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Prince William Sound, Alaska
Risk Assessment Study

FINAL REPORT

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December 15, 1996

Prince William Sound Risk Assessment Steering Committee
Alaska Department of Environmental Conservation
Alyeska Pipeline Service Company/SERVS
Prince William Sound Regional Citizens' Advisory Council
United States Coast Guard
PWS Shipping Companies (ARCO Marine, Inc., BP Oil Shipping Company, U.S.A., Chevron Shipping Company, SeaRiver Maritime, Inc., Tesoro Alaska Petroleum Co.)

Prince William Sound Risk Assessment Project
Executive Summary

The Prince William Sound (PWS) Risk Assessment was initiated to address questions concerning the value and benefits of numerous prevention measures proposed and in place for reducing the risk of oil loss from a Trans Alaska Pipeline System (TAPS) tanker in Prince William Sound. In the spring of 1995, the PWS shipping companies proposed a risk assessment study to the Regional Citizens' Advisory Council (RCAC) and suggested that other interested stakeholders would be the Alaska Department of Environmental Conservation (ADEC), and the United States Coast Guard (USCG). These stakeholders in the PWS oil transportation system along with Alyeska Ship Escort Response Vessel System (SERVS) accepted the proposal and formed a Steering Committee to oversee the project.

The Steering Committee established three primary objectives:

1) identify and evaluate risks of oil transportation in PWS;

2) identify, evaluate and rank proposed risk reduction measures; and

3) develop a Risk Management Plan and risk management tools that can be used to support a risk management program.

The mission of the risk assessment was to "improve the safety of oil transportation in Prince William Sound". To achieve this mission, the risk of oil loss by a TAPS tanker in transit in PWS had to be quantified. For the purpose of the study, a transit was defined geographically as the area encompassed by the vessel route beginning 20 miles before Hinchinbrook Entrance, into and out of Valdez. The risk of oil loss at the dock while discharging or loading was not addressed in this study. The risk assessment was designed to provide system stakeholders, represented by the Steering Committee members, with information, techniques, and analysis to understand and quantify the risk associated with the current transportation of oil in PWS and with proposed measures for managing the current system risk. The PWS Risk Assessment provides a quantitative basis for understanding the current level of risk and evaluating proposed risk mitigation measures. The product of the risk assessment provides a dynamic capability -- the continuing ability to evaluate and quantify system changes and thus aid in the management of system risk.

Four models were developed and used in the risk assessment to determine the statistical expectation of accident frequency and the statistical expectation of oil outflow for seven accident types: collisions, drift groundings, powered groundings, fires/explosions, structural failures, founderings, and allisions. The statistical expectations of accident frequencies and oil outflows were also calculated for thirty six accident scenarios defined as accident type - location specific combinations. The models developed were:

The System Simulation/Regression analysis reflects dynamic changes in the system and their effect on system risk. The system simulation is based on historical data, established system procedures, and expert judgment data obtained from the PWS maritime community and modeled using regression analysis. The system simulation shows how frequently weather, ice and traffic combinations of the system actually occur and uses the regression models to quantify the effect of these combinations on system risk.

The Marine Accident Risk Calculation System (MARCS) is a statistical model that provides a systemwide perspective for indicating the frequency and location of accidents in a marine system.

Fault Trees were used to augment and calibrate the MARCS model as well as to provide a more detailed analysis of the following scenarios:

- powered groundings in the Narrows;
- ice navigation in the Valdez Arm; and
- allision (impact) with the berth at the Valdez Port.

Through a detailed causal analysis and incorporation of historical data and expert judgment, the fault trees determined basic accident frequencies for fires/explosions, collisions, structural failures and powered groundings.

The fourth model, the **Oil Oufflow Model,** was used to estimate the consequences of accidents predicted by the other three models.

The PWS Risk Assessment deals with the modeling of a complex marine system with model parameters estimated from a variety of data sources. Any modeling process involves dealing with uncertainty in model assumptions, data quality, and parameter estimation. This must always be considered when interpreting conclusions from a modeling analysis. The special features of the PWS Risk Assessment such as the active involvement of the Steering Committee, wide access to the PWS community, the combination of a multiple expertise of the contract team and the development of multiple models for analysis, helped reduce this uncertainty and ensure the meaningfulness of the presented results.

Conclusions of the Analysis

The conclusions address the state of the PWS oil transportation system in 1995 and suggested mitigation measures. The study concluded that:

1. Current safeguards in the Prince William Sound oil transportation system have effectively and substantially reduced risk. Analysis revealed that current system safeguards have removed approximately 75 percent of the system risk that would exist if these safeguards were not in place.

2. The single most effective risk reduction measure to date has been the current escort system which effectively reduces potential oil outflows due to groundings.

3. In light of 1 above, and in order to continue process improvement in the system, accident scenarios with the greatest potential for additional risk reduction were identified for further consideration. These included:

    - Powered grounding of a laden outbound tanker in the Narrows caused by the present inability to prevent, detect, or correct human errors which may occur in the operation of the tethered tug.

    - Collision in the Port, Narrows, Arm and Central Sound caused by fishing vessel and tanker interactions, traffic congestion (often due to closure conditions and management of the exclusion zone) and human error.

    - Drift grounding at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance (denoted by the title Gulf of Alaska in this report) caused by propulsion or steering failures and the inability of current escort vessels to prevent larger disabled tankers from grounding in the upper range of weather conditions allowed by weather closure restrictions at Hinchinbrook Entrance.

    - Powered grounding in the Narrows caused by loss of ship control, predominantly due to human error on the tanker.

    - Powered grounding at Hinchinbrook Entrance and in Valdez Arm caused by human error.

4. A significant increase in the risk of collision and powered grounding in the Arm exists when ice is present in the traffic lanes during transits.

5. Methods for achieving the potential risk reduction can be defined in two ways: *targeted risk mitigation measures* (defined as those measures which address problems in specific scenarios) and *systemwide risk mitigation measures* (defined as those measures which address risk from a systemwide perspective). Effective *targeted* risk mitigation measures included:

   - Improved ability to prevent, detect, or correct human error which may occur in the operation of the tethered tugs in the Narrows in order to prevent powered groundings.

   - Improved ability to save disabled outbound laden tankers at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance in the upper range of weather conditions allowed by weather closure restrictions.

   - Coordinating fishing vessel/tanker interactions and escort vessel interactions to minimize the risk of collision in the Port, Narrows, and Arm.

   - Improved ice transit management so as to minimize the risk of powered grounding and vessel damage due to maneuvering in ice.

   Effective *systemwide* risk mitigation measures included:

   - The implementation of safety management systems that have the potential for reducing human error and vessel reliability failures, which reduce both accident frequencies and oil outflows.

   - The replacement of the single hulled vessels with double hulled vessels, with the same carrying capacity, which will reduce oil outflow.

   - A revised escort program that will maintain current system risk reductions, minimize the collision risk due to escort vessels, and provide coverage for inbound tankers.

Recommendations

Recommendations were made on the basis of risk reduction potential only. Issues such as cost, human safety, and feasibility of implementation are to be considered in the development of the Risk Management Plan. Recommendations are made in three groups.

1. **The following changes should be considered for implementation as soon as is practical.**

   - Formal procedures for preventing, detecting, or correcting human error which may occur in the operation of the tethered tug in the Narrows should be developed and implemented.
   - The USCG, the Alaska Department of Fish and Game, shipping companies, and representatives of the commercial fishing industry should continue to coordinate fishing vessel/tanker interactions as was done in 1996. These procedures should specify communications procedures to be followed by the Vessel Traffic Center (VTC), tankers, and fishing vessels; ensure that queues of inbound or outbound tankers are efficiently managed; and prevent tankers from maneuvering through large concentrations of fishing vessels.
   - A strategy, including the use of appropriate equipment and procedures, should be developed and implemented to provide adequate save capability for outbound laden tankers in the upper range of weather conditions allowed by weather closure restrictions at Hinchinbrook Entrance.

2. **The following changes should be considered for implementation with the understanding that they may take more time to implement or to receive the benefits from their implementation.**

   - All Prince William Sound shipping companies should continue to improve formal management and safety systems designed to reduce human and organizational errors. A component of these systems should be improved procedures for collecting data relating to human error and for analyzing accidents and incidents where human or organizational error was a contributing factor.
   - The OPA 90 requirements for replacement of single hulled tankers with double hulls should occur as scheduled.

- Real time weather, ice, and current information should be made available to the USCG, SERVS, and to tanker masters, pilots, and escort vessel masters. This data includes wind, current, and visibility data at the Narrows; wind and sea state information at Hinchinbrook Entrance; and ice, weather, and visibility information in the Arm.

3. The following changes should be considered for implementation should additional analysis, to be completed before the close of the current contract, indicate their net benefits.

- A revised escort program should be developed to address the risk of drift groundings of inbound and outbound tankers and minimize risk of collision with SERVS vessels. This program should provide in Central Prince William Sound. a save capability at least equivalent to that provided by the current escort system and should provide for improved save capability at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance.

- Improved ice navigation procedures, including ice detection and tracking, should be developed and implemented. Ice should be avoided; however, if ice collisions are unavoidable, low energy ice collisions on the bow are preferable to high energy ice collisions to the vessel's sideshells.

The Future

The project has produced a set of closely calibrated and integrated models that will provide the analytic support needed to assist the Steering Committee in the development of its Risk Management Plan or in the assessment of the impact of future system changes.

Prince William Sound
Marine Transportation System
Risk Assessment

Final Report - December 15, 1996

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Prince William Sound Risk Assessment Master Glossary of Acronyms

1 0 Introduction

1.0 Introduction

1.1 Background

In recent years, public and private concern over the safety of marine oil transportation systems has focused regional and national attention on ways to further reduce the risks of oil spills from tankers. This is certainly true in Prince William Sound (PWS), Alaska, the site of the 1989 oil spill. This event stimulated passage of the Oil Pollution Act of 1990 (OPA 90)[1] and the State of Alaska's statutory[2] changes and implementing regulations.

Questions from various stakeholders surfaced in early 1995 concerning the effectiveness and benefits of existing prevention regulations and the effect of the regulations still under consideration. Many other questions surfaced when the PWS shipping companies (ARC0 Marine Inc., BP Oil Shipping Company, USA, Chevron Shipping Company, SeaRiver Maritime Inc., and Tesoro Alaska Petroleum Company) attempted to develop a request for proposals to build a new escort vessel for PWS. The shippers effort was made in response to specific State of Alaska requirements[3] attached to their oil discharge prevention and contingency plans.

The proposal was put on hold because of the need for answers to questions about the effectiveness, mission, performance and operation of the escort vessels before new escort vessels could be built. Even with information learned from a joint industry/government/citizens Disabled Tanker Towing Study (DTTS)[4], completed in July 1994, the debate continued concerning the type of escorts and their operational implementation.

With a number of questions concerning the value and benefits of existing and proposed prevention measures, the PWS shipping companies proposed a risk assessment study to the Regional Citizens' Advisory Council (RCAC)[5] and suggested that other interested stakeholders would be the Alaska Department of Environmental Conservation (ADEC), and the United States Coast Guard (USCG). These entities were stakeholders in the region or were organizations that represented stakeholders. The purpose of this study was to determine the risks associated with shipping oil in PWS and the effectiveness and benefits of prevention measures in place as well as those contemplated. These stakeholders recognized the need for a rational method to evaluate the merits of prevention measures in place and proposed, in order to better allocate resources, and to avoid implementing measures that did not address real risks.

1.2 Steering Committee

The shipping companies, the USCG, ADEC, and the RCAC entered into an agreement to conduct the study in March, 1995. These stakeholders formed a Steering Committee for oversight and management of the study project. The size and composition of the Steering Committee was expanded to include Alyeska/SERVS[6] in early spring of 1995.

The Steering Committee wanted the project to be used as a forum to build trust among stakeholders, to provide for education of all interested parties, and to foster a better and more common understanding of risk and oil transportation. It was important to the Steering Committee that the project be developed with an understanding of the varying levels of risk tolerance to stakeholders, given that stakeholders had different views with respect to risk tolerance or acceptable risk. It was equally important to the Steering Committee that every effort would be made to guarantee the objectivity of the study and the independence of the contractors. Funding for the project came from the RCAC and the shipping companies.

Members of the Steering Committee included ship's captains, commercial fishermen, senior corporate managers, environmental regulators, the USCG Captain of the Port, and community representation. Representatives of the Southwest Alaska Pilots Association; charter shipping companies under contract to BP Oil Shipping Company, USA (BPOSC); and representatives from Crowley and Tidewater participated with the Steering Committee.

In late May of 1995, the committee hired a Project Coordinator. His role was to interface with the contractors on behalf of the Steering Committee, so that no entity on the Steering Committee had access to or influence on the contractors or the research. He also served as chairman of the Steering Committee and was the official representative on all matters associated with the project.

All aspects of the project either came from or were approved by the Steering Committee. They developed the mission statement, goals, scope and objectives, as well as approved the research design and conduct for the project. Members of the Steering Committee are listed in Attachment A.

Study Group - Halfway through the project a subgroup of the Steering Committee was formed. This group was called the Study Group and assigned responsibility by the Steering Committee to review, discuss and make recommendations on topics ranging from the first conceptual draft of the Risk

Management Plan to reviewing routine administrative and contractual matters. Membership on the Study Group consisted of representatives from each stakeholder on the Steering Committee; i.e., the Alaska Department of Environmental Conservation, SERVS, the PWS Regional Citizens' Advisory Council, United States Coast Guard, and three of the PWS shipping companies (ARCO, BPOSC and SeaRiver Maritime). Meetings were typically held once a month.

1.3 Contract Team

Following a request for proposals and interviews in early 1995, Det Norske Veritas (DNV) was selected as the contractor by the shipping companies. Subsequent to their appointment, the PWS Regional Citizens' Advisory Council hired Dr. Martha Grabowski from Rensselaer Polytechnic Institute (RPI) and LeMoyne College as their advisor. Dr. Grabowski then solicited the assistance of Dr. John Harrald from the George Washington University (GWU) to collaborate with her.

Following the first meeting with the Steering Committee, it was determined that the complementary skills and expertise of all institutions should be combined into a single team to maximize the potential benefits from the study; i.e., DNV, RPI, LeMoyne, and GWU would work together. A full time Project Manager, Erling Sæbø, was recruited from Oslo, Norway by DNV to coordinate the work of the team. Attachment B contains a list of the members of the Contract Team.

1.4 Objectives and Scope of the Study

The mission of the study was *"to improve the safety of oil transportation in Prince William Sound"*. This was accomplished by:

1) examining the PWS oil transportation system;
2) developing a series of both static and dynamic models;
3) using the models to articulate the nature of risk in the system;
4) evaluating risk reduction measures that address risk in the system; and
5) implementing a risk management plan.

The collection of usable and relevant data in support of these tasks was also a significant work effort.

The Steering Committee established three primary objectives to:

1) identify and evaluate risks of oil transportation in PWS;

2) identify, evaluate and rank proposed risk reduction measures; and

3) develop a risk management plan and risk management tools that could be used to support a risk management program.

These objectives did not require the contractors to determine a predetermined acceptable level of risk. Rather, the contractors were required to provide tools for the Steering Committee to support the committee's development and implementation of a Risk Management Plan. This plan was to facilitate the ranking or sorting of potential system improvements such that acceptable risk became a product of the degree to which improvements were accepted and implemented.

Tools were also developed to be used by the stakeholders for future analyses of changes that might be forecast or planned for the system. These tools could also be used as a basis to undertake a risk assessment and evaluate the benefits of various risk reduction measures in other locations.

The Steering Committee adopted additional objectives (see Figure 1.1, Project Objectives) dealing with communications, trust, risk tolerance, and believability. The Steering Committee also wanted the project to be prevention based and to seek the most practical prevention system. The study was also to include a definition of prevention that recognized operating and personnel safety as well as address practical and financially viable mitigation alternatives.

PROJECT OBJECTIVES

1) Build a model that identifies and ranks risks.

2) Take output from the model to develop a Risk Management Plan.

3) The project will address the following issues. It will:

- be prevention based,
- seek maximum practical prevention systems,
- include a definition of prevention that recognizes operating and personnel safety,
- be a believable and understandable model of port call systems that:
    a. contains and is based on knowledge and understanding of the limitations of models;
    b. can and will be tested by inputting different variables; and
    c. will produce results that can be ranked.
- be used as forum to build trust among stakeholders working on mutual issues,
- utilize the experience and knowledge of marine transportation operators,
- be high quality work that will withstand peer review,
- foster a better understanding/common understanding for all interested parties,
- provide for education for all interested parties,
- must meet all schedules and be timely,
- address reasonably practical and financially viable mitigation alternatives,
- contribute to the development of performance criteria for ADEC's determination of Best Available Technology,
- be developed with an understanding of the varying levels of risk tolerance to stakeholder (i.e., different stakeholders have different views with respect to risk tolerance or acceptable risk) and
- include weather factors.

Figure 1.1 Project Objectives

The project had a direct link to an ADEC contingency plan regulation dealing with Best Available Technology (BAT)‘. This regulation requires that an oil spill contingency plan provide for the use of the best technology that was available at the time the plan was submitted or renewed. “Technology” was defined as equipment, supplies, and other resources which, in the ADEC’s judgment, meet or exceed the current level of demonstrated technology. For this project, the Steering Committee agreed that the results would contribute to the development of performance criteria for ADEC’s determination of BAT.

The Steering Committee defined the scope of the project (see Figure 1.2), including the geographical extent, the technical aspects of the calling fleet, the operational aspects of the calling fleet, the operational management of the companies and the regulatory requirements.

PROJECT SCOPE/FOCUS

1) Shipping casualty risks
2) Physical extent - geography
   - 20 miles before Hinchinbrook to **Valdez** and return
   - Not while discharging or loading (i.e., finished with engines)
   - Calling tank vessel fleet, engineered features
   - Non-tank vessel **traffic** patterns, seasonal variations
   - Weather **&** external environmental variables
   - Not to include earthquakes
   - Fire/Explosions, collisions, allisions, groundings (causal)
   - Escort Tugs
   - Navigational aids
   - Pilots
   - Traffic separation scheme
   - Situations created when Hinchinbrook Entrance is closed due to weather **and** tankers are either directed to anchorage and/or directed to maintain some **heading** when it is unsafe to anchor
3) Calling Fleet - Technical Aspects
   - Navigation systems
   - Propulsion
   - Steering
   - Maneuvering/maneuverability
   - Advanced instrumentation
   - Bridge design
   - Technical aspects other than PWS
   - Structural failure
4) Calling Fleet - Operational Aspects
   - Speed
   - Use of Tugs (stationing, fender, horsepower, involved at all?)
   - Command and control
   - Human factors
   - Operational aspects other than PWS
5) Operating Company - Managerial
   - Safety **management/culture**
   - Pollution prevention - SEPASM
6) Regulatory requirements
   - State
   - Federal
   - Best Available Technology

Figure 1.2 Project Scope/Focus

1.5 Risk Management Plan

In addition to the primary goals of assessing risk in PWS, and evaluating the effectiveness of various risk reduction measures, the study was also to produce results to be used by the Steering Committee in developing, approving and implementing a Risk Management Plan. The purpose of the Risk Management Plan was to develop a framework for how to use the results of the study, which was acceptable to all members of the Steering Committee.

Key tenets from the approved risk management protocol centered around the development of:

1) the scientifically based, credible and useful representations and evaluations of hazard/risks and the benefits of risk reductions measures;

2) an environment that would facilitate stakeholder consensus on the plan;

3) an audit trail (basis in fact) for what risk reduction measures should and should not be considered for final resolution; and

4) a process for addressing issues where no agreement could be reached regarding the implementation of a specific risk reduction measure or group of measures.

An agreement was reached that the risk management plan should be based on risk reduction measures that:

1) were performance-based (in lieu of prescriptive-based) where possible and practicable;

2) note differences between system measures (i.e., VTS), user-measures (i.e., company or industry specifics) and equipment-measures (i.e., classes of tankers), in addition to those that are currently regulatory, voluntary or industry practice;

3) wherever possible, gave priority to risk reduction measures that interrupt the sequence of events that could cause an accident at the earliest possible time, taking into account human factors and the practicality of achieving reasonable performance for repeated events over time; and

4) recognize measures that require changes outside the control of the membership of the Steering Committee. The Steering Committee agreed that implicit in this process was the knowledge that implementation would be an iterative, on-going work activity.

Consideration for implementation was intended to begin upon receipt by the Steering Committee of sorted and ranked lists of risk reduction measures. From this list, the Steering Committee would work to achieve consensus on those measures that should be considered for implementation and those that merited no further consideration. Effectiveness and financial viability were to be considered. For those measures that could be agreed upon, the relevant stakeholders were to propose implementation plans. Those risk reduction measures that either could not be agreed to by the study group or could not be unanimously agreed to by the Steering Committee were to be assigned to special working groups. Every attempt was to be made to resolve differences and to unanimously agree on the disposition of the particular measure. The Risk Management Plan was to recognize that, with performance-based risk reduction measures, Steering Committee members were empowered to implement plan measures in a variety of ways.

1.6 Peer Review

Prior to project commencement, study sponsors requested the assistance of the Marine Board of the National Research Council to conduct oversight and review of the work, since an independent and scientific review of the project would add credibility to the results. There was also a need to evaluate the effectiveness of the approach and its applicability as a prototype for similar studies in other US ports.

The Marine Board agreed to conduct a case study of risk assessment and management for the project. The PWS risk assessment project thus became part of a larger study designed to examine risk assessment in marine transportation. For this project, the Marine Board agreed to: *'formally review the analytical methodologies used in the PWS...[project]...to assess the appropriateness of the methods employed for addressing issues... in the study.*" Further, "*the review would be limited to the appropriateness of the methodology [emphasis added] used in the study and would not be an audit of the data used in the risk assessment; therefore, conclusions and recommendations of the peer review would be limited.*"

Funding for the peer review was provided from additional project funds and partially supported by the USCG as a part of a larger Marine Board study.

1.7 Study Method

A variety of risk assessment and evaluation methodologies have been used in marine transportation for a number of years. Most of these involve the use of probability methods to assess frequency of event occurrences. The PWS Risk Assessment project offered the opportunity to utilize several methodologies in one risk assessment project in order to arrive at an assessment of risk in the PWS oil transportation system overall, and to provide multiple, complementary views of subsystem level risk.

As a result, fault trees, a statistical model and a system simulation/regression methodology were used to assess risk in the PWS oil transportation system. A management survey and audit[8] was conducted in order to determine relative differences in shipping company organizational parameters used in the three primary methodologies. A set of oil outflow models that reflect accident types and situations, hull configurations and vessel sizes was used to determine the expected impacts of accidents predicted by these methodologies.

The PWS Risk Assessment project had four phases: phase one was an input phase of gathering data and information and constructing data bases. Phase two was a synthesis phase which analyzed this data and information and produced the input required by the assessment methodologies. Phase three was an assessment phase of building, testing and applying PWS specific risk assessment models and methodologies. Phase four was the evaluation phase which provided risk profiles of the current system and a description of the impacts of proposed risk reduction measures. Figure 1.7-1 provides a Gantt chart of the phases of the PWS Risk Assessment project.

Project Plan

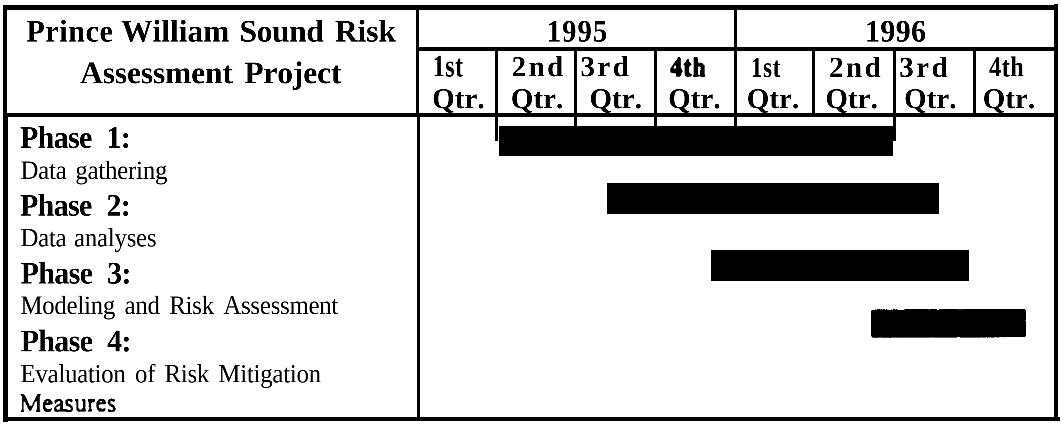

Figure 1.7-1

Considerable effort was required to collect and evaluate data for the Risk Assessment project. For instance, extensive but incomplete environmental data, as well as ship arrival and departure data, had been collected by Alyeska/SERVS and the USCG. However, almost no data describing company demographics, mechanical and human failure rates, the interactions of other marine users (most notably fishing vessels and cruise ships) and the experience of the mariners in the system was available in the public domain.

Capturing, analyzing and utilizing this data were significant tasks. The effort involved company demographic questionnaires, management surveys, failure data surveys, crew incapacitation surveys, lost time and total reportable injury surveys, fishing vessel surveys, expert questionnaires and open ended questionnaires. It also included surveys and searches to capture all PWS historical shipping incident data. Chapter 4 describes the data gathering activities for the PWS Risk Assessment project.

As the project gathered momentum, the Steering Committee felt it would soon fall behind in its ability to follow the detailed progress of the contractors. To maximize their effectiveness they arranged a two day “risk seminar” to review concepts of risk assessment, terminology and communications.

The risk seminar was a hands-on program with interactive computer aids which covered the inter-relationships of risk analysis, risk management and risk communication; interactions between risk analysis and decision analysis; public attitudes and risk perception/risk communication; basic risk assessment methodologies; fault trees; the use of probability; and the use of expert judgment. It was conducted by Dr. Tom Mazzuchi, of the George Washington University.

An objective of the project was to inform and educate those stakeholder groups that had an interest in risk assessment. Contractually, this task was assigned to the Project Coordinator to conduct the project in a manner that earned public trust.

In all, five separate activities took place to deal with the need for stakeholders to be kept informed. First, the PWS Regional Citizens' Advisory Council published a summary of each meeting and distributed that summary to its membership which includes approximately 22 different stakeholder groups in Prince William Sound and adjoining areas. Second, three Information Reports were published which summarized some of the early modeling work and the summary of activities to-date. Third, the Project Coordinator contacted all of the member organizations of the PWS Regional Citizens' Advisory Council and offered to visit that organization, report on progress and discuss the most appropriate type of interaction sought by the organization. Fourth, the Project Coordinator gave a number of presentations to various workshops and symposiums both in state and in other locations. Last, and partly as a result of those organizations that expressed an interest in an ongoing dialogue about the project, the Project Coordinator maintained a regular contact with organizations that desired to know more about the project on a continuing basis.

