO**	**All**

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