1.8 Summary

The PWS Risk Assessment project has generated extensive interest. Much of this interest stems from those who operate vessels or companies in the PWS oil transportation system who need a systemwide picture of risk and a subsequent evaluation of risk reduction measures. As a result of the study, new risk reduction measures may have to be implemented and some existing measures may be discontinued. For stakeholders, the PWS Risk Assessment project is expected to improve the system and provide a basis for longer term planning.

Considerable interest resides with the citizens of PWS who also desire a systemwide picture of risk in the Sound, and thus wait for the results of the evaluation of key risk reduction measures, most notably improvements to the current escort program. They are also deeply interested in the risk management plan as a vehicle to implement the results of the study.

Regulatory interests in the project are specific and focused. To fulfill the BAT regulatory requirements for contingency plan holders in PWS, plan holders are to submit, within 60 days after issuance of the Risk Assessment project final report, a final vessel escort improvement proposal. In the event that a critical risk mitigation measure is identified prior to issuing the final report, or if risk parameters pertaining to tanker escorts are not being successfully evaluated in the Risk Assessment project, ADEC may, upon written notice, require submittal of a final vessel escort improvement proposal prior to issuance of the Risk Assessment project final report. Such a proposal is to give consideration to vessel escort needs for specific locales: the Valdez Narrows and Arm, the open reaches of PWS and Hinchinbrook Entrance, as well as the escort needs taken as a whole for the entire PWS transit. Thus, state regulators are very interested in the results of the Risk Assessment project.

The diversity and richness of differing views and perspectives among individual stakeholders on the Steering Committee has created an environment of intense and productive project oversight. Requiring unanimous agreement at all stages of the project has made each party try just a little harder to achieve consensus without abandoning strongly held convictions. The Steering Committee's resolution to work through difficulties in a constructive manner is one of the project's more enduring successes.

FOOTNOTES

[1] The Oil Pollution Act of 1990. Public Law 101-380, August 18. 1990. Referred to commonly as OPA 90.

[2] State of Alaska, Oil and Hazardous Substances Pollution Control Regulations. 18 AAC 75.

[3] October 2, 1995 Alaska Department of Environmental Conservation, Division of Spill Preparedness and Pipeline Program; Plan Approval Letter. Terms and Conditions: 2.(b). *"To fulfill the Best Available Technology (BAT) requirements of law for the duration of this approval, or for a more extensive time period as may be requested by the plan holder and determined by the Department, the plan holder shall submit within 60 days after issuance of the risk assessment project final report, a final vessel escort improvement proposal for review and approval. In the event that a critical risk mitigation measure is identifiedprior to issuing the final report, or if risk parameters pertaining to tanker escorts are not being successfully evaluated in the risk assessment project, the Department may, upon*

written notice, require submittal of a final vessel escort improvement proposal prior to issuance of the risk assessment project final report. The proposal is to give consideration to vessel escort needs for specific locales; the Valdez Narrows and Arm, the open reaches of Prince William Sound and Hinchinbrook Entrance, as well as the escorts needs taken as a whole for the entire PWS transit. The plan holder is to provide a reasoned basis to assert that the proposed vessel escort system represents Best Available Technology."

[4] Glosten Associates, Inc. July 1994. Prince William Sound Disabled Tanker Towing Study and Appendices A-H. Prepared for the Disabled Tanker Towing Study Group and prepared in collaboration with Maritime Simulation Centre the Netherlands.

Glosten Associates, Inc. July 1995. Computer Simulations to Compare the Escort Performance of Four Tugs in Valdez Narrows Scenarios.

[5] The RCAC is an independent non-profit organization formed in 1989 to advise the oil industry, regulatory agencies and the public on issues relating to safe oil transportation. RCAC is composed of communities and interest groups affected by the 1989 Exxon Valdez oil spill. The RCAC operates under a contract with Alyeska which provides the RCAC with funding but which guarantees its independence. The RCAC fulfills the requirements mandated by OPA 90 for a citizens' oversight group in PWS.

[6] Alyeska Pipeline Service Company operates the Trans Alaska Pipeline and Valdez Marine Terminal. SERVS (Ship Escort Response Vessel System) is the Alyeska business unit which provides on water oil spill prevention and response services for the Terminal and crude oil tankers in Prince William Sound.

'State law requires all contingency plans *'provide for the use...of the best technology at the time that the contingency plan was submitted or renewed."* (AS 46.04.030(e)). Best available technology is not defined by state law, but is defined by regulation as "*...equipment, supplies, and other resources, which, in the department's judgment, meet or exceed the current level of demonstrated available technology" (18 AAC 75.990 (5)).*

*Part of the International Safety Rating System (ISRS). Det Norske Veritas converted system into the International Marine Safety Rating System (IMSRS). System includes elements of the International Maritime Organization (IMO) International Safety Management (ISM) code and the Safety and Environmental Protection (SEP) Rules of DNV.

Attachment A

Members of the Steering Committee:

Mark Hutton, Chairman and Project Coordinator
Steve Alexander, BP Oil Shipping Company, U.S.A.
Tom Chapple, Alaska Department of Environmental Conservation
Bill Deppe, SeaRiver Maritime, Inc.
Tex Edwards, Prince William Sound Regional Citizens' Advisory Council
Roger Gale, BP Oil Shipping Company, U.S.A.
Michelle Hahn O'Leary, Prince William Sound Regional Citizens' Advisory Council
Hersh Kohut, ARCO Marine, Inc.
Glen Kraatz, Chevron Shipping Company
Joe McGuiness, United States Coast Guard
Greg Jones and Ron Morris, United States Coast Guard
Dan Paul, SeaRiver Maritime, Inc.
Tim Plummer, Alyeska Pipeline Service Company/SERVS
Steve Provant, Alaska Department of Environmental Conservation
Richard Ranger, ARCO Marine, Inc.
Gary Richardson, Alyeska Pipeline Service Company/SERVS
Bernie Smith, Tesoro Alaska Petroleum Company
Stan Stanley, Prince William Sound Regional Citizens' Advisory Council

Often alternates participated and included: Gus Elmer (SeaRiver Maritime, Inc.), Victor Goldberg (ARC0 Marine, Inc.), Simon Lisiecki (BP Oil Shipping Company) and Tom Sweeney (Prince William Sound Regional Citizens' Advisory Council).

In addition Tony Joslyn (Southwest Alaska Pilots Association), Bruce Benn (Keystone Shipping), John Ripperger (Maritime Overseas Corporation), Mark Filanowski (Marine Transport Lines Ship Management), Jack Buono (SeaRiver Maritime, Inc.), Steve McCall (Maritime Overseas Corporation), Mike Openshaw (Keystone Shipping), George Clark (Keystone Shipping), Kurt Hallier (ARC0 Marine, Inc.), Richard Halluska (OMI Corporation, Inc.), Stan Stephens (Prince William Sound Regional Citizens' Advisory Council), Robert Wenz (Keystone Shipping), Larry Francois (Tidewater Pacific, Inc.) and Kevin McAree (OMI, Corporation) attended as guests.

On November 1, 1996 Robert Stoltenberg assumed duties of Chairman and Project Coordinator.

Attachment B

The contract team consisted of:

Erling Sæbø, Project Manager, Det Norske Veritas @NV)
Martha Grabowski, Rensselaer Polytechnic Institute (RPI)
Jack Harrald, George Washington University (GWU)
Tom Mazzuchi, GWU
Emil Dahle, DNV-Oslo
Tim Fowler, DNV-London
John Acomb, DNV-San Francisco
John Spahn, GW-U
René van Dorp, GWU
Jason Merrick, GWU
Marianne Hauso, DNV-Oslo
Kåre Kristoffersen, DNV
Bob Arnold, DNV-Atlanta
Tammy Matzke, LeMoyne
Shelley Morrisson, LeMoyne
Kevin Mazzone, LeMoyne
Sudhendar, RPI
David Mendoza, RPI
Sunil Shrestha, GWU
Dukhoon Jeong, GWU
Kari Kelton, RPI
Melanie Simmons, RPI
Jasmit Singer Kochhar, RPI
Miho Hanafuji, RPI
Ken Major, LeMoyne
Scott O'Connor, LeMoyne
Hala Annabi, LeMoyne

2.0 Marine Transportation System Description

2.0 Marine Transportation System Description

Prince William Sound is an extensive body of water covering about 2500 square miles. Its perimeter is very irregular, with many fjords, inlets and bays. The entrance, from Cape Hinchinbrook on the east to Cape Puget on the west, is 58 miles across, but is dotted with islands. The largest of these islands is Montague Island, which extends well out into the Gulf of Alaska. Prince William Sound (PWS) can be visualized in six sectors: the Gulf of Alaska and offshore, Hinchinbrook Entrance, Central Prince William Sound, Valdez Arm, Valdez Narrows, and Port Valdez. This section provides an overview of these sectors, and the marine oil transportation system that operates within it. A full description of the Prince William Sound Oil Transportation System is found in the Prince William Sound System Description Technical Documentation Part I. (See Figure 2.0-l for PWS Chart.)

Hinchinbrook Entrance is the main entrance to Prince William Sound. It is about six miles wide and is a clear passage with the exception of Seal Rocks. (U.S. Coast Guard (USCG), 1994).

Central Prince William Sound refers to the open waters of the Sound between the course change south of Bligh Reef to Montague Island. The distance of the traffic separation scheme from shore for most of the central Sound is greater than 10 nautical miles, except for Naked Island and Smith Island, where distances are approximately 5.5-6 nautical miles (Prince William Sound Tanker Association (PWSTA), 1995; p. 5-12).

Valdez Arm, the main northern arm of Prince William Sound, extends about 13 miles northeast from Busby Island and Point Freemantle to the northern end of Valdez Narrows, then turns east for 11 miles to the head of Port Valdez. The water is very deep and there are no known outlying dangers except for Middle Rock near the northern end of the Narrows, and two shoals at 13.5 and 42 feet, about 0.2 mile apart, near the western edge of the arm, about 3.5 miles to the northeast of Point Freemantle (U.S. Department of Commerce (USDOC), 1994).

Valdez Narrows is about eight tenths of a mile wide, with deep water and bold shores. Middle Rock, near the middle of the northern end of the Narrows, is a pinnacle barely covered at extreme high tides; it is marked with a light.

Port Valdez is the area of water extending from the Valdez Narrows to the head of the bay. Jackson Point is a jutting piece of land extending from the mainland on the south side of Port Valdez. The Valdez Marine Terminal (VMT) is on the south side of Port Valdez between Jackson Point and Saw Island. It is the terminus of the trans Alaska pipeline. The terminal and adjacent waters are within a Safety Zone (USDOC, 1994).

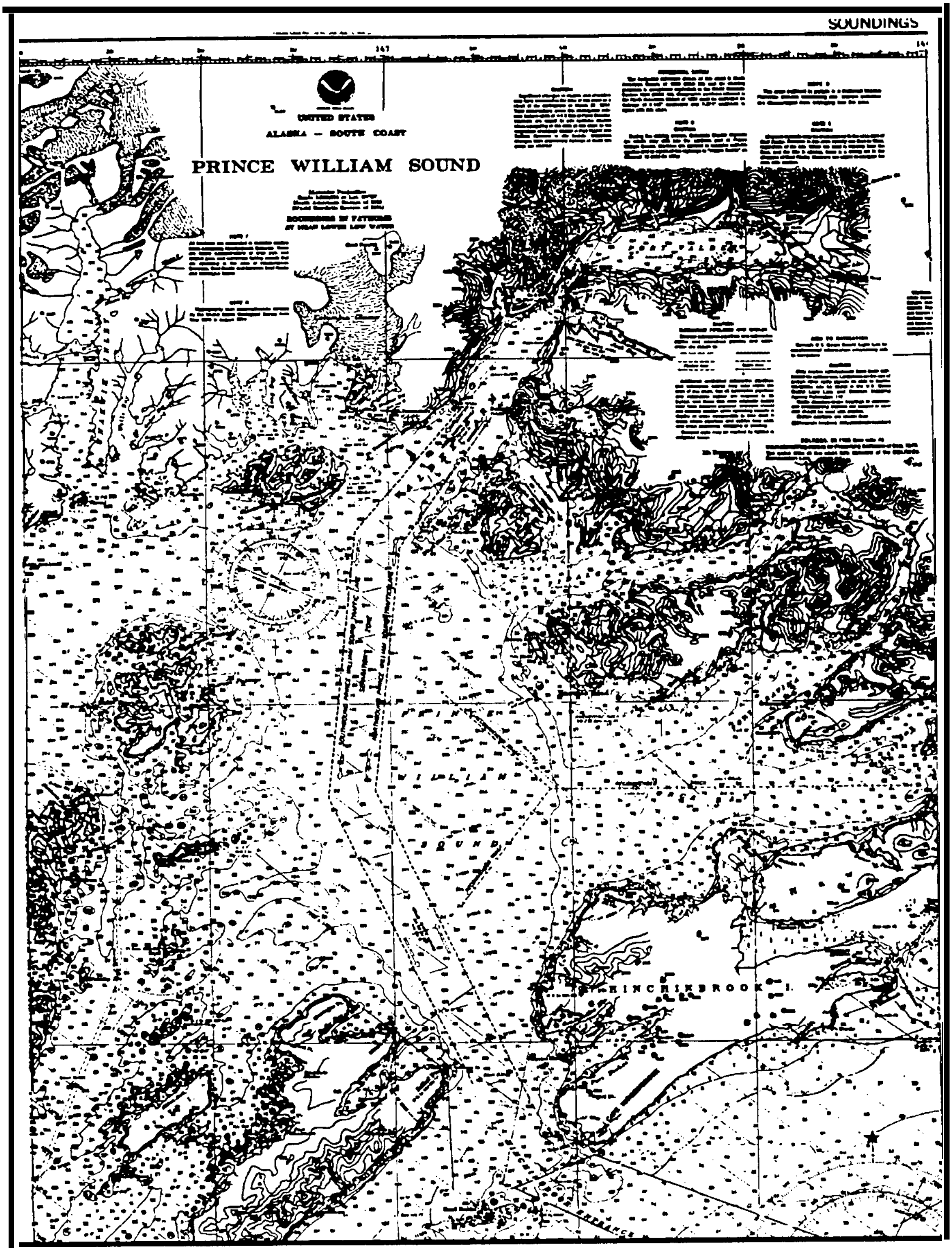
SOUNDINGS
UNITED STATES
ALASKA — SOUTH COAST
PRINCE WILLIAM SOUND
WILLIAM
SOUND
HINCHINBROOK I.

Figure 2.0-1

2.1 Weather and Climate

The waters of Prince William Sound are very deep (with an average water depth of more than 900 feet), and are chilled by the meltwater from the surrounding glaciers. Although the Sound is somewhat protected by the surrounding land mass, it is subject to frequent changes of weather, high winds, and reduced visibility due to fog and heavy precipitation. The meeting of the cold water and the colder air from the mountains with the warmer waters and vapor-laden airs of the Gulf of Alaska causes the changeable weather, and sudden wind squalls and thick fog are common (USDOC, 1994; p. 70). In contrast, the weather to seaward of Hinchinbrook Entrance is often markedly different from that within the Sound, and the Port Valdez areas may have weather entirely different from that of the Sound (USCG 95a, p. l-2). With all this said, however, accurate historical weather data for the Sound is not readily available.

2.1.1 Wind

The east-west orientation of Port Valdez and the surrounding topography greatly influence local winds which are channeled into two distinct directions: prevailing winds during the winter are from the northeast, and those during summer are from the southwest (Hameedi, 1988). The relatively high mountains provide a considerable barrier to the flow of cold, continental air from the interior of Alaska during the fall and winter. However, cold air masses at higher elevations frequently accelerate downslope from the top of the mountains, driven primarily by gravity. The descending air is generally much colder, despite some adiabatic warming, than the surrounding air masses at the sea surface. Such katabatic winds—locally also known as williwaws—are usually responsible for the coldest air temperature at Valdez (Hameedi, 1988; p. 5).

2.1.2 Visibility

There is considerable cloudiness (average yearly sky cover is 75 percent) and precipitation throughout the year in Prince William Sound. Snowfall during the winter can be heavy; over 80 cm of snowfall was recorded in Valdez within a 24-hour period in March 1982 (Hameedi, 1988; p. 6). Periods of considerable darkness (November - March) and daylight (May - August) are also characteristic of Prince William Sound during different parts of the year; time of year and available daylight, therefore, also influence visibility in the Sound.

Data on visibility were reported in the DNV 1990 study for both Valdez harbor and Prince William Sound, using recordings at the airport. The data showed that visibility in Port Valdez and Prince William Sound is good, with less than 0.5 percent of the tune when visibility is less than 200 meters, and over 91 percent of the time when visibility is greater than 4 kilometers (DNV, 1990, p. B.4). However, visibility at the airport and visibility in the Sound are often very different because of differences in geography and prevailing winds. Although accurate visibility records for the Sound are scarce, some data does exist. Limited visibility occurs during both summer and winter months, due to precipitation and fog, and in the winter months, from December to March, on average, there are two days per month with visibility less than one half of a mile (USDOC, 1994; Table T-2).

2.1.3 Tides and Currents

Tides in Prince William Sound are of the mixed, semi-diurnal type, with a maximum range of 5.3 meters. The diurnal range of the tide within Prince William Sound is between 10 and 13 feet: at Rocky Point it is 12.1 feet; at Valdez, it is 12 feet (USDOC, 1994). The replenishment of water in the port is accomplished by means of daily tidal exchange, seasonal or annual exchange with Prince William Sound, and the frequent but randomly occurring passage of storms (Hameedi, 1988; p. 7).

Tidal currents at Hinchinbrook Entrance flow directly in and out of the Sound, except east of Seal Rocks, where the currents usually run east to west, regardless of the tide (USDOC, 1994; p. 71). Offshore of the entrance to Prince William Sound, the currents are strong. Currents along the approach to Prince William Sound set to the southwest and occasionally reach a velocity of two and a half knots. There is a strong set in the direction of Seal Rocks when the wind is blowing out of the east and the tide is ebbing. In Hinchinbrook Entrance, Montague Strait, and Latouche Passage, the velocity of the current is about one knot. The ebb current running out against a large swell causes over-falls, especially in deep water, two or three miles east of Zaikoff Point, which have been mistaken for breakers. There are also tide rips on the broken grounds around Cape Hinchinbrook. The flood entering west of Montague Island sets northeast past Montague Point, and causes rips between it and Johnstone Point (USDOC, 1994; p. 71).

Outside Hinchinbrook Entrance, along the southeast coast of Hinchinbrook Island, the current sets to the southwest almost constantly. Current observations in Elrington Passage indicate a velocity of 1.5 knots (USDOC, 1994; p. 71). Within Prince William Sound, with the exception of the western passages, the tidal currents tend to be weak (less than one knot) and variable. In the various western passages, the current generally follows the axis of the passage with velocities ranging from approximately one knot to three knots (USDOC, 1994).

2.1.4 Ice

Glacial ice is not ordinarily found in the open waters of Prince William Sound. Ice discharged by the Columbia Glacier, north of Glacier Island, is driven into the Sound by northerly winds. That ice, depending on the winds, can be expected from Bligh Reef to as far west as Bald Head Chris Island, and as far south as Storey Island. Large bergs may be found at any time along the northern shore of Prince William Sound from Point Freemantle to Fairmount Island (USDOC, 1994; p. 70).

Valdez harbor is the northernmost port in Alaska that is never icebound. Ice hazards along the tanker route are primarily calved icebergs from Columbia Glacier. However, Shoup Glacier also produces occasional ice in Port Valdez. In a 1990 study (DNV, 1990), it was reported that ice can be expected to exist in a plume across the tanker route for up to 50 days per year (14 percent of the time). As far as tanker navigation is concerned, the major hazard is from icebergs and iceberg plumes from Columbia Glacier, generally in the southern half of the Valdez Arm. The size distribution for icebergs from Columbia Glacier indicates that about 70 percent are less than 3000 tons, and that a very small percentage can be up to 30,000 tons. Although it is possible for ice to be present throughout the year, it is most prevalent in the summer and autumn seasons (Klingel, 1984; quoted in DNV, 1990, pp. B.5-6).

2.1.5 Earthquakes and Tsunamis

Southcentral Alaska is tectonically very active. In this region, the subducted portions of the Pacific Plate dip into the upper mantle beneath the North American Plate. One of these segments is moving in a northwesterly direction beneath Prince William Sound and Cook Inlet, while another appears to be moving in a northeasterly direction beneath the St. Elias and Wrangell mountains. This subduction manifests itself as structural deformation and accompanying seismic and volcanic activities. Numerous earthquakes have been recorded. Since 1899, at least six of them have caused substantial structural damage and property losses (Hameedi, 1988, p. 3).

2.2 Maritime System

Transits to Valdez involve a 66-69 mile port transit (depending on whether the vessel is inbound or outbound), with fjord-like steeply shelving shoals, rocks, and rocky outcrops (DNV, 1990; p. 1.7). Outbound tankers take between eight and ten hours to pass through Prince William Sound.

Vessels transiting Prince William Sound from the Valdez Marine Terminal to Cape Hinchinbrook are required by 33 CFR 161.301 to 161.387 to participate in the U.S. Coast Guard Vessel Traffic Service (VTS). The Prince William Sound Vessel Traffic Services (VTS) area consists of the navigable waters of the U.S. north of a line drawn from Cape Hinchinbrook Light on Hinchinbrook Island to Schooner Rock Light, off Montague Island, between longitude 146 30"W and 147 20"W, and includes Valdez Narrows and Port Valdez (USCG, 1995a).

There is a designated *traffic separation scheme (TSS)* route which is required to be followed by vessels traveling to Port Valdez. Vessels which are required to comply must travel down the TSS on the right hand side, leaving the separation zone to the left (U.S. Coast Guard, 1995a). The traffic lanes begin in Hinchinbrook Entrance, and are each 1500 yards wide from that point to the vicinity of Bligh Reef at the southeast end of Valdez Arm. These lanes then gradually decrease in width to 1000 yards and terminate at Rocky Point. The separation zone is 2000 yards wide between the Hinchinbrook Entrance and the vicinity of Bligh Reef. It then gradually decreases in width to 1000 yards and also terminates at Rocky Point.

2.2.1 Pilots

The Southwest Alaska Pilots Association (SWAPA) and Dispatching Service provides piloting service from Bligh Reef to Port Valdez; SWAPA is comprised of 2 1 full branch pilots, 19 of whom are engaged in the TAPS trade (Eliassen, 1995); there are two associate members and four trainees (Pierce, 1994). Pilotage, except for certain exempted vessels, is compulsory for all vessels navigating the inside waters of the State of Alaska. Exempted from this requirement are:

- vessels under enrollment;
- fishing vessels registered in the United States or British Columbia, Canada;
- motorboats;
- vessels of U.S. registry of less than 300 gross tons and towboats of U.S. registry and vessels owned by the State of Alaska, engaged exclusively on the rivers of Alaska or in the coastwise trade on the west coast of the U.S., including Alaska, Hawaii, and British Columbia, Canada;
- vessels of Canada, including cruise ships, engaged in frequent trade between British Columbia and Alaska (provided that reciprocal exemptions are granted by Canada to vessels owned by the State of Alaska and those of U.S. registry; and
- pleasure craft (USDOC, 1994; p. 57).

Currently, tankers in Prince William Sound must have at least two deck officers on the bridge, one of whom may be a federal pilot, licensed in areas where a federal pilot is required. In those cases, the second officer on the bridge must be a master, mate or officer in charge of a navigational watch. State pilots must now be onboard all the way out past Bligh Reef (Prince William Sound Regional Citizens' Advisory Council (RCAC)1995, p. 22):

- *Each tanker must navigate with at least two licensed deck officers on watch on the bridge, one of whom may be a pilot. In waters where a pilot is required, the second officer must be an individual licensed and assigned to the vessel as Master, Mate, or Officer in charge of a navigational watch, who is separate and distinct from the pilot (i.e., 33 CFR 164.13 (c)). Since foreign licensed officers cannot hold pilotage, two officers are accepted.*

- *[Further], in any area of Prince William Sound where a vessel subject to this section is required to be under the direction of a pilot licensed under Section 7101 of this title, the pilot may not be a member of the crew of that vessel, and shall be a pilot licensed by the State of Alaska who is operating under a federal license, when the vessel is navigating between 60 49'N latitude and the Port of Valdez (46 USC 8502 (g)(2)). The designated pilot station is 60 49'N and 147 01 'W longitude, a position south of Bligh Reef (APSC, 1995b; p. 3).*

2.2.2 Shippers and Vessels

In the years 1993 and 1994, the majority of vessels transiting the Valdez traffic lanes were tanker vessels, their SERVS escort response vessels (ERV's) and tugboat escorts, tugs and tows, passenger vessels, and ferries. Other users of the Sound include public vessels, such as the United States Coast Guard Cutter (USCGC) *Sweetbrier*, USCGC *Mustang*, the National Oceanic and Atmospheric Administration *(NOAA)* ship *Rainier*, miscellaneous naval vessels and cargo ships. Cargoes carried include 20- and 40-foot containers and the Hazardous Materials cargo carried by the *Alaskan Challenger* (USCG, 1994).

The amount of traffic using the traffic lanes has remained relatively steady over the past several years, although the types of vessels which make up the traffic has changed, from being primarily tanker traffic, to a mix of tanker and escort vessel traffk, with passenger vessels (in the summer), excursion and small passenger vessels. A more complete description of vessel traffk in Prince William Sound is given in the Prince William Sound Oil Transportation System Description, Technical Documentation Part I.

2.2.2.1 Trans Alaska Pipeline System Fleet

A total of 6564 tanker port calls have been made at the Valdez Marine Terminal between 1987 and 1994 (APSC, 1995c). Most of the tankers which comprise this fleet are regular visitors to the VMT. The number of tankers ranged from a high of 61 in 1987, to lows of 41 in 1993 and 42 in 1994, with the core of returning vessels decreasing each year. Of these tankers, most are U.S. flag, with 4-7 Liberian flag vessels carrying crude to the U.S. Virgin Islands under the provisions of an Executive Order. In 1994, the tanker fleet ranged in size from 50,000 DWT to 265,000 DWT (APSC, 1995c).

The total number of vessels in the Trans Alaska Pipeline System (TAPS) fleet has decreased almost 33 percent since 1987: in 1987, there were 61 tankers (54 U.S. flag, 7 Liberian) calling on the port of Valdez, Alaska. In 1990, this number had fallen to 48 U.S. flag and 4 Liberian flag vessels. In 1994, 42 tankers-37 U.S. flag and 5 Liberian flag-comprised the TAPS fleet. In the future, the mix of U.S. flag and foreign flag vessels may be expected to change, with a greater percentage of vessels being U.S. flag, as the export ban on the North Slope crude has been lifted and additional U.S. flag vessels could be added to the fleet. A listing of vessels in the 1994 U.S. and foreign flag TAPS fleets are given in Technical Documentation Part I, the Prince William Sound Oil Transportation System Description.

Structural Problems

The TAPS fleet experienced several structural failures over the period 1980-1988, which ultimately led to a USCG report of the problem, which concluded that TAPS trade tankers experienced a higher incidence of structural failures during that period than vessels in other trades. In addition, the American Bureau of Shipping (ABS) undertook simultaneous studies of the structural problems.

Three items resulted from the structural failure studies:

- A USCG structural failure reporting system was developed to track structural failures.

- Owners and operators were required to conduct cargo block surveys and develop Critical Area Inspection Plans (CAIP) for each TAPS tanker. The ultimate goal of the CAIP was to identify problems before they become catastrophic failures (USCG, 1991; pp. 12-13).

- Finally, the following areas were identified as active repair or critical areas for the affected vessels (which includes two vessels remaining in service in 1995):

-side shell longitudinals,
-bilge keels,
-limber holes in bottom longitudinals, and
-transverse erection joint welds in #3 center cargo tank.

In order to combat loading stresses, TAPS fleet operators do not fully load vessels experiencing structural problems, and they take on more ballast than required in order to make the vessels ride more easily. One operator has also installed hull stress monitoring systems to assist ships officers in determining route planning and cargo loading impacts on hull stresses. Changes in ballast patterns, hull stress monitoring systems, repair strategies, and the elimination of bilge keels are changes that have been instituted in order to address loading stress and structural failure difficulties in the TAPS fleet vessels.

2.2.2.2 Non Trans Alaska Pipeline System Fleet

In addition to the TAPS fleet, the Prince William Sound oil transportation system is populated by a variety of other vessels: passenger and cruise ships, log ships, ferries, non TAPS trade tankers, fishing boats and fish processing boats, tugs and barges, Military Sealift Command vessels, container ships, and recreational boats. Members of the non TAPS fleet in Prince William Sound are listed in Technical Documentation Part I, the Prince William Sound Oil Transportation System Description.

Passenger and Cruise Ships

The Alaska passenger vessel and cruise fleet is diverse: of the more than 30 ships deployed throughout Alaska in 1995, 22 are ocean liners, 9 excursion yachts, 1 expedition ship, and 1 riverboat style vessel. Nine of these 30 vessels visit Prince William Sound. Passenger capacities vary from 500 to 1200 people. Passenger vessels that call on Prince William Sound fit into three broad categories: ocean liners, cruise liners, and specialty or expedition vessels (Fodor’s, 1995).

Extensive passenger vessel traffic is a relatively recent phenomenon in Prince William Sound. Over the past five years, passenger vessel traffic has steadily increased from one or two vessels a month to 10-15 vessel port calls per month in the summer months, from mid-May through late September. Turnaround tunes are brief: in most cases, passenger vessels transit Prince William Sound, dock at the container pier in Valdez, stay in port for several hours, and sail outbound. This traffic pattern increases demands on the Prince William Sound support system. Passenger vessel movements (and other non tanker vessel movements) are not restricted by the additional navigation rules applied to tankers by the USCG, the State of Alaska, Alyeska, and TAPS trade owners and operators and passenger vessels (and other non tankers) are not outfitted with automated dependent surveillance system (ADSS) equipment required on tankers, although these vessels ply the same waters and are required to be monitored by the USCG vessel traffic services (VTS). Frequent passenger vessel port calls also require agent, vendor, and sometimes stevedoring support, as well as an increase in requirements for pilot services in the summer months. These requirements are expected to increase in the future, as the number of tourists in Alaska is expected to increase in 1996 and beyond.

Passenger vessels sail on schedules, operate within the traffic lanes, and run at speeds greater than those of the tankers which share the traffic lanes with them (since they are not governed by speed restrictions), often close to glaciers and shore for sightseeing. Passenger safety has become an increasingly important focus in the Sound. With the fire aboard the passenger vessel *Regent Star* in July 1995, the USCG has become increasingly attentive to safety aboard passenger vessels *(Anchorage Daily News,* 1995b).

Ferries

The Alaska Marine Highway system runs ferries in Prince William Sound, with winter and summer schedules. In the summer, the *M/V Bartlett* makes three round trips per week between Valdez and Whittier, leaving early in the morning from the Valdez ferry terminal, passing by Columbia Glacier both ways, and returning in *the* evening. Once a week in *the* summer, *the Bartlett* makes a trip from Valdez to Cordova. Ferries cross the traffic lanes in the center of Prince William Sound. Ferries are required to report into the Valdez VTS, but do not carry the Differential Global Positioning System (DGPS) and (ADSS) equipment. Ferries greater than 1600 gross tons must obey one-way zone restrictions when a tanker greater than 20,000 DWT is navigating (CFR 161.60), although in practice this requirement is sometimes ignored. Ferries smaller than 1600 gross tons can be in one-way zone areas with tankers. Once a week *in the* summer, the larger state ferry, the *M/V Tustumena (2* 174 gross tons), comes into Valdez from Kodiak and the Aleutian Islands.

Fishing Vessels and Fish Processors

Salmon and herring fishing activities dominate the almost two dozen commercial fisheries conducted in Prince William Sound. For example, vessel license data maintained by the Commercial Fisheries Entry Commission (CFEC) in Juneau, Alaska indicates that in 1995 there were 268 purse seine salmon permits, 542 gillnet salmon permits and 106 purse seine herring sac roe permits for Prince William Sound. Not all of these permits are fished in a given year. In addition, 70 processors filed intent to operate licenses with the Alaska Department of Fish and Game; these processors are a mix of company buyers, catcher/processors, exporters, independent buyers, or representatives from shore or a restaurant. See Technical Documentation Part I for more detailed information.

Most of the fishing activity occurs from April through October; beginning with historical herring openings in April. The drift gillnet salmon fishery begins in mid-May and lasts through most of September and occasionally into October. The salmon seine fishery can begin in June and is usually completed in September.

Other fishing activities include other forms of herring fisheries, crab, shrimp, halibut, sablefish (black cod), various mollusks and pollock (B. Blake, 1995).

Tugs and Barges

Transportation of non-persistent petroleum products is often carried by tank barges in Prince William Sound, and operators run on a variety of routes: Valdez to Whittier, Kodiak, Cook Inlet and Dutch Harbor, for instance. In general, such tug barges are running as single or double hull units on a hawser; tugs and barges generally do not run in the traffic lanes, with the exception of Valdez Arm and Valdez Narrows, where it is required that tugs and barges travel in the traffic lanes.

2.2.3 Vessel Crews

TARS vessel crews are a mix of company employees, union and non-union personnel. For some TARS fleet operators, senior officers are permanent company employees, while junior officers come through union hiring halls; in other cases, all officers are company employees, with some belonging to an independent or national maritime union. TARS vessel unlicensed crews reflect the same patterns: some unlicensed crew members are permanent company personnel; some are members of an independent union, a national maritime union, or neither. TARS vessel crews are all U.S. nationals, with the exception of some of the foreign flag vessels, which have multinational crews. Most TARS vessel crews have strong continuity aboard their vessels, and in the Alaskan oil trade. Independent union officers and unlicensed crews exhibit the highest vessel and company continuity, closely followed by national union officers and unlicensed crew members.

Non TARS vessel crews are also a mix of independent union and company employees, national maritime union, and other personnel. Some non TARS fleet operators have senior officers who are permanent company employees, while junior officers come through union hiring halls; in other cases, all officers are company employees, with some belonging to an independent or national maritime union. Non TARS vessel crews reflect the same patterns: some unlicensed crew members are permanent company personnel (some members of an independent union, a national maritime union, or neither).

2.2.4 Escort Services

Outbound and inbound laden tankers are escorted between the Valdez Marine Terminal and Seal Rocks via Hinchinbrook Entrance. Escort vessels remain within one quarter of a mile of the tanker being escorted between Valdez Arm and Hinchinbrook Entrance unless the safety of any vessel is compromised (APSC 1995a; VERP, 15 November 1995). Escort vessels are positioned to provide the maximum possible assistance if needed; this positioning will vary, depending on USCG Captain of the Port rules; weather, ice, or operational conditions; and the judgment of the tanker master or the escort vessel master. Four Escort Response Vessels (ERV's) and three tugs currently handle the escort schedule in a normal rotation. A substitute vessel may be used, if needed, because of routine maintenance, down time, and other circumstances. The number of ERV's and/or tugs available is a function of the tanker traffic (APSC, 1995a; p. 6).

2.2.5 United States Coast Guard

The United States Coast Guard (USCG) Marine Safety Office in Valdez is the federal marine safety regulatory representative, responsible for safeguarding the maritime transportation industry and marine environment. The USCG is committed to protecting the lives and property at sea, port facilities, and the maritime environment of Prince William Sound through the application of new methods and technologies, including vessel traffic services (VTS), and through better liaison with the marine community. The USCG also promotes the safe navigation of vessels in Prince William Sound through surveillance, communication, and informed traffic advisory services for mariners (USCG, 1995b). Recently, at the VTS, the qualifications and training for the USCG's VTS watchstanders have been upgraded, and a new billet of watch supervisor has been added (RCAC 1995; p. 22).

2.2.6 Alyeska Pipeline Service Company Marine Personnel

The Alyeska Pipeline Service Company (APSC) marine operations unit is Ship Escort Response Vessel System (SERVS), an organization that provides an umbrella over Tidewater, Crowley, and TCC employees. The SERVS mission is to prevent oil spills by assisting tankers in safe navigation through Prince William Sound, and to protect the environment by providing effective response services to the Valdez Marine Terminal and Alaska crude oil shippers in accordance with oil spill response agreement and plans (APSC, 1995b).

2.2.7 Alaska Department of Environmental Conservation

The Alaska Department of Environmental Conservation (ADEC) is the state agency responsible for conservation, protection, and regulation of the environment in the state. ADEC policy and program development responsibilities include oil spill prevention and response activities, air and water programs, environmental health programs, and information and administrative services programs. As such, the department has roles and responsibilities in several areas: service delivery (i.e., contingency plan review and approval, ballast water inspection, evaluation of oil spill drills, evaluation of hazardous substance response capabilities), pollution prevention (determining spill and hazards causes, negotiating pollution prevention actions, etc.), public contact, physical facilities (statewide response team equipment consolidation), and cost savings areas. ADEC promulgates and enforces environmental regulations in the state and participates actively in a variety of programs and studies in Prince William Sound.

2.2.8 Prince William Sound Regional Citizens' Advisory Council

The Prince William Sound Regional Citizens' Advisory Council (RCAC) has as its mission promoting environmentally safe operation of the APSC terminal and its associated tankers. The RCAC receives funding for the services provided to APSC and to the public; RCAC is certified as an alternative citizen council for Prince William Sound, under the requirements of the Oil Pollution Act of 1990 (OPA 90), which provides for citizen oversight. Under the terms of its contract, the RCAC provides specific services to APSC and the public. These services include:

- reviewing, monitoring, and commenting on APSC's oil spill response and prevention plans, APSC's prevention and response capabilities, APSC's environmental protection capabilities, and the actual and environmental potential impacts of terminal and tanker operations;

- increasing public awareness of APSC's oil spill response and prevention capabilities, APSC's environmental protection capabilities, and actual and potential environmental impacts of terminal and tanker operations;

- commenting on and participating in monitoring and assessing the environmental, social, and economic consequences of oil-related accidents;

- providing input on actual or potential environmental impacts in or near Prince William Sound;

- commenting on the design of measures to mitigate the potential consequences of oil spills and other environmental impacts of terminal and tanker operations;

- participating in development of the spill prevention and response plan, annual plan review, periodic review of operations under the plan, including training and conducting exercises; and

- commenting on and participating in selection of research and development projects (RCAC, 1994; pp. 2-3).

The RCAC has also participated and jointly sponsored a number of recent initiatives and studies in the Sound, and has completed a number of monitoring, reporting, reviewing, and commenting initiatives.

2.3 Technical and Technological Infrastructure

The Valdez Marine Terminal (VMT) is located on the south shore of Port Valdez. It straddles an area known as Jackson Point. The terminal is located at the southern end of the Trans Alaska Pipeline System (TAPS), and provides facilities for receiving and storing oil from the pipeline until the oil is loaded aboard tankers. Four berths, numbered 1, 3, 4 and 5, have been provided for meeting the total pipeline throughput. The terminal operates continuously throughout the year (DNV, 1990; p. 2.11).

Oil production is decreasing, and is expected to continue to decrease for the next several years; oil production throughput numbers since 1993, and projections for 1996 and 1997, are given as follows (L. Shier, personal communication, December 21, 1995):

Year	Production
1993	1.620 million barrels per day
1994	1.587 million barrels per day
1995	1.522 million barrels per day
1996	1.421 million barrels per day (estimated)
1997	1.371 million barrels per day (estimated)

Other elements of the technological infrastructure in Prince William Sound include a radar surveillance system, an Automated Dependent Surveillance System (ADSS), extensive communication systems and navigational aids.

2.4 Traffic Management

In Hinchinbrook Entrance, inbound vessels enter the northbound traffic lane within a traffic separation scheme (TSS), which is a network of one-way traffic lanes with an intervening separation zone. In addition to the TSS, the existing Prince William Sound vessel traffic services (VTS) consist of a vessel movement reporting system; radar surveillance in Valdez Arm, Valdez Narrows, and Port Valdez; a communications network; and an ADSS network.

The Vessel Movement Reporting System (VMRS) throughout the Prince William Sound VTS areas is controlled by the Vessel Traffic Center (VTC), which is operated by the USCG. The VTC maintains radio telephone communications with vessels in the Prince William Sound VTS area. The VTC receives, assembles, and processes information from vessels through mandatory and voluntary reports, and in turn disseminates information to vessels.

2.5 Escorting

The function of escort vessels is to assist tankers in case of emergency, to warn of impending danger, and to provide initial spill response (APSC, 1995b; p. 6). All laden tankers transiting Prince William Sound (including partially laden inbound tankers defined by 33 CFR 16 1.303 as a tanker with any cargo onboard in excess of normal clingage or residual) are escorted by escort vessels, at least one of which will be an escort response vessel (ERV). Each ERV is designed and equipped for towing and is fitted with fenders to come alongside a tanker as requested by the tanker master. ERV's carry boom, skimmers, and other equipment for immediate response in the event of a spill (APSC, 1995a; p. 6). Once an escort is underway, it normally proceeds to completion; however, during periods of severe weather, masters of the escort vessels may require slower escort speeds, or terminate the escort to seek shelter. If the escort is terminated, the VTC is notified (APSC, 1995a; p. 6).

2.6 System Culture

The Prince William Sound oil transportation system is populated primarily with known participants who interact frequently with other known participants and less frequently with other, less familiar participants. The system is also undergoing change and preparing for changes expected as a result of the U.S. Congress lifting the Alaskan oil export ban *(Anchorage Daily News,* 1995c; *Journal of Commerce, 1995b*), and preparing for changes in the TAPS fleet as a result of OPA 90 phase out schedules, structural failures and hull stresses, and changes in Alaskan oil reserves. These changes will result in tanker retirements, vessel lay ups, and scrappings; losses of tanker billets; the export of previously domestic oil; a shift in attention and emphasis among some members of the APSC oil consortium to different reserves and opportunities worldwide; and potential changes in budgets for the Prince William Sound oil spill response infrastructure installed in the system.

Relationships in the Prince William Sound oil transportation system provide the glue and lubrication for the system; new relationships between members in the system have made possible cooperative efforts not previously attempted because of distrust and rancor in the system (i.e., the aforementioned disabled tanker towing study (DTSS); the current risk assessment project). Questions articulated by system members include whether the current balance between oil spill response and oil spill prevention resource commitments is appropriate, as well as whether the safety focus should be equitably distributed across all participants in the system (i.e., tankers, passenger vessels, ferries, tug barges, etc.) so as to address system safety as a whole.

Each organization in the Prince William Sound oil transportation system has a different culture. Ship owners and operators in Prince William Sound are careful and conscientious vessel and personnel custodians, an approach that is reflected in safety, management, and personnel practices. Most operating companies (who are not vessel owners) have long term charters from the ship owner, and operate as members of the owner management team. Several operators in the TAPS fleet are company shops, top to bottom, owning the vessels they operate and employing the personnel who run them. These relationships are reflected in management attitudes toward training, crew responsibility, work rules, and they govern expectations of shipboard employees by shore-based staff, and vice versa.

The large number of regulations and requirements which pervade the Prince William Sound oil transportation system has had an impact on TAPS trade officers and crews. Tanker crew members remark on the panoply of regulations, and the mental overhead associated with keeping up with changing sets of regulations. Tanker crews are also daunted by the differences in regulations that pervade shipping on the West Coast of the U.S., and the resulting "patchwork quilt" of regulations leaves operators with the sense that they might have missed something. System members discuss the impacts of changing regulations, and resulting decreases in communications, which sometimes occurs in environments characterized by extensive regulation and surveillance, as system members become more wary about formal communications trails which might have a role in future litigation.

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3 .O Methodologies for Assessment of Risk

3.0 Methodologies for Assessment of Risk

3.1 Assumptions/Interpretations of Project Objectives and Scope

The PWS Risk Assessment project had three primary objectives:

1) To identify and evaluate the risks of oil transportation in PWS,

2) To identify, evaluate and rank proposed risk reduction measures, and

3) To develop a risk management plan and risk management tools that can be used to support a risk management program.

The risk of an accident is defined as the product of the frequency of occurrence of the accident and the consequences of that accident. *An accident* is an event such as a collision or grounding that has adverse consequences (i.e., property damage, injury, loss of life, economic loss, environmental damage). *An incident* is a triggering event (such as an incorrect course change) or a vessel failure (i.e., loss of propulsion) that creates a hazardous condition that may result in an accident. Data in USCG databases refers to vessel casualties as both incidents and accidents. The PWS Risk Assessment differentiates between triggering events (incidents) and events with direct adverse consequences (accidents).

The PWS Risk Assessment did not attempt to predetermine an acceptable level of risk. Rather, the analysis described and measured the current level of risk in the system and identified and measured the potential effectiveness of risk reduction measures. The determination of acceptable risk will be a product of the stakeholders' use of the PWS analysis, rather than an initial parameter subjectively determined or a value calculated from some other environment.

3.2 Hazard Identification Exercise

To ensure that all potential hazardous conditions were included in the risk assessment, a hazard identification exercise was conducted for shipping activities in PWS, with focus on the different hazards that could endanger laden oil tankers. A *hazard* is defined as an occurrence that, unless brought under control, can lead to an accident. Laden tankers represent the main sources for potential oil spills. The exercise included verification of hazards by the Steering Committee and other marine users. See Technical Documentation Part I: Hazard List, for further details.

The results of this exercise were used to ensure that all possible incident and accident scenarios would be considered in the risk assessment and to define a common terminology to be used in the project.

The following types of accidents involving tankers were analyzed:

- Powered grounding: The contact with the shore or bottom **by an underway** vessel under power due to navigational error or steering failure and lack of vigilance.

- Drift grounding: The contact with the shore or bottom by a drifting vessel not under control due to a propulsion or steering failure, before the failure can be repaired or the vessel can be towed.

- Allision: The striking of the terminal berth by a tanker during docking or undocking.

- Collision: The colliding or striking of two underway vessels due to human error or mechanical failure and lack of vigilance (inter ship collision) or the striking of a floating object by an underway vessel (e.g., ice collision.)

- Fire/explosion: The occurrence of a fire in the machinery, hotel, navigational, or cargo space of a tanker or an explosion in the machinery or cargo spaces. Fires and explosions while loading or de-ballasting are not within the study scope.

- Structural failure: A structural failure due to hull or frame cracking or erosion, serious enough to affect the structural integrity of the vessel and to warrant repair at the next port of call.

- Foundering: The sinking of a tanker due to water ingress or loss of stability.

For each accident type (grounding, collision, etc.), a set of hazard-accident scenarios were described using the following structure.

Basic/Root Causes	are underlying root causes of an accident, such as inadequate recruitment, training or supervision, or poor preventative maintenance and inspection of critical systems.

Immediate Causes	are the direct causes of accident i.e., human error, such as incompetence or inattention, or component failures leading to an incident.
Incidents	are undesirable events related to control failures or system failures, such as navigation error, loss of steering or loss of propulsion. Incidents are normally detected and corrected in time, or covered by back-up systems before they can cause hazardous situations. It depends on the situation whether or not an incident puts a ship in danger. Temporary loss of propulsion or loss of steering at sea are incidents, while in confined waters they are also hazards.
Accidents	are occurrences which have adverse consequences (damage to tankers, injury, loss of life, economic loss, environmental damage), such as groundings, collisions, allisions, structural failures, tires, explosions or founderings.
Consequences	are the impacts of accidents on people and the environment. In this analysis, oil outflow from the damaged oil tanker is used as the surrogate measure of consequence.

3.3 Definition of Geographical Areas in Prince William Sound Considered In The Study

The project scope covered marine tanker crude oil transportation from Valdez Port to 20 miles outside Hinchinbrook Entrance and return. (See System Description, Technical Documentation Part I.) In order to assess and compare risks in different geographical areas of PWS, subareas were defined for use in the study. Common definitions of subareas were used for all methodologies and models to ensure comparable results.

The subareas were selected in accordance with well known definitions and common understandings in the marine community in PWS and by the Steering Committee.

The introduction of subareas facilitated modeling of variables such as weather, ice, currents, traffic regulations, traffic, pilotage, etc., which were different for the various subareas. The definition of subareas also provided a key for assessing, summarizing, and presenting accident frequencies and risk results per area, such as collisions per subarea, or drift grounding per subarea. The subareas (and their length in nautical miles) used in the study were:

- Gulf of Alaska (20 nautical miles outside Hinchinbrook Entrance)
- Hinchinbrook Entrance (8.5 nautical miles)
- Central PWS (32.5 nautical miles)
- Valdez Arm (16.5 nautical miles)
- Valdez Narrows (4.0 nautical miles)
- Port Valdez (7.5 nautical miles)
- Knowles Head anchorage

An anchorage subarea was also defined, but it was subsequently determined that laden tankers do not transit this subarea routinely, hence the risk of oil spill in the anchorage is always insignificant compared to other areas.

The definition and use of subareas throughout the assessment were required to predict where the different types of accidents were more likely to occur, and hence where risk reduction measures, if implemented, were likely to have the best effect.

The subareas are shown in Figure 3.3-l.

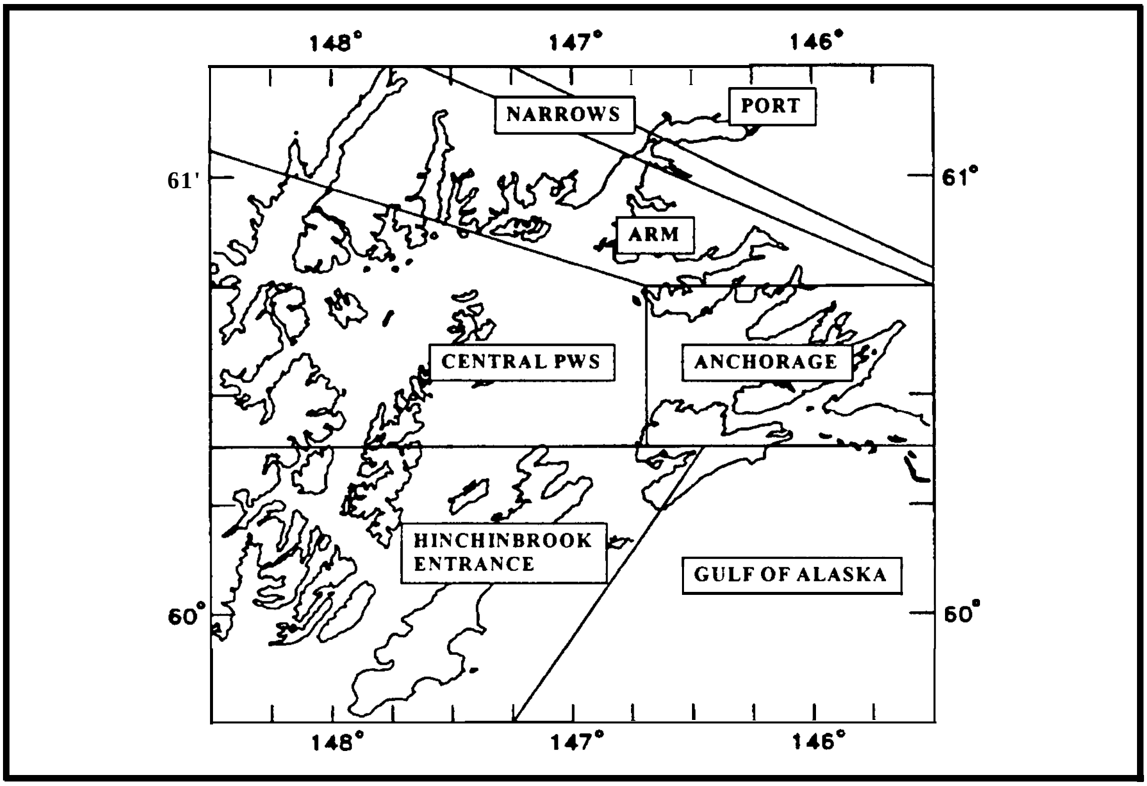

Figure 3.3-l
Prince William Sound Subareas

3.4 Definition of Risk As Used In This Study

The risk of an accident is defined as the product of the probability of occurrence of the accident and the consequences of that accident. In this study, risk was calculated in three steps: First, the frequency of occurrence of all accidents involving tankers was assessed, without regard to the ensuing consequences. Accident frequency is defined as the number of accidents that occur per year within a defined area.

Second, the frequency of occurrence of accidents with a potential for oil spill was assessed. Operational spills were excluded from the analysis.

Third, the consequences of accidents in terms of potential oil outflow was estimated for each type of accident and for different geographic locations.

Consequences other than oil outflow were not considered in the assessment of system risk.

It is assumed, however, that any measure contemplated to reduce the risk of oil spill, will also have to meet acceptance criteria for personnel safety set by the PWS Steering Committee.

System risk is hence described in terms of three parameters:

1) accident frequency, or the expected number of accidents per year;

2) accident consequence expressed, or the potential oil outflow; and

3) frequency--consequence relationships described by an oil outflow distribution showing the expected frequency of discrete size ranges of potential oil outflows.

These frequency and consequence results are expressed in five ways:

- for each of six accident types (collision, drift grounding. powered grounding, fire and/or explosion, foundering. structural failure), at each of the seven geographical subareas (Port Valdez, the Narrows, Valdez Arm, Central Sound, Knowles Head anchorage, Hinchinbrook Entrance, Gulf of Alaska), for each season. A seventh accident type, allisions can only occur at the Valdez Marine Terminal and are reported only for Port Valdez;

- for each of the seven subareas, summed over all accident types and seasons;

- for each of the seven accident types summed over all subareas and seasons:

- for each season, summed over all subareas and accident types; and

- for the system as a whole, summed overall subareas, all seasons and all accident types.

Expected frequencies are presented in two ways: the expected number of accidents/year expressed in scientific notation (0.001 accidents/year = 1 .Oe-3 accidents/year) and the expected return time expressed in years (0.001 accidents/year = 1 accident/1.000 years or a return time of 1,000 years). Potential average oil outflows are expressed in tons of oil released.

3.5 Basis for Consequence Calculations - Oil Outflow Curves

3.5.1 Oil Ouﬄow Curves

- The consequences of accidents were limited to and defined as the potential average oil outflow resulting from a given accident. Several oil outflow models were defined, one for each of the accident types, (i.e., collision, drift grounding, power grounding, fire and explosion, and structural failure and foundering). The oil outflow models are described in detail in Technical Documentation Part IV; Oil Outflow Model Description.

In addition, each oil outflow model considered:

- Hull type (single hull, double side, double bottom, double hull);
- Loading type (full loading, hydrostatic loading);
- Accident severity (for example, effect of impacting ship size on oil outflow); and
- Accident location (for example, effect of waves and/or tide on oil outflow).

Some simplifying assumptions were required regarding the effect of hull type on oil outflow as firm data for every parameter was not available. These are:

1) A double bottom was equivalent to a double hull for grounding; otherwise parameters for a single hull applied;

2) Double side was equivalent to double hull for collision; otherwise single hull parameters applied; and

3) The hull type does not affect the probability of total loss of the vessel.

The main sources of data for populating the oil outflow models were Lloyd's Casualty Returns and their analysis by IMO (IMO, 1987), and extensions of work originally performed by DNV for the National

Research Council (NRC, 1991; Hysing and Torset 1993; DNV, 1996). Some assumptions were derived from Steering Committee judgment (i.e., relative distribution of grounding locations that would influence the probability of oil outflow due to the grounding and specific tanker hull data for the PWS fleet). See Figure 3.5-l for a schematic composite of the cumulative oil outflow probability curve.

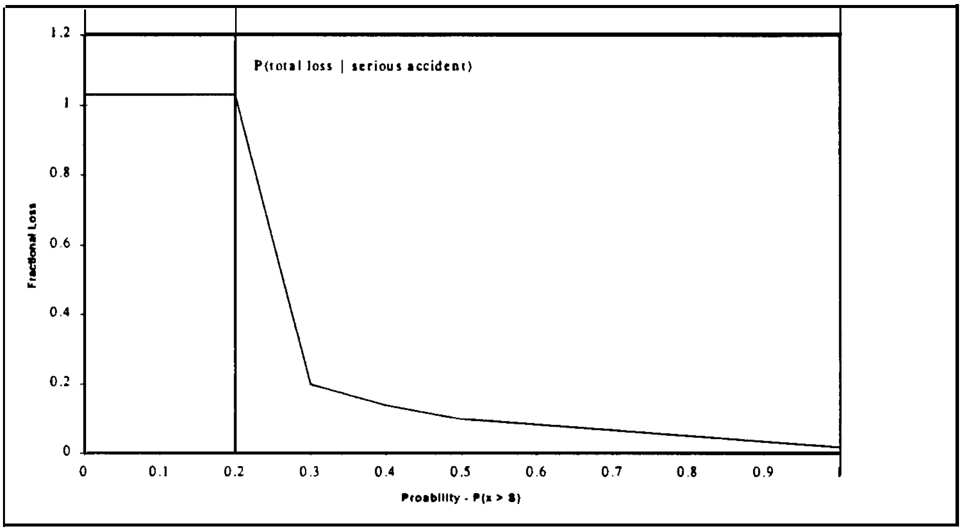

Figure 3.5-l
Schematic Composite Cumulative Oil Oufflow Probability Curve

It should be noted that the maximum total fractional loss of cargo is set to 1.03 to allow for bunker fuel oil released in the case of catastrophic loss and the probability of total vessel loss P_{TOT} generally has a controlling influence on the overall oil spill risk.

The factors taken into account in the models for the different accident types were as follows.

3.5.2 Collisions

The factors of importance in evaluating the quantity of oil lost during ship collisions were:

- The collision geometry (only struck ships sustain damage to cargo tanks);
- The collision energy (only collision energies capable of penetrating the outer steel plates of a tanker were used);
- The hull type of the struck tanker (double hull, single hull); and
- The probability of total tanker loss.

3.5.3 Groundings

The factors of importance in evaluating the quantity of oil lost during ship groundings were:

- The speed of the grounding ship (which determines the energy available for penetrating cargo tanks);
- The characteristics of the shoreline, which determine the probability of grounding on rocks (the hull is not penetrated when the tanker grounds exclusively on soft material);
- The loading type, i.e., full loading or hydrostatic loading; and
- The grounding location (the probability of total loss is reduced when the grounding locations is sheltered from high sea states).

3.5.4 Fire/Explosions

The quantity of oil lost as a result of tires and/or explosions onboard tankers depends on whether the fire starts in, or spreads to the cargo tanks, since small fires in the non-cargo areas rarely lead to oil spill.

The oil outflow distribution was derived from IMO casualty statistics (IMO, 1987) for the following two scenarios:

1) Fire/explosion causes the ship to sink, releasing the entire cargo plus the bunker fuel. The probability of total loss is 64 percent, given that the tanker becomes a serious casualty.

2) Fire/explosion ruptures top of tank, releasing contents down to the waterline. This could involve typically 20 percent of the tank, or typically 2 percent of the cargo. This is assumed to apply for the remaining 36 percent of serious casualties.

Identical oil outflow curves were used for fire/explosion accidents for all hull types, loading types and accident locations while underway. Therefore only one oil outflow curve is used because in these scenarios the oil outflow is dominated by the total loss component, which is independent of hull configurations.

3.5.5 Structural Failure/Foundering

The nature of structural failures considered in connection with oil outflow calculations are serious structural failures which would warrant repair at next port call when detected.

The quantity of oil lost as a result of structural failure and/or foundering depends to some extent on the hull characteristics, since some structural failures onboard double hulled tankers may lead to oil spills that are contained in the outer hull.

The oil outflow distribution was derived from IMO casualty statistics (IMO, 1987) for the following scenarios:

1) Hull damage causes a leak from a single tank, releasing contents down to the waterline. This could involve typically 20 percent of the tank, or 2 percent of the cargo. This is assumed to occur in 50 percent of hull damage casualties, or 42 percent of all hull damage/foundering casualties (foundering accounts for 16 percent of the total combined structural failure/foundering casualties). No spill is assumed to occur for double hulled tankers under this scenario.

2) Hull damage causes rupture of a single tank, releasing all contents, typically 10 percent of cargo. This is assumed to occur in 43 percent of hull damage casualties (for consistency with data below), that is 37 percent of all hull damage/foundering casualties.

3) Structural failure causes ship to split in two, resulting in total loss of cargo and bunkers. This is taken to occur for 6 percent of all hull damage/foundering casualties.

4) Ship founders due to flooding of engine room, resulting in total loss of cargo and bunkers. This is assumed to occur for all foundering casualties, that is 15 percent of all hull damage/foundering casualties. This should not occur for ships greater than 235m in length (SOLAS, 1974), however the assumption is retained and is therefore conservative.

Therefore, two oil outflow curves were used for structural failure/foundering accidents: one for double hulled tankers and one for non-double hulled tankers.

Technical Documentation Part IV: Oil Outflow Model Description, contains all technical supporting information including data and oil outflow curves, for different accident types and situations.

3.6 Methodologies Used/Integration of Methodologies

As shown in Figure 3.6-1, the methodology developed for the PWS Risk Assessment consisted of four interrelated stages:

1) The input stage consisted of gathering data and information and constructing data bases.

2) The synthesis stage consisted of analyzing this data and information and producing the input required by the assessment methodologies.

3) The assessment stage required the building, testing and application of Prince William Sound specific risk assessment models.

4) The evaluation stage consisted of providing a risk profile of the current system (baseline risk) and the evaluation of proposed risk reduction measures.

Since no single risk assessment methodology could provide the level of detail required by this analysis, four methodologies were linked to provide the assessment capability. Three methodologies were used to assess the frequency of incidents and accidents. A single oil outflow model, developed by DNV and described in Section 3.5, was used to calculate an estimate of the expected impacts of accidents predicted by the other three methodologies. The methodology of fault trees was used to examine specific high interest hazard scenarios that could not be examined in detail by other methodologies, such‘ as powered grounding in the Narrows, allision at the dock, and collision with ice. Fault trees, described in Section 3.9, provided insight into the causal chains producing these significant events and can be used to determine where and how risk reduction measures interrupt these causal chains. The DNV Marine Accident Risk Calculation System (MARCS), described in Section 3.8, provided a static statistical picture of the risk for all accident types at all locations. This statistical model provided a systemwide perspective on what events are likely to happen and where they are likely to occur. The statistical model is suitable for evaluating measures that change system parameters (i.e., evaluation of the save potential of escort tugs of different capabilities). A system simulation developed by GWU, described in detail in Section 3.7, provided a dynamic picture of risk. The simulation methodology is suited to evaluate risk reduction measures that affect the dynamics of the system (traffic control) and can evaluate relative risk of system states (improved human performance, vessel reliability).

The data used in the analysis included failure data for the PWS tanker calling fleet, worldwide accident data (used in fault trees and MARCS model), PWS accident and incident data (used to modify worldwide accident data and to calibrate the system simulation), and PWS specific weather, current, ice, visibility, and traffic data. A management system assessment of the PWS oil shipping companies and vessels, described in Section 3.11, was performed by DNV auditors. The management audit was used as the basis for determining relative differences in organizational parameters used in all three assessment methodologies and in estimating failure rates for each company based upon reported rates and the assessment of the effectiveness of the each company’s internal incident reporting system.

The three risk assessment methodologies were integrated in three ways:

1) All three models used common input data and system parameters, including traffic data, weather, ice and current data, and failure rate data.

2) The models were calibrated against each other. The accident frequency results of the fault tree and MARCS model were reconciled. The incident and

accident frequencies calculated by the MARCS and system simulation were reconciled by calibrating the simulation on selected failure rates and accident frequencies.

3) The accident frequency and oil outflow results described in Chapters 6 and 8 were compiled by reconciling and integrating the results of the three risk assessment models. In most areas, the models produced risk predictions that differed by less than a factor of two. In these circumstances, described in detail in Chapter 6, the results of the different approaches were used to establish upper and lower risk bounds. In some cases, however, one model was clearly better able to represent a portion of the system and, for these situations, the accident frequencies calculated by one model were used. For example, the Fault Tree approach was used to model the interaction of tethered tugs and tankers in the Narrows, the MARCS model was used to model the save potential of alternative escort vessels, and the system simulation was used to capture the dynamic interactions that resulted in collisions.

PWS Risk Assessment Methodology

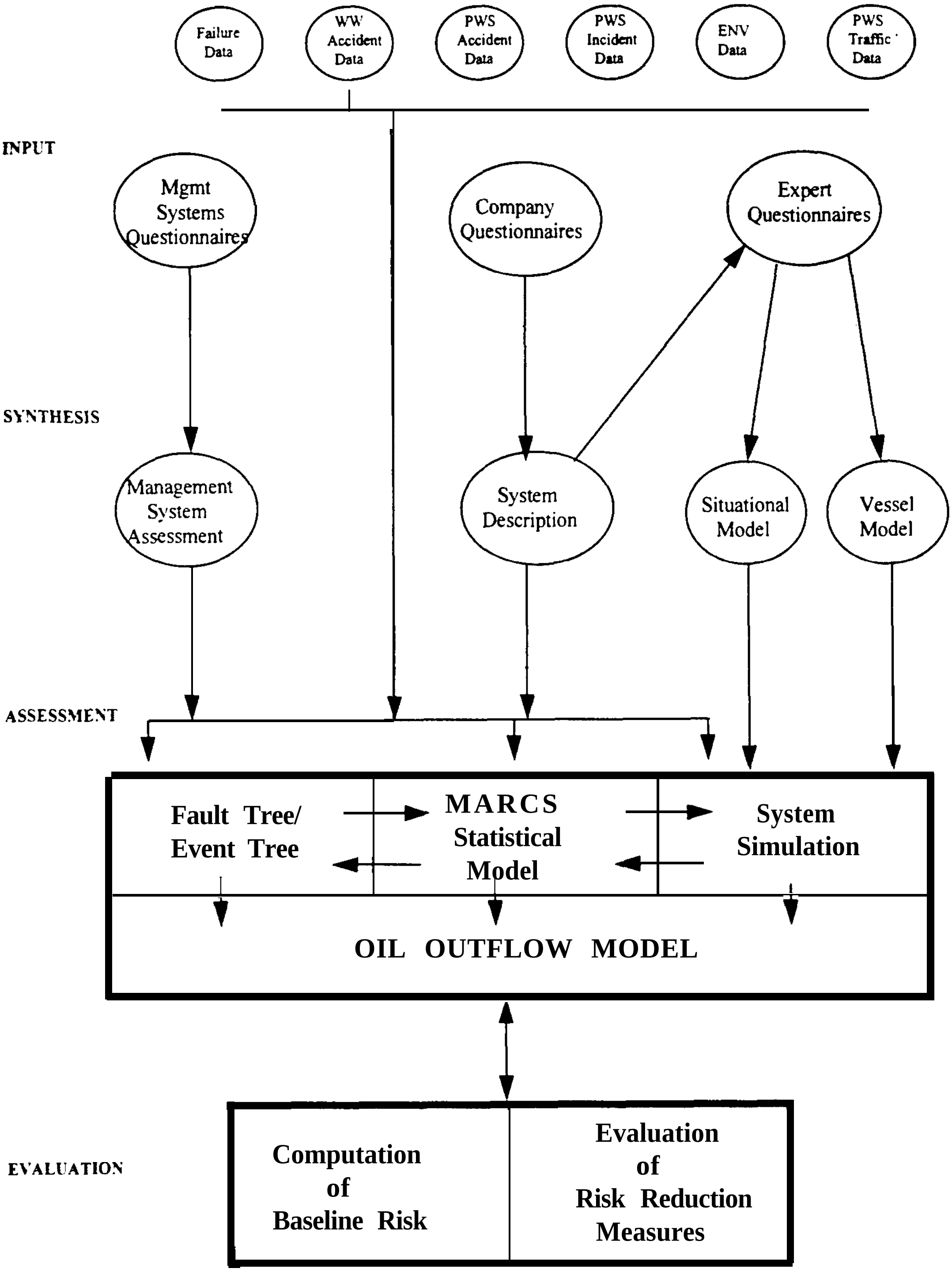

Figure 3.6-1

3.7 The System Simulation

3.7.1 Overview of the Dynamic Simulation Approach

The dynamic simulation approach to maritime risk was developed to compensate for two real world constraints on the current state of the art of risk assessment:

1) A comprehensive causal analysis of a busy port or waterway requires the creation of a complete logical construct representing all possible causal chains in the system. Existing research and data do not provide a basis for this complex construct.

2) Data describing human error and other basic failures are not available. Data that is available is partial, misleading, or not applicable to the PWS system.

The system simulation methodology developed for the PWS Risk Assessment is based on two assumptions:

1) Risk is a dynamic property of the maritime system in PWS.

2) The judgment of the experts that have a deep understanding of the system provide a more accurate basis for the calculation of risk than does the sparse data.

Illustrated in Figure 3.7-1, the attributes of a vessel and the characteristics of the vessel's owner and operator are predictor's of the likelihood that vessel will experience a mechanical failure or human error. The situational attributes of the waterway (waterway configuration, location, traffic density, weather, current, etc.) will determine if that incident will become an accident. In the language of probability, the system simulation is based on conditional probabilities: the probability that an incident will occur is conditioned upon the vessel; the probability that an accident will occur is conditioned upon the environmental, traffic, and other situational variables and the occurrence of a triggering incident.

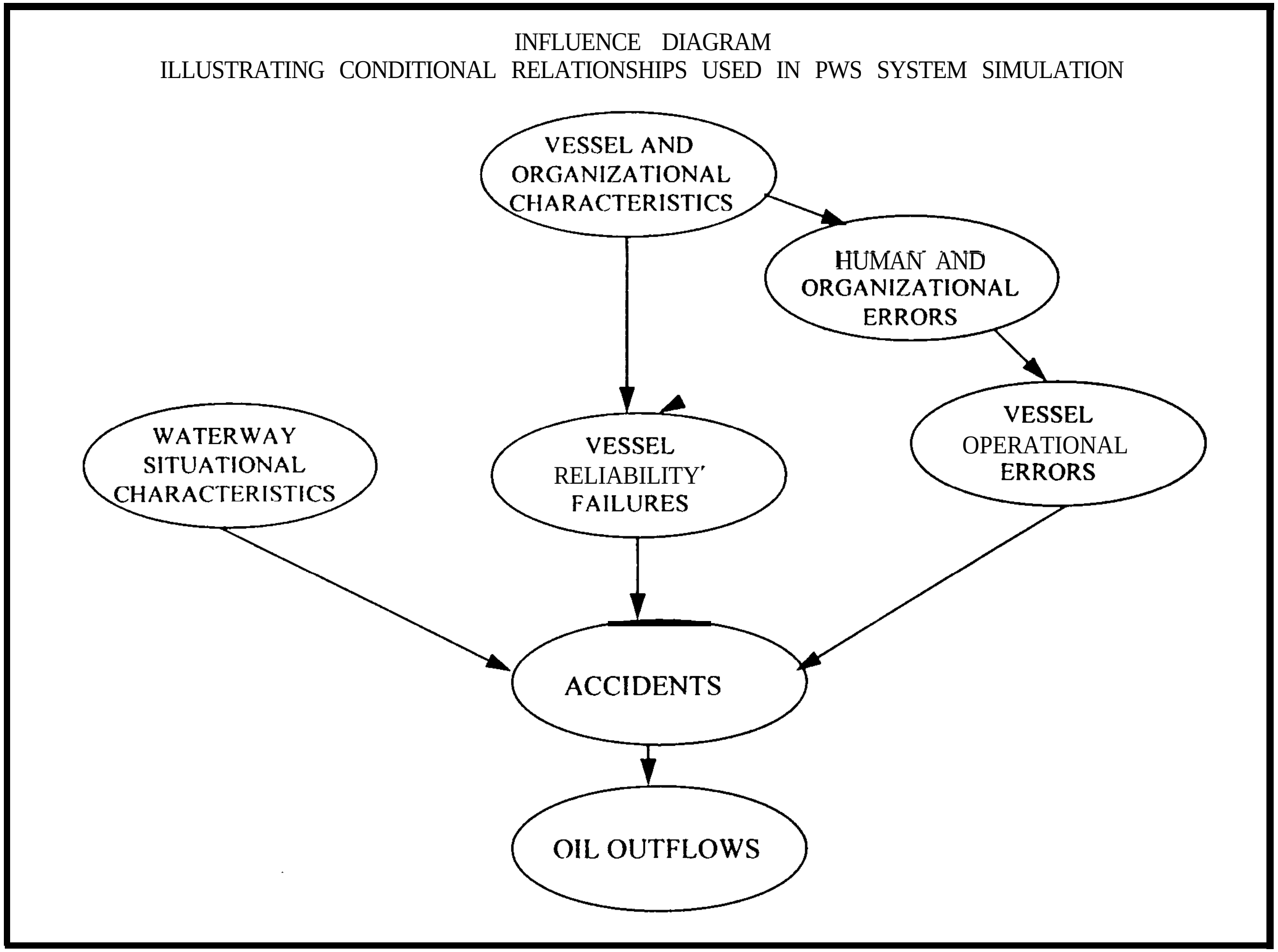
INFLUENCE DIAGRAM
ILLUSTRATING CONDITIONAL RELATIONSHIPS USED IN PWS SYSTEM SIMULATION
VESSEL AND ORGANIZATIONAL CHARACTERISTICS
HUMAN AND ORGANIZATIONAL ERRORS
WATERWAY SITUATIONAL CHARACTERISTICS
VESSEL RELIABILITY FAILURES
VESSEL OPERATIONAL ERRORS
ACCIDENTS
OIL OUTFLOWS

Figure 3.7-1

The dynamic risk assessment process, therefore, requires the calculation of the following four quantities:

1) The relative probability of occurrence of a vessel reliability failure or human/organizational error was calculated for each vessel in the PWS tanker calling fleet.

2) The relative probability that an accident would occur if an error or failure occurred on a tanker during a given state of the system was calculated for each of the different situational conditions used to model the set of all possible system states in PWS.

3) The frequency of occurrence for each situational condition was calculated.

4) The frequency of occurrence of each accident type was calculated by calibrating relative frequencies against actual incident and accident data and accident frequencies determined by the MARCS model.

The primary strengths of the application of the system simulation /regression risk assessment approach to Prince William Sound were:

1) Expert judgment provided a basis for structuring a causal analysis where historical accident data was sparse. In PWS, the study team was provided almost unlimited access to maritime experts with extensive experience relevant to the analysis.

2) Extensive data is required to accurately simulate a system. In PWS, accurate data on traffic densities, traffic routes, weather, and ice was made available to the study team.

3) The dynamic simulation is an appropriate modeling technique for identifying systemic interactions and for observing systemwide effects of interventions intended for specific purposes. For example, the simulation captures the systemwide effects of closure conditions, not just the elimination of exposure to hazardous conditions at a specific time or place.

The primary weaknesses of a simulation/regression risk analysis approach are:

1) Expert judgment can only provide measures of relative risk. A source must be found to calibrate model results. In the PWS Risk Assessment the simulation output was calibrated against MARCS output and historical data.

2) Experts can only provide expert judgment within their domains of expertise. Sometimes it is difficult to determine where the boundary is and data of uncertain validity will be used.

3) The questionnaires used to collect expert judgment are developed early in the analysis process. The elicitation of expert judgment is a long and difficult process. If it is discovered late in the process that critical areas were not included in the questionnaires, recovery is difficult.

3.7.2. Structuring the Model for the Use of Expert Judgment

The attributes used to describe tankers and situations in the PWS system simulation are shown in Table 3.7.-1.

Table 3.7-l

WATERWAY AND VESSEL ATTRIBUTES

Vessel Attributes	Waterway Attributes
Vessel size	Location
Vessel age	Traffic Proximity
Vessel material (high tensile or mild steel)	Traffic type
Vessel hull type (single, dbl. bottom, dbl. hull)	Traffic direction
Officer type (U.S., Int'l, union, company)	Escort vessels
Officer years service on vessel	Wind speed
Officer years service in billet	Wind direction
Percent of officers sailing below license	Visibility
Bridge team stability	Ice conditions
Officer training (individual, team)	Current
Management type (oil co. owned, charter)	Own vessel type
Flag (U.S. other)	

Four categories of vessel reliability failures were used to describe most common technological (non human) causes of maritime accidents as shown in Table 3.7-2. Note that the definition of a structural failure incident is broader and less severe than is the definition of a structural failure accident given in Section 3.2.

Table 3.7-2

VESSEL RELIABILITY FAILURE TYPES (VFW)

	Failure Classification	**Description**
1	**Vessel Propulsion Failure**	A loss of the vessel's ability to propel itself through the water (i.e., loss of boiler, turbine, main diesel, loss of propeller, broken shaft)
2	**Vessel Steering Failure**	Loss of the vessel's ability to control rudder (i.e., steering gear or steering motor failure, jammed or lost rudder)
3	**Vessel Electrical Power Failure**	The loss of ship's electrical power to all critical systems such as navigation and lighting
4	**Vessel Structural Failure**	The cracking of the vessel's hull while under way

Table 3.7-3 describes five types of basic vessel related human and organizational errors that were defined based on the USCG Prevention Through People Report (1995). The premise of the dynamic simulation is that the probability of these failures is conditional on the vessel and the owner/operator organization.

The relative probability that, given a vessel type, a vessel reliability failure or a human and organizational error would occur was calculated based upon data elicited from 162 PWS maritime experts intimately familiar with the Alaskan tanker fleet. The questionnaires used to elicit these expert judgments were based on the technique of paired comparisons; the experts were asked to compare hundreds of pairs of vessel/organizational descriptions. The experts that completed detailed questionnaires included PWS tanker Masters, Chief Mates, Chief Engineers, and Southwest Alaska Pilots Association (SWAPA) pilots. The expert judgment elicitation process is described in Chapter 4 and in detail in Technical Documentation Part III, Section 3.4.

Table 3.7-3

ORGANIZATIONAL AND HUMAN ERROR TYPES (VOE$_1$)

	Human/Organizational Error Classification	Description
1	**Diminished Ability**	Physical, mental, motivational or emotional conditions that degrade performance
2	**Hazardous Shipboard Environment**	Poor ergonomic design, poor maintenance, or poor vessel housekeeping
3	**Lack of Knowledge, Skills, or Experience**	Lack of general professional knowledge, ship specific knowledge, knowledge of role responsibility, or language skills
4	**Poor Management Practices**	Poor supervision, faulty management of resources, inadequate policies and procedure
5	**Faulty Perceptions or Understanding**	Inability to correctly perceive or understand external environment

The triggering event (or incident) in the risk model were the vessel reliability failures (VRF) described in Table 3.7-2 and vessel operational errors (VOE) that result from the human and organizational errors described in Table 3.7-3. Four categories of triggering vessel operational errors were defined as shown in Table 3.7-4.

Table 3.7-4

HUMAN ERROR TYPES (VOE$_2$)

	Vessel Operational Error Classification	Description
1	**Poor Decision Making**	Navigation or ship handling error due to failure, to obtain, use or understand critical information
2	**Poor Judgment**	Ignoring potential risks, excess speed, passing too close, etc.
3	**Lack of Knowledge**	Inaccurate knowledge of position and situation, inability to use navigational equipment and aids
4	**Poor Communications**	Confusing or misunderstood communication within bridge team, or between vessel and VTS, or between vessels.

Expert judgment elicited from PWS maritime experts was the basis for calculating the conditional probability that an accident would occur given that a triggering event (a vessel operational error or vessel reliability failure) had occurred. As described in Chapter 4, questionnaires for this stage of the analysis were administered to tanker masters, mates, and chief engineers, state pilots, fishermen, and other local maritime experts.

From the above definitions, then for any situation, or opportunity for incident i (OFI$_i$,), given the probabilities of occurrence of the VRF, and VOE$_{1j}$ and VOE$_{2j}$ defined in Tables 3.7-2,3,4, the probability of an oil outflow (0) can be calculated as described in Technical Documentation Part III, Section 3.4. The opportunity for incident ((OFI$_i$,), is a specification of a system state in terms of the waterway and vessel attributes defined in Table 3.7- 1. The allowable values for each of these attributes were determined through analysis of available data and through expert interviews as described in Technical

Documentation Part III, Section 3.4. The resulting discrete values for these waterway and vessel attributes are shown in Tables 3.7-5 and 3.7-6 and were used as the basis for the expert judgment elicitation questionnaires described in Section 4.5.

OFI$_i$:

Table 3.7-S
WATERWAY ATTRIBUTE MATRIX

Location	Port Valdez	Valdez Narrows	Valdez Arm	Central PWS	Hinchinbrook Entrance	Gulf of Alaska	Knowles Head Anchorage			
Traffic Proximity	No vsls within 10 miles	Vessels within 2-10 mi.	Vessels within 2 miles							
Traffic type	Fishing Vessels	Ferry or tour boat same direction	Ferry or tour boat opposite direction	Cargo vessel same direction	Tanker same direction	Cruise vessel same direction	Tanker Opp. direction	Cargo vessel same direction	Cruise vessel opposite direction	Tug with tow
Own tanker size and Direction	Inbound less than 150K DWT	Inbound more than 150K DWT	Outbound less than 150K DWT	Inbound more than 150K DWT						
Escort Vessels	Two or more	One	None							
Wind Speed	Less than 20 kts	20 to 30 kts	30 to 45 kts	more than 45 kts						
Wind Direction	Parallel to Vessel track (offshore in Gulf)	Perpend. to vessel track (onshore in Gulf)								
Ice Conditions	No bergy bits w/i 1 mile	Bergy bits w/i 1 mile								
Visibility	Greater than 1/2 mile	Less than 1/2 mile								

Table 3.7-6

TANKER ATTRIBUTE MATRIX

Tanker Size	Less than 100K DWT	100K to 150K DWT	150K to 200K DWT	More than 200K DWT
Age	Less than 7 years old	8 to 18 years old	Over 18 years old	
Material	Mild Steel	High Tensile Steel		
Officer Crew Type	U.S. Company	U.S. Union Personnel	Foreign Company	Int. hiring agency
Officer service on vessel	More than 5 years	0 to 5 years		
Officer service in billet	More than 1 year	1 year or less		
Percent below license	More than 60 percent	21 to 60 percent	Less than 20 percent	
Bridge Team Stability	More than 1 year	1 year or less		
Officer Training	Individual and team	Individual		
Management Type	Oil company owned	Charter/Ind. Shipowner		
Flag	U.S.	Other		

3.7.3 The System Simulation/Regression Model

The simulation models actual system behavior as determined by historical data and established system procedures. The role of the simulation is to count how many times each opportunity for a vessel reliability incident or a vessel operational error will occur in a well defined time period. The system simulation allows system states to change every five minutes. In the PWS Risk Assessment, 1995 was selected as the base case year and twenty-five year runs using the base case input data were used to produce a base case risk picture. In order to do this, the simulation had to present an accurate picture of the dynamics of the system--it had to accurately portray the dynamic changes in weather conditions, ice conditions, traffic, and traffic conditions. In PWS, the waterways management rules (VTS rules, industry closure conditions) and escort rules had to be accurately represented. The simulation also had to capture the complexity of the PWS fisheries, tour boat and cruise line operations. The simulation is described in detail in Technical Documentation Part IV, Section 4.5.

The relative incident and accident probabilities conditioned by situational and vessel descriptions used in the simulation were computed using the regression models described in Technical Documentation Part III, Section 3.6. These relative probabilities were converted to absolute probabilities by calibrating with actual data as described in Section 4.5 The data used for this calibration were the failure rate data reported by companies whose internal reporting systems were evaluated as outstanding by DNV, historical incident data for PWS collected and processed by RPI, the projected collision rate for specific areas calculated by the DNV MARCS model, and selected accident data. Figure 3.7-2 shows how the simulation/regression methodology combines available data with expert judgment to produce a systemwide risk picture.

The two primary advantages of using simulation are the quantifying of situational dependencies and the identification of situational trade-offs. If the weather, traffic, and geographic data are simulated with vessel traffic rules and practices properly modeled, then dependencies between weather traffic and situational rules are automatically incorporated in determining how often a given situation occurs during any time interval. Examples of situational dependencies that could be modeled are the impact of increased ice in traffic lanes and increased non tanker traffic. Trade-off analysis can show that interventions that reduce the risk of one accident type (i.e., groundings) can increase the risk of other accident types (i.e., collisions).

The system simulation/regression methodology allows significant analysis beyond the calculation of the frequency and location of incidents and accidents. Incidents and accidents can be described in terms of the states of the system that exist when they occur. This analysis can show the relative rate of occurrence of accidents during infrequent high risk system states (vessels with propulsion or steering failures under adverse circumstances) and those occurring during more frequent less risky system states.

One goal of the risk assessment is the development of tools that will allow risk reduction measures to be evaluated. As described in Chapter 6, the ability of the system simulation to model dynamic system trade-offs is essential to this analysis.

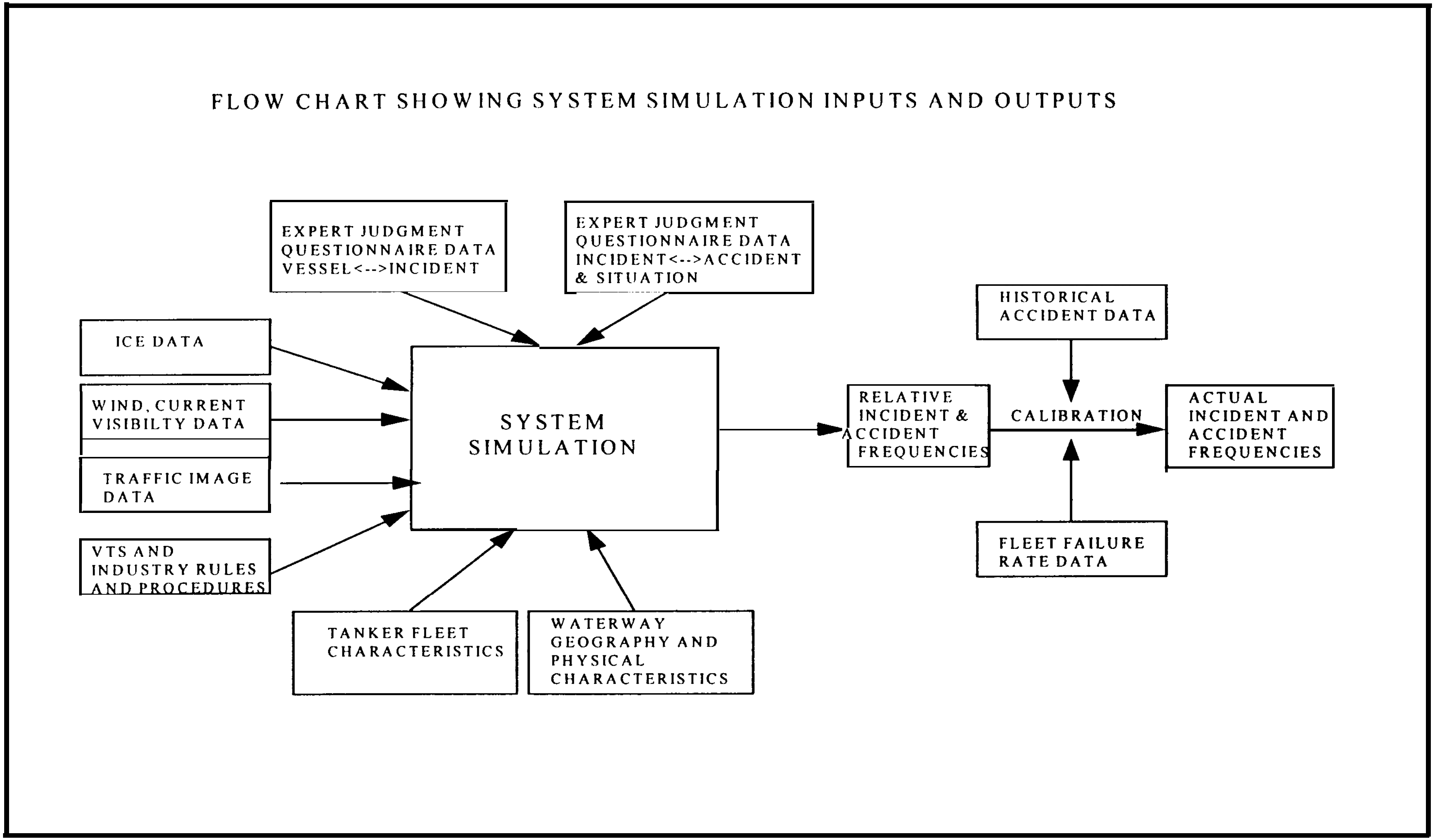
FLOW CHART SHOWING SYSTEM SIMULATION INPUTS AND OUTPUTS
EXPERT JUDGMENT QUESTIONNAIRE DATA VESSEL<-->INCIDENT
EXPERT JUDGMENT QUESTIONNAIRE DATA INCIDENT<-->ACCIDENT & SITUATION
ICE DATA
WIND, CURRENT VISIBILTY DATA
TRAFFIC IMAGE DATA
VTS AND INDUSTRY RULES AND PROCEDURES
SYSTEM SIMULATION
TANKER FLEET CHARACTERISTICS
WATERWAY GEOGRAPHY AND PHYSICAL CHARACTERISTICS
RELATIVE INCIDENT & ACCIDENT FREQUENCIES
HISTORICAL ACCIDENT DATA
CALIBRATION
FLEET FAILURE RATE DATA
ACTUAL INCIDENT AND ACCIDENT FREQUENCIES

Figure 3.7-2

3.8 MARCS Model and Data Input Requirements

3.8.1 Outline Description

MARCS uses a statistical representation of reality to calculate the frequency, consequence (and hence risk) of marine accidents. The program uses location specific input data and accident models described in Technical Documentation Part IV to calculate the location of marine accidents and the consequence of these accidents. The consequence of accidents is calculated as the quantity of oil lost from containment into the environment, including oil that burns as a result of an accident which is counted as oil lost into the environment. Thus, MARCS is a “source term” risk assessment tool in that it calculates the frequency of an accident, the location where oil is lost into the environment and the quantity of oil lost; MARCS does not calculate the subsequent dispersion and fate (“exposure”) of oil spills within the environment, nor does it calculate the effects (“impacts”) of the spill. The calculation of both exposure and impact is beyond the scope of the project.

The majority of the data enters MARCS in the form of either frequencies, probabilities, probability distribution functions, or parameter distribution functions. It is important to recognize that this statistical approach has both strengths and weaknesses. On the positive side, MARCS is capable of calculating marine risks in relatively large areas (such as the United Kingdom Continental Shelf). However, MARCS is not easily able to represent certain types of real time system behavior, nor can it easily track specific vessels within a system.

A detailed description of the MARCS model is provided in Technical Documentation Part IV.

3.8.2 Overview of MARCS

MARCS is based upon an analysis of the historical causes of major marine incidents and accidents involving crude oil tankers (IMO, 1987). This analysis established that the major shipping accidents at sea that lead to crude oil release are:

- Inter-ship collisions;
- Ship grounding (powered and drifting);
- Ship structural failure or foundering; and
- Fire or explosions onboard ship while underway.

The accident frequency factors and oil spill probability factors applied by MARCS can be based on any set of data that is selected for a project. In this project data specially gathered for the PWS tanker fleet as described in Chapter 4 has been used, and fault tree analyses have been applied to calculate accident frequencies, taking into account PWS specific conditions, as interpreted by expert judgment.

Worldwide statistical data has only been used for accident frequencies for fires and explosions, for which all tankers today follow the same international conventions.

3.8.3 Collision Model

The Collision Model calculates the frequency of inter-ship collisions between powered vessels at a given geographical location and in two stages. First, the frequency of ship crossings (defined as when two ships pass within a ships length of each other) is calculated by taking account of the shipping density and the vessel speeds, based on the traffic information for PWS provided in Technical Documentation Part III. Second, the probability of a collision for each crossing is applied to give the collision frequency. The collision probability factors are derived from the fault tree analysis for crossing interactions. They take account of a number of factors including the number of qualified officers on the bridge (internal vigilance), the number of onlookers (external vigilance), the presence of navigational aids (radar) and environment factors such as visibility. The fault tree modeling and data used are provided in Technical Documentation Part IV.

3.8.4 Powered Grounding Model

The Powered Grounding Model calculates the frequency of powered groundings which result from marine traffic lanes located in close proximity to the shoreline or shallow water. Four powered grounding modes are identified in the fault tree analysis:

1) Powered grounding due to a hard-over rudder failure;

2) Powered grounding due to failure to make a required course change;

3) Powered grounding caused by errant behavior of an attached tug; and

4) Powered grounding through wind or current from the side and crew inattention.

The fault tree analysis of these accident modes takes account of the degree of internal and external vigilance, navigational aids and visibility conditions.

3.8.5 Drift Grounding Model

The Drift Grounding Model calculates the frequency of drift groundings that occur when a ship loses its ability to navigate, due to steering or engine failure, and is subsequently forced onto the shore by the action of wind and current. A frequency factor is used to determine the frequency of mechanical breakdown. A drifting vessel may regain navigational control by three mechanisms.

1) It may effect repairs (self-repair);

2) It may be taken in-tow by a suitable tug; and

3) It may deploy its anchor if sea bottom and water depth conditions permit.

Wind speed and sea state (the height of waves) have an important influence on drift grounding frequencies. They affect the vessel drift rate, the maximum size of vessel a particular tug may control (prevent from grounding), the speed of tugs and the time taken to establish a line to the drifting vessel.

In order to avoid double counting, or underestimation, of accident frequencies it is important to clearly distinguish between drift and powered groundings. This distinction becomes less clear when a tanker is tethered to a tug. The definition used in the PWS Risk Assessment project is that, provided the tethered tug retains its ability to navigate, then all groundings of the tethered tug-tanker combination are considered to be powered groundings. The only way for a drift grounding to occur for a tethered tug-tanker combination is for both the tug and tanker to suffer mechanical breakdown simultaneously.

3.8.6 Structural Failure/Foundering Model

The Structural Failure/Foundering Model calculates the frequency of such accidents by combining frequency factors derived from fault tree analysis with the exposure time of vessels to particular sea state conditions. The frequency factors take account of a number of factors including the period between structural inspections, presence of strain gauges and quality of ship management. The top event frequency for structural failure is taken from worldwide IMO statistics, and the distribution into the fault tree branches is done by expert judgment. See Technical Documentation Part IV, Section 4.2.

3.8.7 Fire and Explosion Model

The Fire and Explosion Model calculates the frequency of such accidents while underway by combining frequency factors derived from fault tree analysis with the vessel exposure times. The frequency factors applied depend mainly on the quality of ship safety management and inspection. The basic event frequencies are taken from worldwide statistics provided from Lloyds Register. See Technical Documentation Part IV, Section 4.2.

3.8.8 Spill Size Frequency Calculation Program

The MARCS model is completed by the spill size frequency calculation program. This calculates the cumulative frequency of crude oil spills within a specific spill size range by combining the individual accident frequency maps with spill size probabilities. The spill size probabilities are dependent on a range of factors including the accident type, the accident severity, the accident location and the hull type of the tanker involved.

3.8.9 Data Structures in MARCS

The MARCS model requires a wide range of data sets in order to function at its full potential. All data input used in MARCS have been as far as possible PWS specific. These data requirements are satisfied by the model by using two basic data structures. These data are characteristics of marine traffic lanes, and data that are characteristic of locations. Data used in MARCS is described in Technical Documentation Part III, and assumptions and model descriptions are given in Technical Documentation Part IV.

Lane specific data are not limited to obvious data elements such as lane coordinates, lane widths and annual traffic frequency. Each shipping lane has a unique lane identifier assigned to it. This identifier can be used to access information such as:

- The size distribution of ships on the lane;
- The proportion of single, double sided, double bottomed and double hulled tankers on the lane; and
- The class of tug escorting the tankers in the lane.

It follows from the above that different shipping lanes may share identical geographical coordinates, but differ in other associated parameters.

Location specific data used in the MARCS includes:

- Location of coastline and other physical features such as shallow water;
- Tug location, availability and performance data;
- Ship speed data (as these vary with location);
- Accident frequency factors (where these vary with location);
- Vessel Traffic Service (VTS) zones and level of assistance provided;
- Visibility data;
- Wind rose and current rose data; and
- Sea state data.

These location specific data elements are stored within MARCS as data layers. It should be noted that the boundaries between subareas within each data layer do not have to coincide with subarea boundaries in other data layers. This allows considerable modeling flexibility.

3.9 Fault Trees and Data Input Requirements

Fault trees were applied in the project work as follows:

1) To provide input and calibration for the systemwide models (in particular the MARCS model) by calculating basic accident frequencies for fires/explosions, collisions, structural failures and powered groundings, taking into account PWS specific conditions and data.

2) To provide stand alone close-up examinations where fault tree analyses were the only suitable method, namely for:

- powered grounding in the Narrows;
- ice navigation in the Valdez Arm; and
- allision (impact) with berth in Valdez Port.

The structures of the fault trees and data used are described in detail in Technical Documentation Part IV; Fault Tree Descriptions. An independent review of the fault tree structure and calculation methods for powered grounding was carried out to bound the uncertainties inherent in the fault trees; this analysis is documented in Technical Documentation Part IV; Uncertainty Analysis.

The fault tree results (for 1 and 2 above) are presented in Technical Documentation Part V.

Human errors drive the fault tree results for powered groundings and collisions. The parameters used were estimated by a panel of experts based on previous research and studies, mainly from North Sea offshore activities.

3.9.1 Collisions

The fault trees provide conditional probabilities for collisions given ship-to-ship encounters, taking into account:

- human performance on the tanker bridge;
- internal vigilance (i.e., extra officer and/or pilot);

- external vigilance (i.e., vessel traffic control);
- navigational equipment failure rates;
- visibility; and
- steering and propulsion failure rates.

3.9.2 Powered Grounding

Powered grounding frequencies are calculated by the fault trees given that the tanker is on a dangerous course close to the shoreline.

The powered grounding fault tree contains four main branches:

1) Powered grounding caused by hard-over rudder failure;

2) Powered grounding through failure on the tanker to make a course change in time, while on a dangerous course;

3) Powered grounding caused by failure of a tug tethered to the tanker; and

4) Powered grounding caused by substandard navigation with wind or current from the side.

All above branches are analyzed taking into account human performance, internal and external vigilance, technical failure rates on tankers and tugs, and visibility.

3.9.3 Structural Failure/Foundering

The structural failure/foundering accident frequency model in MARCS applies accident frequency parameters derived from fault tree analysis with calculations of the tanker exposure time to obtain the accident frequency. The total tanker exposure time (number of vessel hours) in any area for a given wind speed category is calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds) and the local wind speed parameters. The structural failure/foundering frequency is obtained by multiplying these vessel exposure times by the structural failure frequency factor for the wind speed category, taking into account PWS specific failure data.

3.9.4 Fire/Explosion Frequency Model

The fire/explosion accident frequency model in MARCS applies the accident frequency parameters derived from the fault tree analysis with calculations of the tanker exposure time to obtain the accident frequency. The total tanker exposure time (number of vessel hours) in any area is calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds). The fire/explosion frequency is then obtained by multiplying these vessel exposure times by the fire/explosion frequency factor. It should be noted that fire/explosion frequency factors are assumed to be independent of environmental conditions outside the ship, and based on IMO casualty statistics.

3.9.5 Drift Grounding

The fault trees are not used for drift grounding, since this accident type is very location dependent and too many fault tree calculations would be required. The MARCS model has the more suitable capability to handle drift groundings.

3.9.6 Human Performance Parameters In Fault Trees

The human error parameters taken into account in the fault trees in connection with collisions and groundings are probabilities related to:

- substandard human performance by officer on watch on tanker;
- officer on watch on tanker being absent;
- officer on watch on tanker being absorbed;
- officer on watch on tanker being injured or ill;
- officer on watch on tanker being asleep;
- officer on watch on tanker being intoxicated;
- failure of internal vigilance due to incapacitation; and
- failure of internal vigilance due to substandard human performance.

The data used for human errors is described in Technical Documentation Part V, Section 5.3 Fault Tree Results.

The parameters used were estimated by a panel of experts based on previous research and studies, mainly from North Sea offshore activities.

The human factors drive the fault tree results for powered grounding and collisions, and therefore an uncertainty analysis was performed to document the importance of these parameters for the results. See Technical Documentation Part IV, Section 4.3.

3.9.7 Fault Tree Terminology

The calculations of frequencies by fault trees are based on common fault tree techniques (Henley, E.J., 1981; Kumamoto, H., 1985; Cooke, R.M., Van Dorp, R., 1996), as presented in References to this Chapter.

3.10 Basis for Computation of Baseline Risk

3.10.1 General System Parameters

The assessment of risk in PWS required the development of a detailed definition of the parameters of the system as it currently operates. The starting point for this development was the system definition (see Technical Documentation Part I). A detailed, verified definition of system parameters was required to establish a common basis for the risk models to ensure that the calculation of base case risk and the evaluations of changes to the base case were comparable. This section contains a detailed definition of system parameters as follows:

1) Section 3.10.2 describes the PWS traffic image: the sailing routes and traffic densities of all vessel types. The traffic image data is contained in Technical Documentation Part I, Section l-3;

2) Section 3.10.3 describes the internal operational and incident data that defines how the PWS tanker calling fleet operates and how appropriate failure rates were determined;

3) Section 3.10.4 describes external operational data--the operations of the USCG Vessel Traffic System and the Alyeska SERVS;

4) Section 3.10.5 describes the sources of environmental data used in the analysis. Summaries of the weather and ice data are included in Technical Documentation Part II; and

5) Section 3.10.6 details the base case traffic rules and procedures established through USCG regulation and/or industry procedures.

3.10.2 Traffic Image Data

Traffic image data is made up of three types: first, there is the geographical definition of routes, traffic lanes and lane widths; second, there are the parameters which describe the traffic; third, there are the transit rules which place restrictions on the traffic flow. The traffic image data is defined for all vessel traffic in PWS: Oil Tankers; Cruise Ships; Ferries; ERVs; Tour Boats; Tows (Barges); "Tethered" Tugs; Fishing Boats; Log Ships or Log Barges, and Cargo Ships. The rules (federal and industry) controlling traffic in PWS are described in Section 3.10.6. Descriptions of the traffic lanes for all vessels other than tankers are included in Technical Documentation Part I, Section 1-3. The vessel speeds and other parameters for each vessel type are specified for each geographical subarea defined by Figure 3.3-1 :

Subarea A: Gulf of Alaska
Subarea B: Cape Hinchinbrook Entrance
Subarea C: Central Prince William Sound
Subarea D: Valdez Arm
Subarea E: Valdez Narrows
Subarea F: Port Valdez
Subarea G: Knowles Head Anchorage

Oil Tankers

Since the PWS Risk Assessment is based on frequencies of all accidents involving tankers, data describing oil tankers is critical. The geographical description of VTS lanes followed by PWS tankers is defined in Technical Documentation Part I, Section 1-3. The vessel speed parameters are shown in Table 3.10.2-1; the base case tanker calling fleet is described in Table 3.10.2-2.

Table 3.10.2-l

TANKER SPEEDS

Subarea	Laden Vessel Speed (knots)	[illegible]
Gulf of Alaska	14	15
Cape Hinchinbrook Entrance	10	15
Central Prince William Sound	10	15
Valdez Arm	10 (6 under ice escort, 8 in vicinity of Buoy 9)	12 (6 under ice escort)
Valdez Narrows	5	12
Port Valdez	10 max., 8 average	12
Knowles Head Anchorage	-	

Source: VERP dated 15 Nov 1995 and updated Apr 1996.

Table 3.10.2-2 PWS TANKER FLEET

Ship Name	Year Built	[illegible]	[illegible]	[illegible]
Eastern Lion	1973	S	269	0
Northern Lion	1974	S	269	0
Southern Lion	1975	S	265	0
Western Lion	1974	S	265	0
ARCO Independence	1977	S	262	23
ARCO Spirit	1977	S	262	19
Mount Cabrite	1971	S	255	0
S/R Long Beach	1987	S	211	20
ARCO Alaska	1979	DB	189	20
ARCO California	1980	DB	189	21
B.T. Alaska	1978	DB	188	25
Denali	1978	DB	188	25
S/R Benicia	1979	S	173	19
S/R North Slope	1979	S	173	19
OMI Columbia	1974/83	S	137	23
Prince William Sound	1975176	DH	124	27
Kenai	1979	DH	123	25
Tonsina	1978	DH	123	28
Overseas Boston	1974/81	S	121	23
ARCO Anchorage	1973	S	120	32
ARCO Fairbanks	1974	S	120	32
ARCO Juneau	1974	S	120	9
Overseas Juneau	1973	S	120	23
Overseas Chicago	1977	DB	91	22
Overseas Ohio	1977	DB	91	23
Overseas Washington	1978	DB	91	0
ARCO Texas	1973/81	S	90	26
Overseas NewYork	1977	DB	90	22
S/R Baton Rouge	1969	S	76	25
S/R Philadelphia	1970	S	76	27
S/R San Francisco	1969	S	76	25
Chevron Mississippi	1972	S	70	30
Overseas Alaska	1970	S	62	30
Chesapeake Trader	1983	DB	51	30
Potomac Trader	1983	DB	51	0

Oil tanker movements are restricted by the imposition of transit rules. Transit rules may be self-imposed by the oil industry or by state or federal regulation. A list of the transit rules defined in PWS is in Section 3.10.6.

The proportion of incoming (unladen) tankers that cannot proceed directly to berth and hence go to anchorage and the proportion of out-going (laden) tankers which cannot pass Hinchinbrook and go to race-tracks are determined from the output of the simulation model.

Cruise Ships

The geographical definition of lanes is given in Section 3.10.6 and shown in Technical Documentation Part I, Section 1-3. The vessel speed parameters are shown in Table 3.10.2-3.

Table 3.10.2-3

ESTIMATED CRUISE SHIP PARAMETERS
(Not Subject to Speed Restrictions)

Subarea	Vessel Speed (knots)
Gulf of Alaska	18
Cape Hinchinbrook Entrance	18
Central Prince William Sound	18
Valdez Arm	12
Valdez Narrows	12
Port Valdez	10
Knowles Head Anchorage	

Escort Response Vessels

The geographical definition of lanes is shown in Technical Documentation Part I, Section 1-3, and the vessel speed parameters are shown in Table 3.10.2-4. (ERVs are not required to enter the Gulf of Alaska except in emergency.)

Table 3.10.2-4

ESCORT RESPONSE VESSEL PARAMETERS

[illegible]	[illegible]	[illegible]
Gulf of Alaska	--	--
Cape Hinchinbrook Entrance	10	13
Central Prince William Sound	10	13
Valdez Arm	10 (6 as ice escort, 8 1 in vicinity of buoy 9)	3
Valdez Narrows	5	13
Port Valdez	10 knots max., 8 avg.	13
Knowles Head Anchorage		

Ferry Ships

The geographical definition of lanes is given in Technical Documentation Part I, Section 1-3, and the vessel speed parameters are shown in Table 3.10.2-5.

Table 3.10.2-5

FERRY SHIP PARAMETERS

Subarea	Vessel Speed (knots)
Gulf of Alaska	15
Cape Hinchinbrook Entrance	15
Central Prince William Sound	15
Valdez Arm	12
Valdez Narrows	12
Port Valdez	8
Knowles Head Anchorage	-

“Tethered” Tugs

The geographical definition of lanes is given in Technical Documentation Part I, Section l-3, and the vessel speed parameters are shown in Table 3.10.2-6. It should be noted that the “Tethered” Tugs are only tethered from Entrance Island through the Narrows and into Valdez Arm (weather permitting) to Buoy 9. They differ from ERVs in that they loiter at Hinchinbrook until the tanker is well offshore. (ERVs are not required to enter the Gulf of Alaska except in emergency.)

Table 3.10.2-6

"TETHERED" TUG PARAMETERS

Subarea	Vessel Speed (knots)
Gulf of Alaska	**10**
Cape Hinchinbrook Entrance	10
Central Prince William Sound	10
Valdez Arm	10 kts (6 in ice, 8 in vicinity of buoy 9)
Valdez Narrows	**5**
Port Valdez	10 kts max.. 8 avg.
Knowles Head Anchorage	

Tour Boats

The geographical definition of lanes is given in Technical Documentation Part I, Section 1-3, and the vessel speed parameters are shown in Table 3.10.2-7.

Table 3.10.2-7

TOUR BOAT PARAMETERS

Subarea	Vessel Speed (knots)
Gulf of Alaska	--
Cape Hinchinbrook Entrance	--
Central Prince William Sound	18
Valdez Arm	15
Valdez Narrows	**9**
Port Valdez	**9**
Knowles Head Anchorage	

Tow Boats (Barge Traffic)

The geographical definition of lanes is given in Technical Documentation Part I, Section l-3, and the vessel speed parameters are shown in Table 3.10.2-8.

Table 3.10.2-8

TOW BOAT PARAMETERS

Subarea	Vessel Speed (knots)
Gulf of Alaska	9
Cape Hinchinbrook Entrance	9
Central Prince William Sound	9
Valdez Arm	9
Valdez Narrows	9
Port Valdez	9
Knowles Head Anchorage	-

Fishing Boats

The geographical definition of fishing boat locations is given in Technical Documentation Part I, Section l-3. The collection of the data used to determine these locations is given in Technical Documentation Part II, Section 2-6.

3.10.3 Internal Operational and Incident Data

Tanker Manning Levels

Internal operational data (how ships are run) is of critical importance to risk.

Manning levels on the bridge relate to internal vigilance (people to see that a critical person is incapacitated) and competence redundancy (second officer to check decisions of navigating officer). Thus a helmsman is an internal vigilance, but not a competency redundancy, whereas a second officer (or pilot) acts as both internal vigilance and competency redundancy. Tankers have two officers on the bridge throughout the transit. A state pilot provides a third officer from the berth to the pilots station.

Tanker Failure Rates

Tanker breakdown (propulsion failure plus steering failure) frequencies and repair times and structural failure incident rates are calculated from data obtained from PWS shippers and other sources as described in Chapter 4.

Fire/Explosions

The expected failure frequency due to fire/explosion is based on worldwide statistics from IMO and Lloyd's. The frequency is calculated for a laden tanker per ship hour.

Structural Failure Accidents

The Base Case structural failure accident rate is defined to be similar to worldwide conditions, i.e., the expected failure frequency due to structural failure is based on worldwide statistics from IMO. Structural failure accidents are defined as those failures serious enough to affect the structural integrity of the vessel and to warrant a repair at the next port of call. The impact of local weather conditions are included. The frequencies are calculated for a laden tanker per ship hour.

3.10.4 External Operational Data

Vessel Traffic Services

VTS may reduce oil transportation risk by providing external vigilance on the PWS system. VTS coverage is at three levels:

- There is radar coverage for all vessels in Zones D, E and F;

- There is ADSS coverage for some vessels (including all tankers) in Zones A to G inclusive;

- VTS coverage in Zone A is restricted to ADSS for tankers. Radio communication is assumed to be not sufficient to count as external vigilance.

Escort/Tethered Tugs

The definition of escort/tethered tugs is an important element of the transit rules defined in Section 3.10.6. An escort tug is defined as a tug that follows the tanker but is not attached to the tanker by either a slack or a hard tether. A tethered tug is defined as a tug made up hard to the stem of the tanker.

Risk modeling uses the following definitions to represent tug escort and tethering :

- The tethered tug is deployed from Entrance Island to Buoy 9 within Zone E (Narrows) and Zone D (Valdez Arm). The tug may not be tethered in the Arm during adverse weather. In other places tugs are not tethered.

- Tugs escort the tanker through Zones B, C, D and F. All tugs used in PWS lie in the performance range 60 to 109 tons bollard pull. Tugs are less than 0.5 mile from the tanker throughout the transit, and are available 99.8 percent of the time (historical data indicates that 0.2 percent of the time the escorts have been diverted to deal with other emergencies in the PWS).

3.10.5 Environment Data

The environment variables used in the modeling are derived from three NOM weather buoys (Potato Point, 46060 and 46061) and the SERVS escort vessel observations (at Seal Rocks, Naked Island and in the Narrows) as defined in Table 3.10.5-l. The actual environment parameters used are presented in Technical Documentation Part II, Section 3-2. Note that the weather observation locations are not consistent with the locations of weather based traffic restrictions defined in Section 3.1 O-6, nor are they consistent with the subareas used for analysis as shown in Figure 3.3-l.

Table 3.10.5-l

WEATHER DATA FOR PWS

Zones	Wind Direction	Wind Speed	Visibility
A	Buoy 46061	Buoy 46061	Seal Rocks
B	Seal Rocks	Seal Rocks	Seal Rocks
C, RaceT	Naked Island	Naked Island	Naked
D	Buoy Potato Pt.	Buoy Potato Pt.	Narrows
E	Buoy Potato Pt.	Buoy Potato Pt.	Narrows
F, Jetty	Narrows	Narrows	Narrows
G	Buoy 46060	Buoy 46060	Naked

Source: SERVS ERV Observations 1990-1995, NOAA Observations June-December 1995.

The detailed location of ice relative to the traffic lanes is taken from the historical data base of observations made by SERVS escort vessels. These reports report ice concentrations in twelve zones in Valdez Arm and in the Central Sound. The reporting zones are shown in Technical Documentation Part I, Section l-3.

3.10.6 Base Case Traffic Rules and Procedures

I. FEDERAL TRAFFIC AND ESCORT RULES (DEFINED BY CFR)

A. CG RULES-ESCORTS (33CFR 168)

Outbound tankers must be escorted by two vessels within a line drawn from Cape Hinchinbrook Light to Seal Rocks Light to a point on Montague Island at 60 14.6"N, 146 59"W and the waters of Montague Strait east of a line between Cape Puget and Cape Cleare (33 CFR 168.40a).

Tankers must be accompanied at all times during transit “positioned relative to the tanker such that timely response to a propulsion or steering failure can be affected” (168.50).

Tankers and escorts "must not exceed a speed beyond which the escort vessels can reasonably be expected to safely bring the tanker under control within the navigational limits of the waterway, taking into consideration ambient sea and weather conditions, surrounding vessel traffic, hazards, and other factors that may reduce the available sea room" (168.50).

Escort vessels must meet performance criteria specified in 168.50.b.

Tanker master must operate the tanker within the performance capabilities of the escort vessels, taking into account speed, sea and weather conditions and other factors.

B. CG RULES PILOTAGE (46 CFR 15)

Federally licensed pilots, holding a state pilotage license, and not a member of the tanker crew are required North of 60 49" (15.8 12).

Tankers must have federally licensed pilot or two licensed officers on the bridge when operating South of 60 49" and in the approaches through Hinchinbrook Entrance. (15.812)

C. CG RULES: TANKERS UNDERWAY IN NAVIGABLE WATERS (33 CFR 164)

Tanker must navigate with at least two licensed deck officers on watch on the bridge, one of whom may be pilot (164.13).

Tanker must have an engineering watch capable of monitoring the propulsion system, communicating with the bridge, and implementing manual control measures immediately when necessary, must be present in main control/machinery space, must be licensed engineer (164.13).

D. CG RULES: TRAFFIC SEPARATION (Originally published in 33 CFR161.383, now Int. Rules)

Separation zone 2,000 yards wide from Hinchinbrook Entrance to Valdez Arm west of Bligh Reef and decrease in width from 2,000 yards to 1,000 yards from the entrance to Valdez Arm to where it terminates at the entrance to the Valdez Narrows Exclusion Zone. Separation Zone is bounded by:

1)	60 58'43"N	146 47'50"W
2)	60 49'47"N	147 02'06"W
3)	60 34'43"N	147 05'16"W
4)	60 17'04"N	146 49'15"W
5)	60 16'56"N	146 46'57"W
6)	60 34'53"N	147 03'14"W
7)	60 49'23"N	147 00'08"W
8)	60 58'26"N	146 47'02"W

Traffic lanes are 1,500 yards wide from Hinchinbrook Entrance to Valdez Arm west of Bligh Reef, and decrease in width from 1,500 yards to 1,000 yards from the entrance of Valdez Arm to Valdez Narrows one-way traffic area. Inbound traffic lane is between Separation Zone and a line connected by:

1)	60 58'09"N	146 46'16"W
2)	60 49'07"N	146 46'16"W
3)	60 35'00"N	147 01'42"W
4)	60 16'49"N	146 45'13"W

Outbound traffic lane is between Separation Zone and line connected by:

1)	60 59'01"N	146 48’37”W
2)	60 50'04"N	147 03'35"W
3)	60 34'36"N	147 06'48"W
4)	60 17'11"N	146 50'59"W

Valdez Narrows Exclusion Zone is from a line bearing 307 degrees true from Rocky Point at 60 57’ 45"N and west of a line bearing 000 degrees true from Entrance Island at 61 05’ 07"W.

The TSS leads into a Safety Fairway at Cape Hinchinbrook. The Safety Fairway is not part of the VTSA. The theoretical inbound lane of the Safety Fairway touches shallow water, laden tankers stay in the outbound theoretical lane.

E. CG COTP RULES: VTS (33CFR 161)

Vessels must report to VTS area Vessel Movement Reporting System (161.2):

- power driven vessels > 40 meters
- towing vessels > 8 meters
- vessels certificated to carry > 50 passengers for hire

Vessels must maintain a listening watch on VTS VHF frequency (CH 13)

Special operating requirements (16 1.13)

- tow on as short a hawser as safety and good seamanship permit.
- not enter or get underway without VTC approval.
- not meet, cross or overtake other VMRS user in the area without VTS approval.
- communicate intentions to other vessel before meeting, crossing, or overtaking.

PWS VTS area is north of a line drawn from Cape Hinchinbrook light to Schooner Rock light, and between 146 20" W and 146 30" W (16 1.60).

Valdez Narrows VTS Special area is from line bearing 307 degrees true from Tongue Point at 61-02'-06"N, 146 40"W; and SW of a line bearing 307 T from Entrance Island light at 61 05'06"N 146 36'42"W.

- No northbound user shall proceed north of 61N, no southbound user will be allowed west of 146 35"W and north of 61 06"N without VTS approval.
- Approval to enter area will not be granted to vessels > 1600 GT or towing vessels > 8 m if a tank vessel > 20,000 DWT is navigating in special area.

VTS reporting points are Cape Hinchinbrook (Northbound only), Schooner Rock (Southbound only), Naked Island, Bligh Reef Light (embark/disembark pilot at 60 49'N) Rocky Point, Entrance Island.

F. CG RULES: ANCHORAGE (33CFRIIO)

Knowles Head Anchorage bounded by 60-40N, 146-40W; south to 60-38N, 146-40W; east to 60-38N, 146-30W; north to 60-39N, 146-30W; NW to start point.

G. CG RULES: ADSS (33 CFR 143)

Tank vessels required to carry automated dependent surveillance system. Vessels with ADSS do not have to make voice radio reports at reporting points except when directed by the VTC.

H. CG RULES: VTS/COTP (VTC MANUAL DTD 10 MARCH 1995, VTS USERS MANUAL)

Participation in system voluntary for vessels not specified by 33 CFR 161; however all vessels operating or at anchor in the VTS area may be required to comply with regulations.

VTC will deny entry into exclusion zone if vessel is experiencing any condition which may impair its navigation or restrict its maneuverability.

When a laden tanker or tank barge over 20,000 DWT is in the Narrows Special Area, other vessels over 1,600 GT and towing vessels greater than 8 meters are not allowed in the zone.

The VTC will manage traffic in Valdez Arm, using traffic routing measures, when traffic congestion exists.

VTC manages Port of Valdez for departures and arrivals of ships > 1,600 DWT. One arrival or one departure at a time is allowed.

Tank vessel more than 20,000 DWT (33CFR165) must:

- have two radiotelephones capable of operating on VTS frequency, one battery operated;
- and have ADSS installed.

Vessels entering the VTSA, including vessels crossing the TSS are required to report 15 minutes prior to entering the VTSA. Inbound vessels are encouraged to report 3 hours before ETA Hinchinbrook; outbound vessels 30 minutes before departure.

Vessels participating in VTS must monitor Channel 16.

VTC exercises control in VTS Narrows Special Area, occasionally control is exercised on outbound laden tankers at Cape Hinchinbrook Entrance when weather is restrictive.

Speed Restrictions in VTS Narrows Special Area:

- Laden Tank vessels >20,000 DWT shall not exceed 10 knots in VTS Special area except 6 knots (speed over the ground) between Middle Rock and Potato Point.
- Unladen tank vessels >20,000 DWT shall not exceed 12 kts.

Ice Rules:

- When ice is reported in the TSS, traffic is routed around ice as appropriate.
- When no safe routing exists, port is closed.

Vessel Escorts and Wind restrictions (see below for more constricting industry restrictions defined by VERP)

- PORT VALDEZ: if winds < 30 kts, tankers may loiter up to 3 hours awaiting berth, if winds are >30 kts vessels are not allowed to loiter.
- Cape Hinchinbrook closure: tankers may steam in TSS, race-track in Orca Bay, or anchor at Knowles Head anchorage. Escorts must remain with tanker.

II. INDUSTRY RULES (Valdez Escort Response Plan (VERP) 15 Nov 1995 as amended April 1996)

A. ESCORT PROCEDURESAND RULES

Laden tankers (inbound or outbound) are escorted by two vessels (one ERV, one tug) between Terminal and a line between Cape Hinchinbrook and Seal Rocks (p. 2-l);

Outbound tankers entering the Narrows remain in maneuvering zone defined in VERP (p. 2-l l/l 2);

All laden tankers use tethered escort between 146 35' and Potato Point (p. 2-l);

Tankers use tethered escorts between Potato Point and Buoy 9 weather permitting (p. 2-l);

When not tethered, escorts are within 1/4 nm of tanker (p. 2-l); and

Escort and closure criteria for Narrows (p. 2-l-b) are shown in Table 3.10.6-l.

Table 3.10.6-l

Wind Speeds	**Tanker<150K DWT**	**Tanker>150K DWT**
Above 40 kts	Closed	Closed
Above 30 to 40 kts	3 escorts: Tethered SEA VOYAGER* tug SEA SWIFT tug ERV	Closed
Above 20 to 30 kts	**2 escorts** tethered tug ERV	**3** escorts: Tethered SEA VOYAGER tug SEA SWIFT tug ERV
Up to 20 kts	**2 escorts:** tethered tug ERV	**2** escorts: Tethered SEA VOYAGER tug ERV

* Tankers under 100K DWT may substitute a STALWART class tug for SEA VOYAGER class.

VERP defined escort equivalents are (p. 9-2):

Escort	**Equivalent**
SEA VOYAGER	GULF BRENT
STALWART	DR JACK/COMMANDER/GULF BRENT
SEA SWIFT	SEA FLYER/PATH FINDER/DR JACK COMMANDER/GULF BRENT
ERV	PIONEER SERVICE/HERITAGE SERVICE/ LIBERTY SERVICE/FREEDOM SERVICE/ CONSTITUTION SERVICE

Performance characteristics and principal dimensions of the charter escort fleet are given in Table 3, page 30 DTTSG Part 1 (reproduced in VERP).

Interim Escort Rules effective January 15, 1996 through March 31, 1996:

- The basic escort requirement increased from two (2) to three (3) vessels, additional escort may be either a tug or an ERV;

- Tugs required due to high winds in the Narrows will be in addition to three (3) escort vessels; tugs will continue to be released when tank vessel is abeam Tongue Point; and

- One escort tug will continue to stand by in the vicinity of Hinchinbrook Entrance until the tanker has proceeded to a position 17 nm from a line drawn between Seal Rocks Light and Cape Hinchinbrook Light.

- Recommended formations for escort vessels are:

    1) In Narrows: tug tethered, escort vessels within 0. lnm off port/starboard quarters; 4th vessel (when required), 0.1 nm aft of tethered tug

2) Arm and Sound: tug tethered or within .25nm aft of tanker. Escort vessels within 0.25 nm off port/starboard quarters

Escort Procedures

- Narrows--tug tethered, ERV directly astern (see above In Narrows).
- Valdez Arm

  1) Tanker masters may request permission to deviate into the Separation Zone when wind conditions are such that this will provide a greater distance off the lee shore and there is no conflicting traffic.

  2) Tethered escort maintained when wind and sea conditions permit.

- Central Sound: Close escort (See above Arm and Sound).
- Hinchinbrook Entrance

  1) Master may request permission to deviate into the Separation Zone when wind conditions are such that this will provide a greater distance off the lee shore.

  2) Close escort: Escort tug stands by in vicinity of Cape Hinchinbrook until outbound laden tankers are 17 nm from a line drawn between Seal Rocks Light and Cape Hinchinbrook Light.

B. *SPEED, MANEUVERING, AND CLOSURE RULES*

Tanker speed restrictions:

Table 3.10.6-2
Tanker Speed Restrictions

Area	Laden	Ballast
Valdez Narrows	5 kts	12 kts
Buoy # 9 area	8 kts	None
Central Sound	10 kts or as requested by escorts	None
Under ice escort	6 kts	6 kts

Closure Conditions

- Hinchinbrook
  1) inbound--none
  2) outbound--winds>45 kts OR seas > 15'
- Narrows and Port Valdez
  1) closed to all tanker traffic winds > 40 kts
  2) inbound--between 30 and 40 kts
     <150,000dwt requires 2 escorts, 1 may be ERV
     >150,000dwt requires 3 escorts, 1 may be ERV

Valdez Narrows Approach Maneuvering Zone: all outbound laden tank vessels will stay within the zone defined by the following points in April 16, 1996 VERP change.

A.	61 05' 27.0 N	146 37' 35.0 W
B.	61 06' 00.0 N	146 36' 50.0 W
C.	61 06' 35.5 N	146 35' 30.0 W
D.	61 06' 35.5 N	146 34' 00.0 W
E.	61 05' 50.0 N	146 34' 00.0 W
F.	61 05' 40.5 N	**146 35' 30.0** W
G.	61 05' 30.5 N	**146 36' 25.0** W
H.	61 05' 15.5 N	146 37' 15.0 W

Ice Navigation Procedures

- PWS VTS has eliminated one-way zone in ice area. VTS will route traffic around ice as appropriate (including movable one-way zones). The port will be closed to tanker traffic if no safe routing exists.
- Outbound tankers use Ice Scout Vessels (ISV) when ice is within 1 mile boundary of TSS during periods of darkness or reduced visibility.
- Inbound tankers will use Ice Scout Vessels (ISV) when ice is within 1 mile boundary of Northbound traffic lane during periods of darkness or reduced visibility or if no report of ice conditions has been received for 6 hours.

III. INDUSTRY RULES (PORT INFORMATION MANUAL)

A. *DOCKING TUGS AND LAUNCHES*

- Alyeska schedules tugs on behalf of all tank vessels calling at the Alyeska terminal.
- Tank vessels must use the following minimum number of docking and undocking tugs unless mutually agreed by the tank vessel Master, the Pilot, and the Terminal Lead Technician:

- Tank vessels of 150,000 DWT or less:	***2*** tugs
- Tank vessels of more than 150,000 DTW:	***3 tugs***

- At least three 7,000 HP twin screw tugs and two 300 HP single screw mooring launches are usually available at the terminal to provide docking and undocking services.
- Undocking tugs are not allowed alongside tank vessels until after the loading arms have been disconnected and secured, all cargo tank openings have been secured, and the oil containment boom has been removed. Mooring lines should not be slackened off until a tank vessel has been advised by the berth operator that the oil containment boom has been secured, the shore side gangway has been removed, and all work boats are clear.

B. SPEED RULES FOR TANKERS APPROACHING BERTH

- Maximum allowable mooring velocities, calculated assuming a 40 percent ballast condition, are specified in Table 3.10.6-3
- Berthing aids such as docking radars or Doppler logs are not available

Table 3.10.6-3

Maximum Allowable Mooring Velocities

Vessel DWT	**Berth 1**	**Berth 3, [illegible]**
85,000	9 in/sec	12 in/sec
120,000	8 in/sec	11 in/sec
265.000	NA	7 in/sec

3.11 Management System Audits and Its Link To The Assessment of Risk

A management audit was carried out on all the Shipping Companies in PWS, both at their head offices and onboard their tankers.

The purpose was to assess the standard of their management systems against a common yardstick. The questionnaire developed for this project is in Technical Documentation Part II.

The management questionnaire developed for the PWS project was extracted from the IMSRS - the International Marine Safety Rating System, jointly developed by the Loss Control Institute in Atlanta, and Det Norske Veritas. (See Technical Documentation Part III.)

The four basic requirements for this extraction process were:

1) Maintaining all ISM requirements;

2) Maintain the applicability of the ISRS/IMSRS process and systematics;

3) Focusing on the specific risk type of concern to the PWS Risk Assessment - accidental spillage of oil into PWS resulting from an accident occurring during the operation of the ship (not resulting from loading operations at the terminal); and

4) Maintain the relative importance between the elements assessed.

The team that developed the tool included the main IMSRS development team, plus the DNV members of the PWS Risk Assessment team. The resulting document was reviewed to ensure it met the main requirements, while still being practical as an audit tool, given the time constraints for the ship-board audit.

The management questionnaire was structured in the following sections (elements):

1) Leadership and Administration
2) Leadership Training
3) Planned Inspections and Maintenance
4) Critical Operations and Task Analysis
5) Accident/Incident Investigation
6) Emergency Preparedness
7) Company Safety Rules and Work Permits
8) Accident/Incident Analysis
9) Knowledge and Skill Training
10) System Evaluation
11) Engineering and Change Management
12) Personal Communications
13) Personnel Recruitment
14) Materials and Services Management

The scores attained from the management audits were used as follows:

- to establish the range of management performance in the PWS tanker fleet, by means of their scores from the audit.

- to relate failure reporting to the standard of the reporting system (elements 5 and 8 in the questionnaire).

- to relate management performance to independently obtained safety indices for the same shipping companies, such as LTIR (Lost Time Injury Rates),

- to use the correlation between management performance (scores) and accident rates (LTIR) as basis for adjustment of other failure rates.

The results of the management audits are provided in sanitized form in Section 4.6.

When management scores for each company were compared with accident rates (LTIR) reported independently for the same companies, a clear reduction in accident rates could be seen for those companies which had better management performance (higher audit scores). See Figure 3.1 l-l.

The correlation between management scores and accident rates is further described in Technical Documentation Part III.

The correlation between management scores and accident rates as shown in Figure 3.1 l-l indicates an approximate factor of 5, or half an order of magnitude, lower accident rates for companies in PWS with the highest management scores compared to those with the lowest scores.

It has been assumed in the risk assessment that accident rates in general, including failure rates, will show a similar reduction with improved management performance.

Hence, different failure rates have been used in the risk assessment for different companies. The failure rates used in MARCS and the Fault Trees for the whole fleet for the Base Case are weighted averages taking into account the failures reported by the companies, the standard of their reporting systems and the mileage of the individual ships. The system simulation calibrates all failure rates against this average and assigns individual failure rates to each vessel based on the results of the expert judgment comparisons described in Chapter 4, Section 4.5.

Figure 3.1 l-2 shows the failure rates used for the Best Case and the Worst Case assuming that all companies had well established management systems or less established management systems respectively.

Management Scores in Percent versus Accident Rates

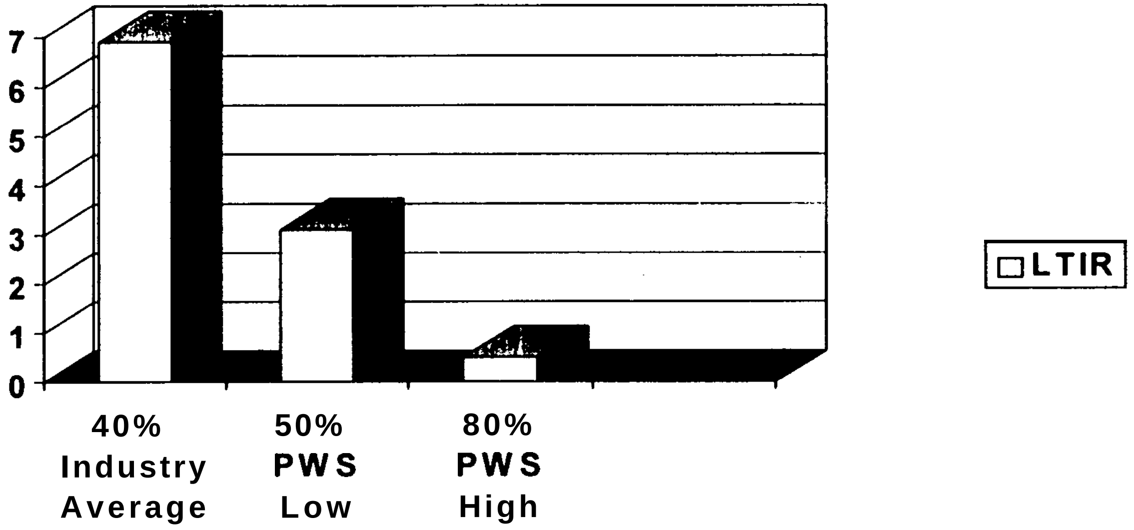

Figure 3.1 l-l

Tanker Failure Rates per Nautical Mile

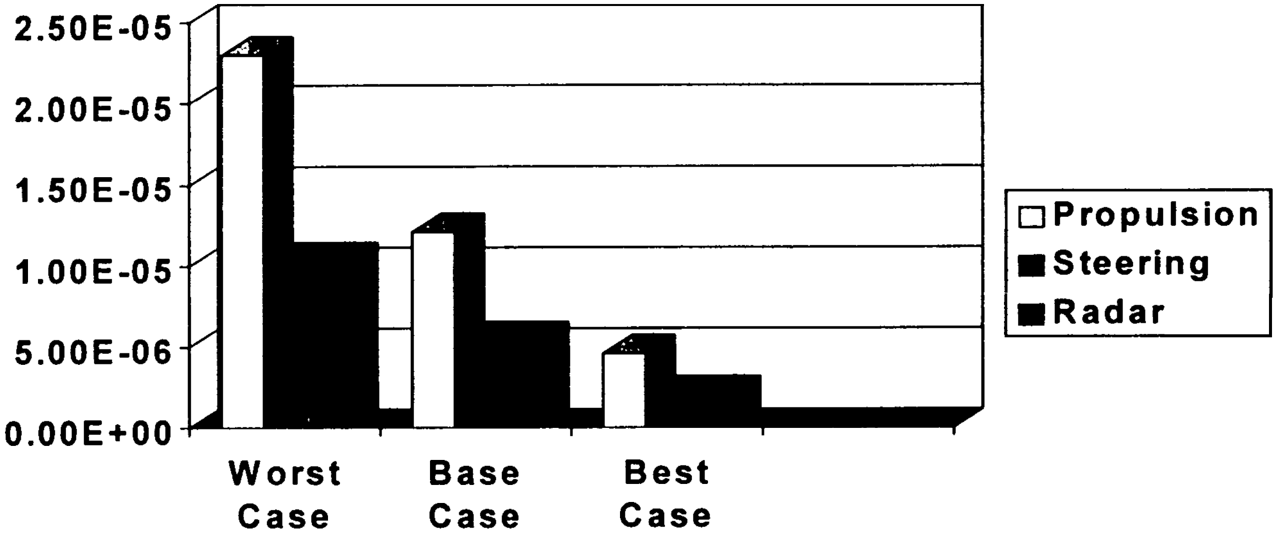

Figure 3.1 l-2

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4.0 Data Gathering Process

4.0 Data Gathering Process

Difficulties with data to support risk analyses in the marine environment have been identified for a variety of agencies over the past decade (National Research Council, 1983; 1990; 1994). Considerable marine safety data are collected under protocols established by the USCG. 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 (National Research Council, 1990a; 1994). 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.

> *Until data designed to support quantitative [risk] assessment are available that could help guide safety initiatives intended to reduce operational risk, such assessments will remain difficult to conduct and will be based on historical data (National Research Council, 1994, p. I 78).*

In most ports and waterways, limited information is available on traffic flows, seasonal variations, daily variations, trouble spots, trouble conditions, problem vessels, commodity flows, effectiveness and utility of navigation support systems such as VTS and onboard 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 used to plan or guide safety programs. The need for improved safety data and systematic performance assessment has been indicated in a variety of National Research Council studies (National Research Council, 1990a; 1991; 1994).

Fully effective administration of safety programs depends on adequate data resources. Without reliable and statistically valid data, safety shortcomings cannot be identified with clarity, and once safety programs are in place, they cannot be evaluated to determine if they are effective and whether resources committed to safety are being used wisely (National Research Council, 1991 a).

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 have been identified in a variety of National Research Council reports; these alternatives include the establishment of near-miss reporting systems, establishment of an exposure data base, and establishment of a comprehensive risk assessment program (National Research Council, 1994).

4.1 Historic Event Data for Prince William Sound

In order to overcome the shortcomings posed by available data sources (as noted above), and in order to supplement available world and nationwide data with local data, an effort to construct an event database for Prince William Sound TAPS tankers was undertaken. The purpose of the effort was to construct a database to provide background and a source of analysis for incidents, accidents, and near-misses which occurred in Prince William Sound, and to TAPS fleet tankers around the world.

The database was to be used to develop failure rates and bounded estimates of events of interest: groundings, collisions, allisions, steering and propulsion failures, electrical and mechanical failures, navigation equipment failures, structural failures, fire, explosion, and other events of interest. Failure rates were determined based on this event database, and propagated in the dynamic simulation model, the MARCS model, and the fault trees.

4.1.1 Data Approach

Because no database of TAPS trade tanker accidents or incidents in Prince William Sound existed, such a database was developed. Where local data was available and reliable, it was utilized. The project contracting team also had access to worldwide and fleet data, which was used for calibration and sensitivity analysis, where appropriate. A mixture of private and public data was used in the construction of the database, and confidentiality of the resulting product was requested by the steering committee. All events in the event database were verified by two independent data sources before inclusion; resolution of open items in the event database in most cases required manual reconciliation of archival data from several sources.

In all cases, where multiple sources of data were available (i.e., failure data, near-miss data, environmental data, fishing fleet data), it was used, and deviations between multiple data sources were reconciled. The use of multiple data sources offered the opportunity for sensitivity analyses on the different data sources to be conducted, in order to address questions posed by the Steering Committee about what difference a particular data set made in the analysis conducted.

4.1.2 Data Uncertainties

There were a number of strengths and weaknesses associated with the data gathering effort for historical incidents and accidents in Prince William Sound. Structurally, the project enjoyed a number of advantages, which assisted the data gathering processes for historical incident and accident data:

- Members of the project's steering committee included all TAPS trade tankers, each of whom agreed to provide confidential failure, incident, and near-miss data.
- Members of the steering committee included most of those affected by TAPS trade oil transportation in Prince William Sound: escort and tug vessel operators, Alyeska/SERVS, the United States Coast Guard, the State of Alaska Department of Environmental Conservation, and the Prince William Sound Regional Citizens' Advisory Council. Participation of the Southwest Alaska Pilots Association, fishermen, TAPS trade operators, SERVS contractors, escort and response vessel operators, and other members of the Prince William Sound oil transportation system was also secured. These organizations also agreed to provide company confidential data to the risk assessment project.
- Finally, unanimous approval for all decisions taken by the Steering Committee was required, which meant that agreements between committee members were (a) hard won, and (b) the collective opinion of the study's Steering Committee.

Given these structural strengths, however, uncertainties in the data exist in several places:

- *The problem of different reporting systems.* In the data collected, shipping companies with mature and stable reporting systems have failure rates higher than those companies with poor reporting systems; thus, accident, incident and near-miss rates are proportionately higher for those companies with fully developed reporting systems vs. those that have not yet implemented these kinds of reporting systems.
- *Not all members of the Prince William Sound oil transportation system participated in the study.* Although all TAPS trade tanker owners and operators participated in the study, as did Alyeska/SERVS, the Southwest Alaska Pilots Association, and fishermen in PWS, several

key participants, who interact with tankers on a daily basis in PWS, did not: ferry operators, passenger vessel operators, tour and recreational boating operators, tug/barge operators, etc. Thus, data reflecting their activities comes from observations of other participants in PWS about their activities, rather than data from the organizations themselves. Although these non-participants did not provide data to the study, they were contacted throughout 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.

- *There does not exist an accessible, independent, reliable source of accident, incident, or near-miss data.* As a consequence, the project contractors constructed an event database describing accidents, incidents, and near-misses which occurred in Prince William Sound or to TAPS trade tankers. The data used in the construction of this database was a mix of publicly available data and company confidential data as described below. Absent a reliable, independent and accessible source of accident, incident, and near-miss data, and given the need for trust in the data (see below), the approach adopted offered one means of providing 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, etc.--complicates data requirements.* Approaches to collecting, assembling, and verifying data in the Prince William Sound risk assessment project in some ways also 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 to support the risk assessment.

Approaches undertaken to address data uncertainties are addressed individually in each section below.

4.1.3 Data Sources

Public references were used to develop the initial event database: the United States Coast Guard's Marine Safety Information System (MSIS), in all variants over the period 1980-1995, was reviewed initially as a source of data. USCG Headquarters provided copies of CASMAIN, MINMOD and pollution data for the periods 1984 -1995. (U.S. Coast Guard, 1992, 1995a). The Captain of the Port, Valdez provided data, graphics, and narratives from the Prince William Sound Vessel Traffic Service (PWS VTS) incident reports, which recorded all incidents, near-misses, or unusual events in Prince William Sound. The PWS VTS Incident Reporting System was inaugurated in 1994; the Captain of the Port (COTP) Valdez provided reports that covered the period 1994-1995. During the period of the risk assessment, USCG Headquarters published the result of its Quality Action Team report *Prevention Through People (U.S.* Coast Guard, 1995b); Appendices H and K of the QAT provided additional event data of use to the database development effort.

The USCG COTP Valdez provided copies of the VTS Quarterly Activities reports dating from 1989-1995, as well as U.S. Coast Guard weather observation data at Cape Hinchinbrook from 1964-1974. VTS Quarterly Activity reports provided information on numbers of vessel transits, any special transits or activities during the quarter, U.S. Coast Guard equipment (i.e., radar) status and downtime, VTS support provided (i.e., for search and rescue, pollution response, etc.), wind restrictions in force, port closures, sea restrictions, casualty data, casualties prevented, and ice routing measures and deviations.

The Coast Guard COTP Valdez also provided the Waterways Analysis and Management System (WAMS) Reports for Prince William Sound for the years 1991-1995. Those reports detailed navigational and waterways management information on a yearly basis, including narrative descriptions of the waterways, its risks and hazards, users of the waterway, traffic patterns, casualty histories, details of charts and surveys conducted on the waterway, and navigational aids. Contained in these WAMS reports were also an analysis and user survey of existing and planned navigational aids, and an assessment of USCG management of the waterway during the previous year. The USCG Marine Safety Office Anchorage also provided a variety of reports and data for inclusion in the database: the Coast Guard's Marine Casualty Report Log, 19851989 (U.S. Coast Guard, 1990), which detailed all events which occurred in Alaska between January 1985 and August 1990, and its port inspection log, which detailed all vessels boarded or scheduled to be boarded for marine inspection, and the reasons for the boarding (i.e., equipment failure, annual survey, etc.).

The U.S. Department of the Interior, Minerals Management Service (MMS) produces on a periodic basis a tanker spill database (Anderson and Lear, 1994) that contains general and specific information about worldwide tanker spills from 1974 onward. The MMS database was surveyed for relevant information, and data from the MMS database entered into the Prince William Sound event database. Another MMS data source, *Shipwrecks of the Alaskan Shelf and Shore (MMS,* 1992) was also surveyed for data relating to shipwrecks in Prince William Sound, or which had occurred in TAPS trade tankers.

Marine Publishing, Inc.'s *Marine Response Bulletin,* a weekly digest of West Coast oil spill prevention and response activities, was surveyed for incidents relating to TAPS trade tankers (i.e., structural failures, steering failures, etc.) and events which occurred in Prince William Sound. *The Bulletin was* begun in 1991, and editions from 1991 to 1995 were surveyed for input to the database.

The Prince William Sound Regional Citizens' Advisory Council (RCAC) provided a copy of a historical analysis of tanker oil spills in Prince William Sound from 1960 - 1993 (Parker, 1993), which provided descriptions and analysis of 63 oil spills occurring over that 33 year period. In addition, the RCAC also provided an internal database of oil spills and incidents kept by the RCAC from 1992 on. In this database, narrative descriptions of events occurring in Prince William Sound and to TAPS fleet tankers anywhere were detailed, including critical incidents or unusual events.

The Alaska Department of Environmental Conservation (ADEC) maintains a database of oil spills in Prince William Sound, a copy of which was provided by ADEC and by RCAC (Alaska Department of Environmental Conservation, 1995). The data contained in the ADEC database include information about spills from 1992 onward: spill date and time, responsible party, location, type of material spilled, cause of the spill, amount spilled, area affected, and a narrative description.

A variety of books and reference material available in the open literature was also reviewed: of the group, one of the most useful was Lethcoe and *Lethcoe's Cruising Guide to Prince William Sound,* Volumes 1 and 2, which contained information about shipwrecks, hazards, incidents and events, both recent and historical, which provided information not available in other sources, to the database. A search of all relevant U.S. National Transportation Safety Board (NTSB) reports, and casualty investigation reports throughout the world (i.e., the Republic of Liberia's Transportation Research Board) was conducted. The Anchorage Public Library, Valdez Public Library, University of Alaska, U.S. Merchant Marine Academy and Maine Maritime Academy's libraries archives, electronic and paper collections, and databases were searched for relevant information. Each of these sources proved worthwhile, either because they proved sources of information not available in other places or because they confirmed information already identified (but not confirmed) for the database. A Lexis/Nexis database search for events or incidents in Prince William Sound, or occurring to TAPS trade tankers was completed, as was a Worldwide Web search of sites, bibliographies, and legal/administrative data.

Private sources were also provided. Alyeska Pipeline Service Company/SERVS provided Ice Scout Listings and Tanker Delay Listings for 1994 and 1995, which were used to provide input for unusual events and ice collisions in the database. In addition, Alyeska provided the Valdez Marine Terminal's 1995 Water Spills Report, which detailed all spills which occurred at the terminal, in the Valdez small boat harbor, or in the port of Valdez. TAPS tanker owners and operators provided proprietary casualty, incident, and event logs and database to the database development effort for the periods 1988 -1995; the information from those databases and logs was critical to the development of a robust and valid database of events in Prince William Sound, or occurring to TAPS tankers. Finally, a variety of private citizens provided personal records and databases of events and incidents which occurred in Prince William Sound, and to TAPS trade tankers. As can be seen by the variety and amount of data produced, the role of private and proprietary company data in the development of the Prince William Sound event database was critical.

4.1.4 Database Structure and Content

The goal for the database was to provide a reliable data source regarding all accidents, incidents or near-misses which had occurred in Prince William Sound or to TAPS trade tankers.

It was anticipated that such a database would have several uses:

- it would provide a basis for assessing patterns of events or incidents in PWS;
- it would provide a common foundation for members of the Risk Assessment project team in determining failure rates for vessels and shipping companies in PWS;
- it would provide a common point of departure for members of the risk assessment project team in providing common input to the different models being used during the study; and
- it would provide informed input to discussions of events or incidents which occurred in PWS, for all members of the Risk Assessment project--contractors, coordinators, and Steering Committee members alike.

The data contained in the database was, by nature, a mix of public and proprietary data, and as such, required special handling and disposition agreements prior to the development of the database. For instance, in return for the agreement of the shipping companies to provide confidential incident and accident data, agreements were required of the project team about the protection and disposition of the database following completion of the project. Moreover, since the goal of the database was to support analysis and input to the risk assessment models, completeness and accuracy of the data were of importance during development.

Information contained in the database included dates and times that events occurred; vessel(s) involved; responsible parties; vessel types; location, including body of water, latitude and longitude; the nature of the event by type (i.e., collision, allision, grounding, etc.), particulars of the event (i.e., lost propeller, which caused difficulties in steering); cause of event (if known); amount of oil spilled, if any; environmental, human, or mechanical causal factors involved; names of the master, chief engineer, and pilot involved; and sources that confirmed the incident. The structure of the database and a data dictionary for the fields contained in the database is provided in Table 4.1- 1.

Implementation of the database required that all data be entered into common electronic form, which required integration of 32 individual databases. Once all data was available electronically, data verification and reconciliation efforts required to complete missing items from the database began. Because not all databases or sources were constructed with the same goals in mind, the information captured and the levels of granularity, the reliability of the root data varied considerably. Once the data was verified for inclusion (requiring two independent sources and manual reconciliation) analysis of the database and sensitivity analysis of the data contained in it was performed.

Table 4.1-1
DATABASE STRUCTURE AND DATA DICTIONARY
PRINCE WILLIAM SOUND EVENT DATABASE

The following are the data fields and their description for all items in the Prince William Sound Event Database.

VESSEL NAME	*The name of the vessel (text, 30 characters)*
EVENT	*Short description of incident occurring (text, 60).*
RESPONSIBLE	*Party responsible for vessel involved in incident (text, 30).*
DATE	*Date of incident (date format mm/dd/yy).*
MCCASE	*MCCASE number (Coast Guard reference number) (text, IO).*
UNIT	*Coast Guard unit where incident occurred (i.e., Valdez) (text, IO)*
TIME	*Time of incident. 24-hour or Military format (date/time format, hh:mm).*
LOCATION	*Location of incident (text, 30).*
CITY	*City where incident occurred (text, 25).*
STATE	*State where incident occurred (text, 4).*
WATER	*Body of water where incident occurred (text, 20).*
LATITUDE	*Latitude of vessel at time of incident (text, 9).*
LONGITUDE	*Longitude of vessel at time of incident (text, 9).*
NATURE	*Nature of incident (collision, allision, grounding...) (text, 30).*
NUMVESSELS	*Number of vessels involved in incident (number, 4).*
SOURCE OF REPORT	*Reporting agency(ies) (text, 7.5).*
DIST	*Coast Guard District within which incident occurred (number, 4).*
MPCASE	*MPCASE (Coast Guard pollution case number reference) (text, 10).*
SPILL AMOUNT	*Amount spilled as a result of incident, in barrels (text, 30) .*
HUMAN FACTORS	*Human factors affecting vessel at time of incident (text, SO).*
VESSEL TYPE	*Tvpe of vessel involved in incident (i.e., tanker, ferry) (text, 50).*
MASTER	*Master in charge of vessel (text, 50).*
PILOT	*Pilot of vessel (text, 50).*
CHIEF ENGINEER	*Chief Engineer of vessel (text, 50).*
COMMENTS	*Comments on incident (text, 30 characters).*

4.1.5 Database Analysis

The Prince William Sound Historical Event database contains information about 604 tanker incidents which have occurred in Prince William Sound, or to Prince William Sound TAPS fleet tankers, since 1975. The database contains information about both incidents (i.e., structural failures, loss of propulsion) and accidents (pollution incidents); this distinction is important in the analysis to be described in this section.

There have been four types of *accidents* which have occurred to TAPS fleet tankers since 1975: pollution instances, groundings, allisions, and collisions with ice. There have been no ship-to-ship collisions between tankers and other vessels since 1975. Accidents not involving tankers also occur in Prince William Sound: collisions between fishing boats, tank barges, and recreational boats; fires on passenger ships and pilot boats; fishing and recreational boats lost; and a variety of groundings. However, these events are not discussed in this section, because the focus of the Prince William Sound Historical Event database was on events involving tankers, and because not all interested parties with non-tanker information were involved in the Risk Assessment. As a result: the database is incomplete with respect to non-tanker events, and non-tanker events were not analyzed. Finally, no near-miss data was available in the system; thus, no near-miss analysis was conducted during the Risk Assessment.

Several *types* of *incidents* have occurred to TAPS trade vessels since 1975: structural failures, navigational aid losses, steering losses, propulsion losses, and equipment failures are the most predominant. Mechanical failures, electrical failures, and steering failures represent the remainder of the incidents recorded in the database which have occurred on TAPS trade tankers.

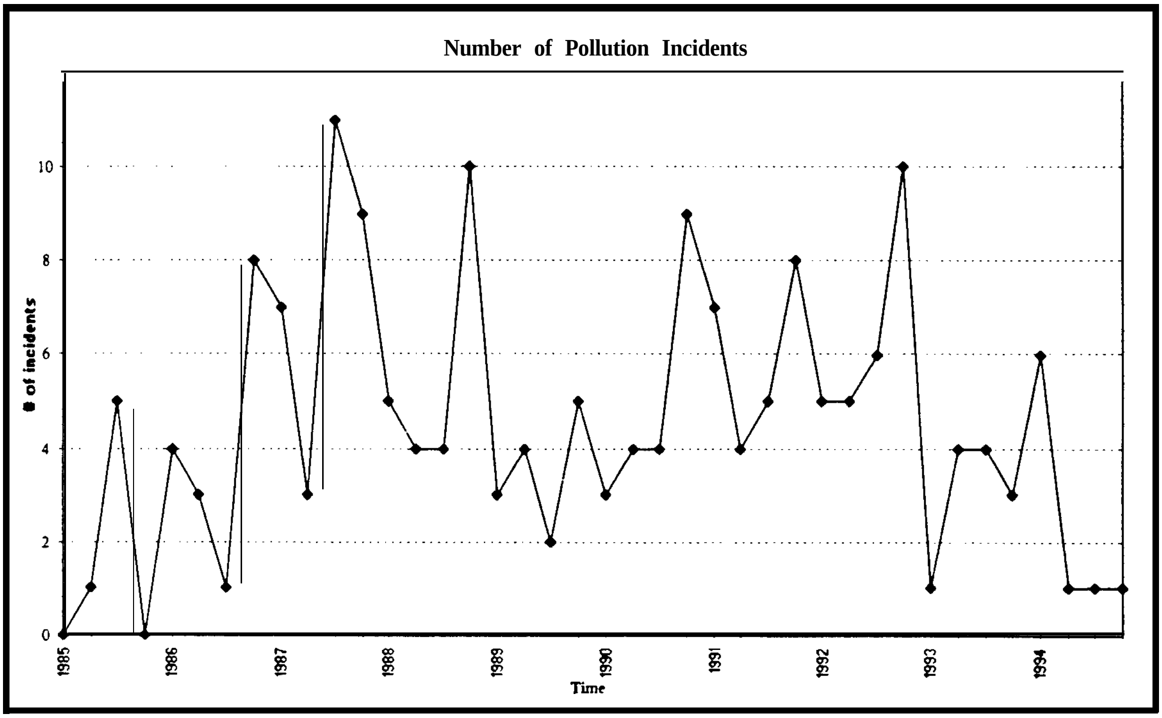
Frequency Analysis of Accidents and Incidents

Most of the accidents that have occurred in Prince William Sound have been pollution incidents: there have been 118 pollution instances in the Sound, two groundings, several allisions, and one ice collision. However, as can be seen in Figure 4.2a, a time series plot of pollution incidents over time, the trend in pollution events is significantly down-down to one event per year since 1994, from a high of 11 events in 1987.

The trend for *incidents* in the Sound, however, is significantly different, and varies by type of incident (structural failure, loss of power, navigation equipment loss, etc.). There have been 82 structural failures on TAPS trade vessels since 1975, and 60 navigational aid losses. As can be seen in Figure 4.2b, the number of structural failures occurring in the system is increasing steadily, and has been since 1993.

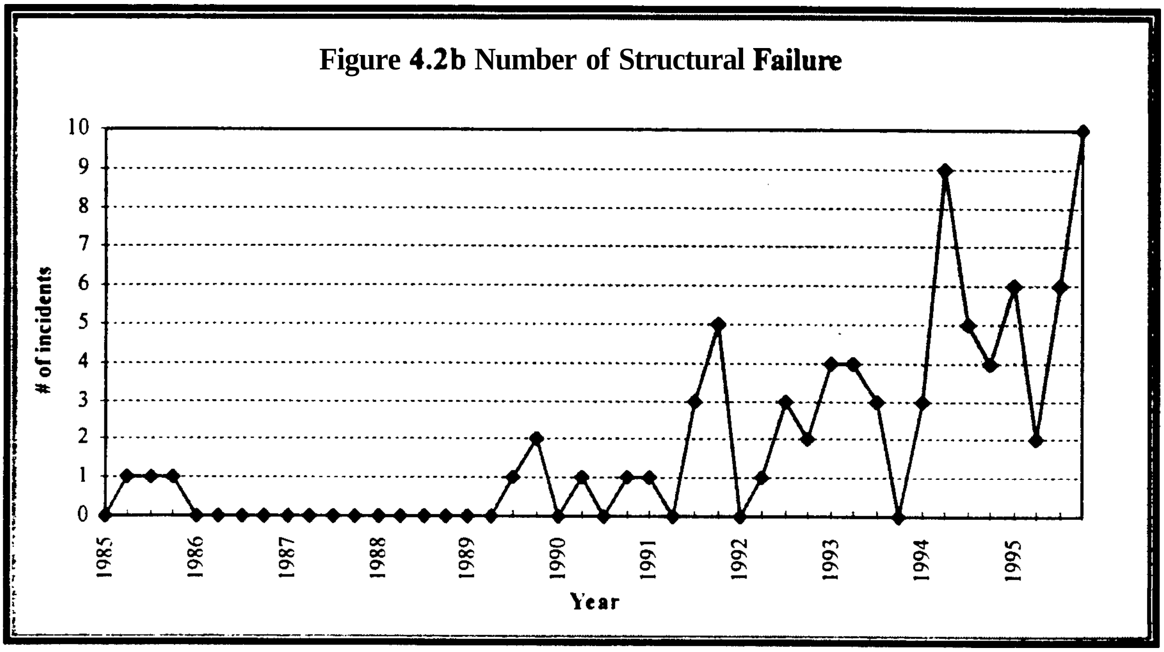
Other incidents in the Sound (propulsion loss, steering loss, and mechanical equipment failures) are also increasing, although at a less precipitous rate (Figure 4.2c).

Numbers of vessel accidents and incidents that have occurred in PWS are illustrated in Figure 4.2d. When numbers of vessel accidents and incidents are normalized over numbers of vessel transits (Figure 4.2e), the trends identified in the frequency analysis are echoed: the fraction of vessel accidents (numbers of accidents/numbers of vessel transits) is declining while the fraction of vessel incidents (numbers of incidents/numbers of vessel transits) is increasing.



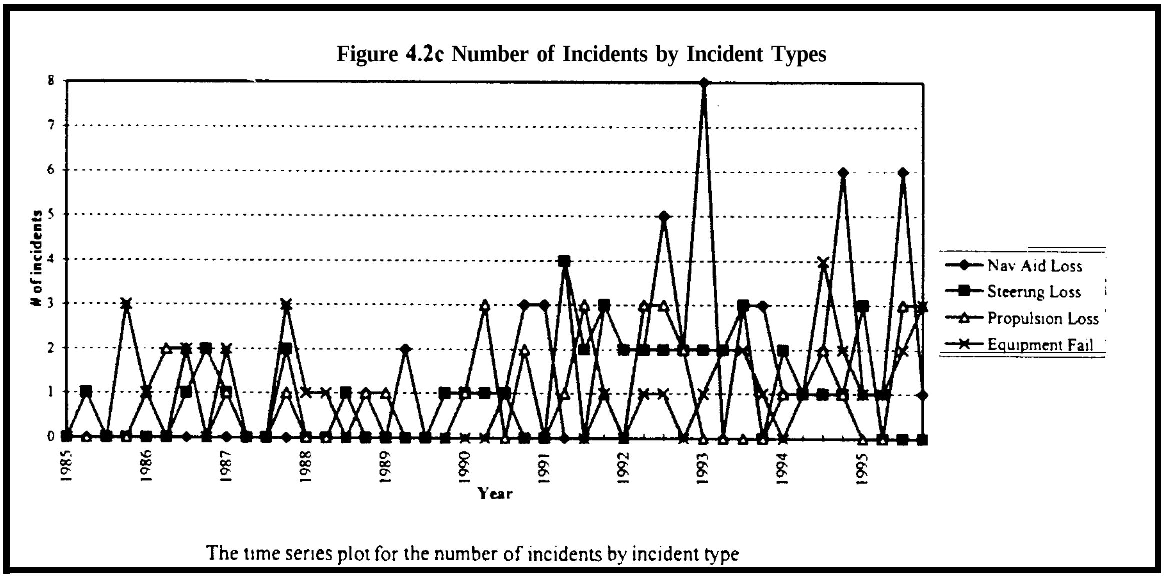
The time series plot for the number of pollution incidents from 1985 to 1996.

Figure 4.2a



The time series plot for the number of structural failures. The number of reported incidents increases after 1991.

Figure 4.2b



The time series plot for the number of incidents by incident type

Figure 4.2c

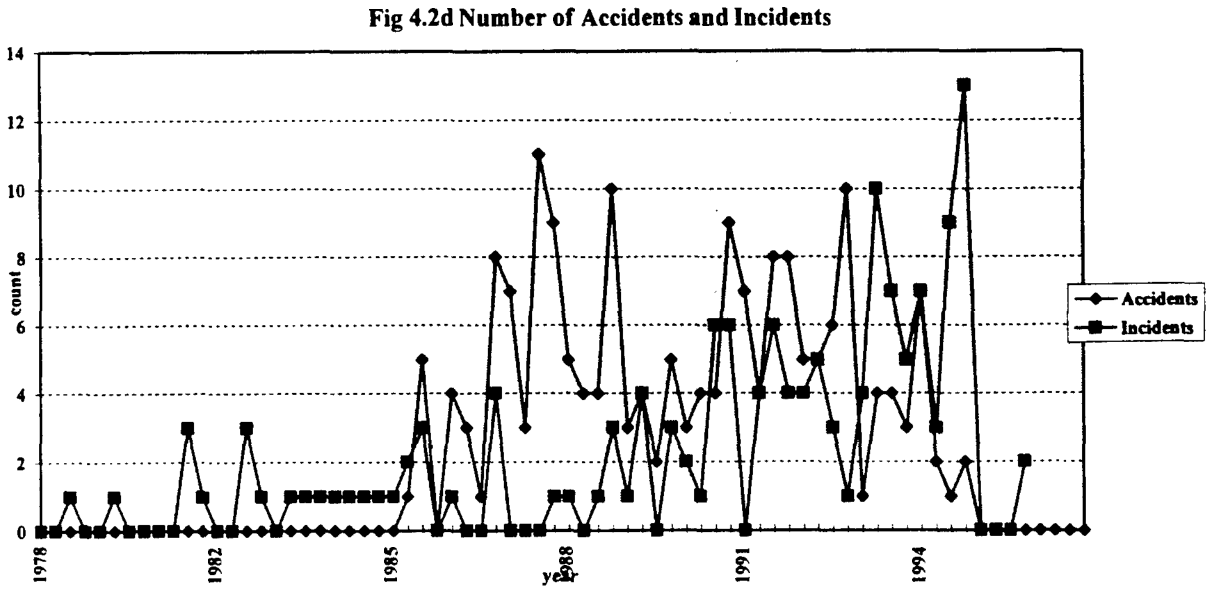


Fig 4.2d Number of Accidents and Incidents

Time series plot for the number of accidents and occurrences. There is no record for any incidents described in the group of accidents until 1984. During time period of 19851994, the number of accidents is relatively stable with some substantial variation. On the other hand incidents are increasing especially after 1990.

Figure 4.2d

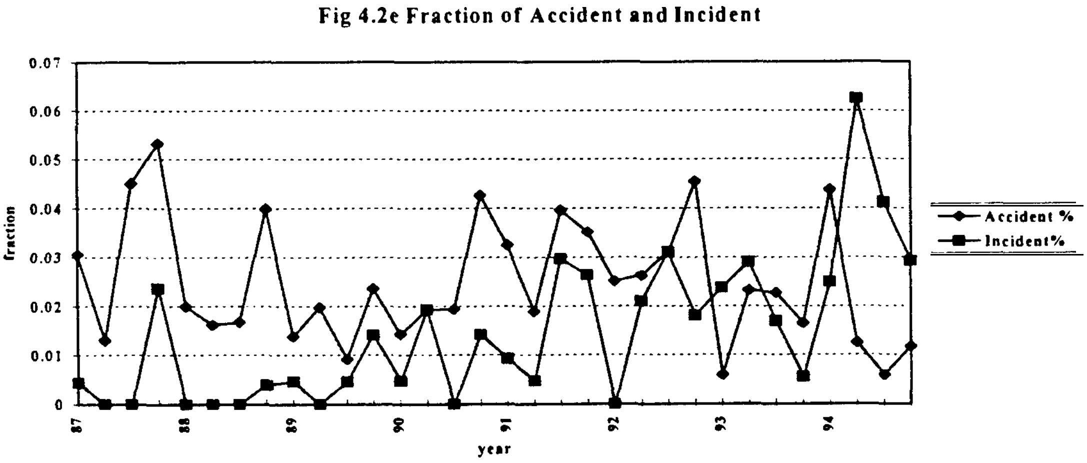


Fig 4.2e Fraction of Accident and Incident

Time series plot of fraction for the group of accident and occurrence.
The fraction is the ratio of the number of accidents / occurrences to the total number of incidents occurred in the particular season in each year.
The fraction of accident is stable with some variation, however, the fraction of occurrence is increasing especially after 1990.

Figure 4.2e

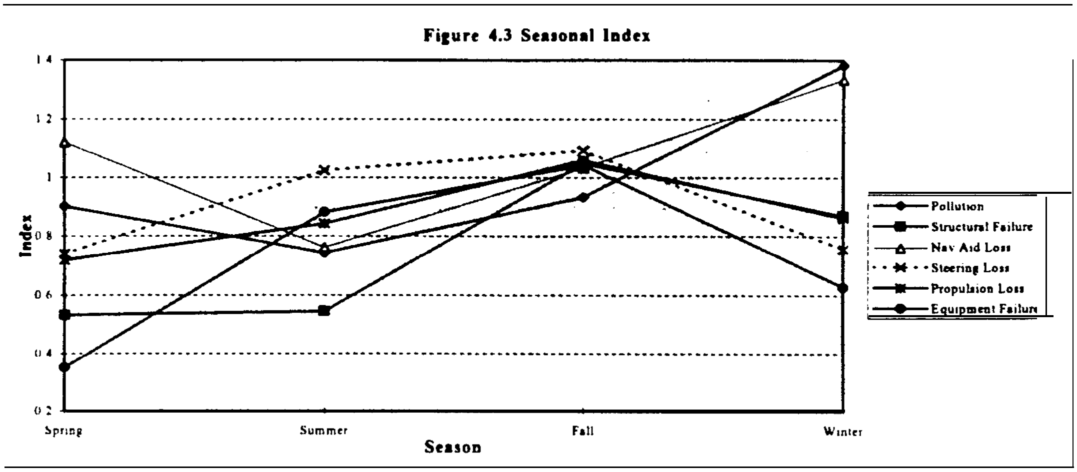


Figure 4.3 Seasonal Index

Seasonal indexes for the principal incident types. For every incident type, the highest index is either winter or fall Usually the seasonal index for summer is relatively low. However, steering loss has high index for summer

Figure 4.3

Seasonal Analysis

Pollution Instances

A time series graph for pollution instances is given in Figure 4.2a. The peak for pollution instances is in the fall of 1987, when 11 pollution instances were reported between October and December. Ten pollution instances were reported in the winter of 1988 and the winter of 1992. After the winter of 1992, pollution instances in Prince William Sound decrease significantly.

A seasonal index analysis was used to examine the seasonal effect of pollution instances. Overall, the highest index for pollution instances is in winter, where a seasonal index of 1.3834 indicates that the number of pollution instances is 38 percent greater in winter compared to other seasons.

Other Types of Incidents

Seasonal indices for the other incident types in the database (structural failures, loss of propulsion, loss of steering, etc.) indicate that winter and fall are the seasons during which most of the other incidents occur, with the exception of steering losses, which occur more frequently in the fall and summer months. The seasonal index for fall has small variance, with values concentrated between 0.93 and 1.10.

The seasonal index for structural failures indicates that fall (1.4860) and winter (1.3834) are the periods during which structural failures have occurred; for navigational aid losses, the seasonal index indicates that winter (1.3345) and spring (1.211) are the periods during which most navigational losses have occurred. Steering losses have occurred slightly more frequently in fall (1.0928) and summer (1.0238) than in other seasons. Finally, like structural failures, propulsion and equipment failures have historically happened slightly more frequently in the fall (seasonal index = 1.0594, 1.0428, respectively).

Analysis of Incidents and Accidents by Vessel

An analysis of the number of accidents and incidents reported by vessel shows that a small number of vessels in the system account for a large percentage of the accidents and incidents in the system. This can be attributed to two reasons: first, different vessels have different propensities to incidents and accidents, and second, several of the vessels with high numbers of reported incidents belong to companies with stable and mature reporting systems (the paradox of good reporters, Section 4.1.2). Thus, accounting for differences in reporting systems among members of the oil transportation system provides important insight as to the numbers of incidents and accidents in Prince William Sound.

Shippers in the PWS oil transportation system have been proactive in monitoring incidents and accidents in the Sound: for instance, during the period from 1975 - 1995, there were twenty-three vessels which had more than seven accidents and five incidents. However, when numbers of miles traveled and numbers of transits made into PWS are taken into account in the accident and incident analysis, the number of significant vessels drops to seventeen. Normalizing the numbers of accidents and incidents by vessel miles between 1985 - 1995 shows that of these seventeen vessels with the highest accident fraction (number of occurrences/number of vessel miles traveled) and/or incident fraction (number of occurrences/ number of vessel miles traveled) rates, ten are out of service, one is being removed from service, and six continue in service.

The analysis of accidents and incidents by vessel also points out the paradox of good reporters: vessels and shipping companies with stable and reliable reporting systems show higher numbers of incidents and accidents. Management audit data assessing the stability and reliability of company reporting systems is thus important in analyses of incidents by vessels and by shipping company.

Analysis by Company

Analysis of accidents and incidents by company shows that several operators have significantly higher average number of accidents and incidents per vessel, and significantly higher incident and accident fractions (percentages of incidents and accidents, normalized over vessel miles traveled, and numbers of transits into PWS made). Using the results of the management audit (Section 3.11), these operators also have the most stable and reliable accident and incident reporting system. Thus, the relatively high number of accidents and incidents recorded by these operators could be seen as reflective of their reporting systems, as well as reflective of their performance with respect to accidents and incidents. Interestingly, when vessel incident fraction numbers are considered (number of accidents/vessel miles traveled, or number of incidents/vessel miles traveled), the operator with the highest percentage of accidents is the operator with the lowest rated management reporting system.

Summary

The historical patterns for accidents (pollution incidents, groundings, collisions, allisions, etc.) and incidents (structural failure, propulsion loss, navigational aid loss, etc.) are different, based on the analysis performed. The frequency of occurrence of the most prevalent accident type (pollution incidents) has declined precipitously since 1993, and is expected to decline in the future. In contrast, the frequency of occurrence of the most frequent incident type (structural failure) is rising, as is the frequency of occurrence of the remaining incident types (navigational aid loss, steering loss, propulsion failure, and mechanical equipment failure).

These results point out the importance of considering risk reduction measures which interrupt the causal chain of errors before the occurrence of an accident (i.e., decreasing the impact of human and organizational error, increasing vessel and human reliability). As indicated by the historical analysis, these interruptions are currently occurring, as evidenced by the small number of accidents in the system, and the decline in those numbers in recent years. However, without the proper attention to risk reduction measures which interrupt the error chain at the incident stage (vs. the accident stage, or later), the numbers of accidents in the system may increase, as the rising numbers of incidents in the system begin to overwhelm the safeguards currently in place to trap errors. The historical analysis of accidents and incidents in Prince William Sound thus not only provides a view of accident and incident performance of the system, it also provides clues as to what system performance might be in the future, and suggests where risk reduction measures might best be focused in order to account for trends and changes in the system.

The historical seasonal analysis underscores the importance of providing risk reduction measures in a timely fashion. Since fall and winter are historically the times of the year when the greatest number of accidents and incidents occur, the timeliness of advice with respect to risk reduction measures is important. Moreover, the historical analysis confirms popular folklore in the Prince William Sound oil transportation system, which has long suggested that most accidents and incidents occur in the fall and winter months. The higher incidence of steering casualties in the summer months is not explained, even when the steering failures are normalized over vessel miles traveled (which would be higher in the summer months, when traffic is heavier).

As is often the case, risk has a face in the Prince William Sound oil transportation system. The historical analysis of accidents and incidents in the system with respect to vessels and companies points out what that face is. However, the vessel and company analysis points out two points important to this analysis: the paradox of the good reporters (whose accident and incident performance appears worse than other vessels and operators in the system because of the maturity and stability of their reporting systems), and the steady withdrawal from the system of vessels and companies whose accident and incident performance is not consistent with performance of most of the operators in the system.

The operators with the greatest numbers and percentages of accidents and incidents in Prince William Sound are also the operators with the most reliable and stable accident and incident reporting systems. The performance of these operators might appear to be less than optimal, when in fact, their performance numbers might also be reflective of the status of their reporting systems. Operators and vessels with less stable and reliable reporting systems, and with unsatisfactory accident and incident performance records, may well be dissuaded from participation in the Prince William Sound oil transportation system. The evolution of reporting system and safety performance expectations in the system may thus prove a deterrent to new entrants without equivalent safety and reporting records.

4.2 Worldwide Tanker Casualty Data

Casualty data can be obtained for the world fleet of tankers from Lloyd's Casualty Reports in London, and the best available tanker casualty data was produced by IMO in 1987 covering the period 1972-1986. This mainly covers serious casualties, involving total loss or casualties rendering the ship unseaworthy. Oil Tanker Casualty Rates from this report showing serious casualties are shown below in Table 4.2-l.

Table 4.2-l

Oil Tanker Casualty Rates

Casualty Category	Casualty Rate Per 10^3 Vessel Years
Foundering	0.3
Grounding	4.3
Impact	1.7
Collision	3.3
Fire/Explosion	5.8

The most important categories of serious casualties are groundings, collisions and fires/explosions.

Further, the worldwide casualty data shows that minor casualties which do not disable the ship (i.e., dented plates, bent guardrails, cabin fires, scrapes on the bottom, etc.) are highest for groundings and collisions. See Table 4.2-2.

Table 4.2-2

Oil Tanker Casualty Rates

Casualty Category	[illegible]
Foundering	0
Grounding	10.5
Impact	8.3
Collision	18.6
Fire/Explosion	3.5

Comparison of serious casualties in Table 4.2-l and minor casualties in Table 4.2-2 shows that:

- founderings as defined are always a serious casualty, although they rarely occur;
- fires and explosions, once such accidents occur, are likely to be serious casualties, although their frequencies of occurrence are lower than for collisions and groundings; and
- groundings, collisions and impacts (allisions) are more often reported as minor casualties than as serious casualties, and their frequencies of occurrence are higher than for fires and explosions.

For the PWS Risk Assessment, the casualty data for founderings, fires and explosions from IMO have been used as input to the analysis of these accident types. This is because casualty data for fire, explosion and foundering can be said to be generic to tankers, and not normally dependent on situational factors such as traffic density, sea room, weather, etc.

Accident types such as groundings, collisions and impacts are, however, dependent on situational factors, and worldwide casualty data are therefore of limited value for assessment of these accident types. In the PWS Risk Assessment, these accidents have been calculated taking into account the situational factors prevailing in the PWS using PWS-specific data as described in Chapter 4, to the extent this could be modeled and assessed with the different methods and tools, as described in Chapter 3.

Worldwide data were therefore not utilized for collisions and groundings in the PWS Risk Assessment. These accident frequencies were calculated based on PWS-specific data for initiating events such as propulsion failures, steering failures, radar failures, traffic picture, etc. Worldwide data is not available for such initiating events, and data had to be obtained as described in Section 4.4.

4.3 Shipping Company Background, Training and Crewing Questionnaire

During the System Requirements phase of the Risk Assessment project, a System Description (Grabowski, 1996) was developed in order to describe the system being modeled during the risk assessment project. The System Description depicted the key components, attributes, relationships, and environment in the Prince William Sound oil transportation system, and provided required background for the subsequent phases of the Risk Assessment project, the modeling and simulation tasks.

As one of the tasks of the System Requirements phase, a questionnaire was administered by the Prince William Sound Risk Assessment project team in the fall of 1995 to the TAPS tanker companies (see Technical Documentation Part II). The questionnaire asked questions about the ages of TAPS and non-TAPS vessel crews; the length of time crews spent aboard TAPS vessels, in the Alaska trade, and in their particular sailing billet; as well as the percentage of those officers sailing beneath their highest license held. In addition, the questionnaire requested information about the nationality and organizational affiliations (union, non-union, company union) of TAPS and non-TAPS tanker crews, crew work rotations, continuity aboard vessels, vacation schedules, training requirements and schedules for crews, work hours limitations and requirements, and the impacts of changes in these variables on vessel crews. The responses to the questionnaire were summarized in the System Description (see Technical Documentation Part II).

4.3.1 Data Analysis

Questionnaires were provided to all 10 crude oil tanker companies operating in PWS, to all tug/barge operators, to one ferry operator, and to all passenger vessel companies operating in Prince William Sound. Of those, eight tanker companies responded (Chevron, ARCO, SeaRiver, Interocean Management, Keystone Shipping, Maritime Overseas Corporation, Marine Transport Lines, and Penn-Attransco Corporation). Of the TAPS tanker companies, three organizations operate company-owned vessels (ARCO, Chevron, and SeaRiver); the remainder are charter operators to BP in the TAPS trade. Two tug/barge operators replied (Crowley and Petro Marine). as did the ferry operator (the Alaska Marine Highway System), and one passenger vessel operator (Regency Lines). Of the 55 questionnaires mailed out, 12 responses were returned. Where numerical analysis was possible (i.e., there was sufficient response to the questionnaires), those results are provided. Where such data was not available (primarily due to the sparseness of responses to questionnaires administered to non-TAPS personnel), summary narrative information is provided.

Vessel crews aboard TAPS fleet vessels are relatively homogeneous: based on survey results gathered during September 1995, the average age of TAPS fleet vessel masters is 47; of chief engineers, 43; of mates (other than masters), 37; and of unlicensed personnel, 41. TAPS fleet officers have, on average, 8 years' service on the vessel they are on; two operators are notable exceptions to this average, with officers having, on average, over 20 years' service on their vessels. Thus, TAPS fleet crews have substantial periods of service on their vessels, in Alaska, and in the billets in which they are currently sailing. Overall, TAPS fleet masters have been sailing as masters for an average of 7 years; mates have been sailing as mates, on average, for 4.8 years, and unlicensed personnel have been sailing in unlicensed billets for an average of 12 years (Grabowski, 1996). On average, 65 percent of TAPS fleet licensed personnel are sailing below their highest license held; two notable exceptions to the average include two operators whose percentages of licensed personnel sailing below their highest license held are 79 percent and 90 percent, respectively.

TAPS vessel crews are a mix of company employees, union and non-union personnel. For some TAPS fleet operators, senior officers are permanent company employees, while junior officers come through union hiring halls; in other cases, all officers are company employees, with some belonging to an independent or national maritime union. TAPS vessel unlicensed crews reflect the same patterns: some unlicensed crew members are permanent company personnel; some are members of an independent union, a national maritime union, or neither. TAPS vessel crews are all U.S. nationals, with the exception of some of the foreign flag vessels, which have multinational crews. Most TAPS vessel crews have strong continuity aboard their vessels, and in the Alaskan oil trade. Independent union officers and unlicensed crews exhibit the highest vessel and company continuity, closely followed by national union officers, and unlicensed crew members.

Vessel crew rotations vary from senior officers, to junior officers, to unlicensed personnel. A mix of rotation and vacation schedules exists among the TAPS vessel crews, with some officers earning day for day vacations (i.e., 60 days on, 60 days off), and others with slightly less than day for day vacation schedules. In general, TAPS officers work on a 60 days on, 60 days off schedule; variants exist in the system, and officers generally have some latitude in fixing their work schedule--from those with very little control over their work schedule to those who have a great deal of flexibility arranging their work schedules. Unlicensed personnel work schedules on TAPS fleet vessels are generally 2 for 1 vacation schedules (i.e., 120 days on, 60 days off; 75 days on, 50 days off; or 60 days on, 42 days off), and crew members generally have less flexibility in arranging their work schedules. For officer and unlicensed national maritime union members, work rotations and work schedules are set by the union and are a function of vessels available to ship out on.

Training is required for most officers and unlicensed personnel in the TAPS fleet; for officers that are company employees, companies usually pay for training, and training (aside from that required for licensing) is often required for advancement and promotion. For crew members that are national maritime union members, the company pays for training through the union; unlicensed company personnel are trained in in-house and outside courses, in general, are paid for by the company. Officers and crew members are most often trained in off-duty or vacation periods; in addition to off-duty training, some onboard training occurs on TAPS fleet vessels. A variety of courses are offered and taken by TAPS fleet personnel: some of the courses are required for license maintenance or upgrade; others are required certifications (i.e., FCC radiotelephone, radar, firefighting, cardiopulmonary resuscitation). Still others represent courses above those of general maritime interests: most operators are sending their officers to bridge resource management (BRM) training. One operator sends crews as a team from vessels, including local pilots, to bridge resource management training. Almost all TAPS fleet owners or operators are pursuing ISM certification; some owners and operators are currently IS0 9000 and ISM certified.

There is a paucity of similar data for non TAPS fleet vessel crews. Although some respondents to the Risk Assessment project questionnaire provided such data for non TAPS fleet crews. Non TAPS fleet vessel personnel have slightly less service aboard their vessels, in the Alaska trade, and in their billets; among the non TAPS fleet crews, crew members are about the same ages: but have between 2 and 5 years' service in Alaska, on their vessels, and in their billets. Non TAPS trade vessel personnel can be of different nationalities, particularly on passenger vessels, where the numbers and types of nationalities and languages represented on those vessels is varied. In contrast to TAPS vessel officers, where a substantial percentage of officers are sailing beneath their license, fewer (about 20 percent) non TAPS fleet vessel crews are sailing below their highest licenses held, indicating that TAPS vessel crews hold higher licenses and are perhaps more experienced than crews aboard non TAPS vessels.

Non TAPS vessel crews are also a mix of independent union and company employees, national maritime union, and other personnel. Some non TAPS fleet operators have senior officers who are permanent company employees, while junior officers come through union hiring halls; in other cases, all officers are company employees, with some belonging to an independent or national maritime union. Non TAPS vessel crews reflect the same patterns: some unlicensed crew members are permanent company personnel; some members of an independent union, a national maritime union, or neither.

For non TAPS vessel crews, crew rotations vary from senior officers, to junior officers, to unlicensed personnel. A mix of rotation and vacation schedules exists among the non TAPS vessel crews, with some officers earning day for day vacations (i.e., 60 days on, 60 days off), and others with slightly less than day for day vacation schedules. For non TAPS vessel crews, officers generally have more freedom in fixing their work schedule, while unlicensed personnel typically have little control over their work schedules.

Training is required for most officers and unlicensed personnel in the non TAPS fleet; for officers that are company employees, companies usually pay for training, and training (aside from that required for licensing) can be required for advancement and promotion. For crew members that are union members, the company pays for training through the union; unlicensed company personnel are trained in-house and outside courses, in general, are paid for by the company. Officers and crew members are most often trained in off-duty or vacation periods; no onboard training was indicated for non TAPS vessel crews. A variety of courses are taken by non TAPS fleet personnel: some of the courses are required for license maintenance or upgrade; others are required certifications (i.e., FCC radiotelephone, radar, firefighting, cardiopulmonary resuscitation). Still others represent courses above those of general maritime interests, including bridge resource management (BRM) training. Some non TAPS fleet owners or operators are pursuing IS0 9000 certification; others are developing their own in-house safety measurement and training programs.

Most TAPS fleet (and worldwide) owners and operators are shrinking numbers of billets in the fleet, with several effects:

- the average experience of a TAPS crewmember, licensed or unlicensed, is relatively high;
- as with other U.S. seamen, TAPS crew members are concerned about retention and loss of jobs, which impacts morale (although this varies among operators);
- competition for new jobs and ‘step up’ promotions is keen; and
- entry level jobs for officers and unlicensed personnel are limited, and can be populated with highly- and overly-qualified personnel (despite the fact that most shipping organizations have abandoned earlier policies of hiring licensed personnel to till unlicensed billets).

4.4 TAPS Tanker Fleet Failure Data

TAPS tanker fleet failure information was also gathered from the PWS shipping companies. In general: events of interest can be characterized in the following ways (See Figure 6.1.2):

Stage 1: Basic/Root Causes
Stage 2: Immediate Causes
Stage 3: Incidents
Stage 4: Accidents
Stage 5: Consequences
Stage 6: Impacts

The failure data obtained from the PWS shipping companies was related to Stage 3: Incidents and Stage 4: Accidents. This data was used to determine the rates (frequency of occurrence) of incidents which under certain circumstances might lead to an accident. This data was also used to cross-check the historical data in the PWS event database described in Section 4.1.

The selection of incidents for the survey was based on the Hazard identification exercise, (see Section 3.2) and included the following incidents and accidents:

- Loss of Propulsion (incident)
- Loss of Steering (incident)
- Loss of Navigational Aids (incident)
- Structural Failures (incident)
- Impact/Allision with Berth at Terminal (accident)
- Ship Collision with ice in Prince William Sound (accident)

The survey covered all tankers active in the oil trade, for all vessel miles traveled over the last five years. The questionnaire forms are provided in Technical Documentation Part II.

For Propulsion Failures the following information was recorded:

- Diesel or steam engine
- Cause of propulsion loss
- Time to restore propulsion (self repair time)
- Whether or not the incident led to an accident

For Steering Failures the following information was recorded:

- Cause of steering loss
- Time to restore steering function
- Whether or not the incident led to an accident
- Did hard-over rudder ever occur

For Navigational Aids the following information was recorded:

- Type of equipment which failed
- Cause of failure
- Was back-up system working
- Time to restore failed equipment

For Structural Failures the following information was recorded:

- When ship was built
- Types and number of failures
- Did failure occur in laden or ballast condition
- Did shell plates crack all through

- Was there an oil leak, and how much
- Could the occurrence of structural failures be related to bad weather/sea state

For Allision with berth in Valdez Port the following information was recorded:

- Description of damage to ship, if any
- Description of damage to berth, if any

The results of the survey were verified against other data sources, as seen in Section 4.1, and were used for calculation of failure rates.

It was also considered necessary to assess the quality of the failure reporting system of each shipping company. This was done by means of the management system audit, described in Sections 3.11 and 4.6. Elements 5 (accident/incident reporting investigation) and 8 (accident/incident analysis) of the audit contained a series of questions related to reporting of failures. The scores on these elements corresponded with other scores and accident rates to indicate some companies had more reliable failure reporting systems than others.

The failure rates calculated for the Risk Assessment were based on the companies considered to have well-defined and well-established failure reporting systems.

The failure rates used (base case) were as shown in Table 4.4-l.

Table 4.4-l
Failure Rates For PWS Tankers Used For Base Case

Incident Type	Number Of Failures Per Ship, Per Nautical Mile
Loss of Propulsion	1.21 E-05
Loss of Steering	5.4 E-06
Radar Failure	5.4 E-06
Structural Failure	1.14 E-05

4.5 Expert Questionnaires

Expert judgment was used in the systems simulation to determine the probability of situations resulting in vessel incidents or accidents. The expert judgment questionnaires were developed in a way that experts could visualize and answer the question and so that the responses could be quantified for subsequent use. Section 3.7 covers attribute definitions and discretization. The goal of discretitizing exercise was to describe the risk in the PWS in a workable set of well defined attributes that could be adapted to expert judgment paired comparison questionnaires.

4.5.1 Development of Expert Questionnaires

The development of the expert questionnaires was an interactive process. An initial set of primary questionnaires (Questionnaires 1 through 4) was developed to establish the appropriateness of the attributes, the discretization levels of attributes, to identify significant interactions between attributes, and to determine the stamina of the experts answering the questionnaires. A limitation of the study was the number of questions that could be asked of the experts in any given interview session. The questionnaires were broken into several separate booklets. Each booklet took between 45 minutes to over 2 hours to till out. Prior to actually filling out the questionnaire, 15 minutes of background information about the project and typically 20 minutes of instruction were given. Thus, the average interview session was 2 hours total. The questions in the booklets were grouped so one class of expert could answer all the questions in that particular booklet. The logical grouping of the questionnaires is shown below. The acronyms VOE|VA (Vessel Operational Error given Vessel Attributes), VRF|VA (Vessel Reliability Failures Given Vessel Attributes, Accident|WA,VRF (Accidents given Waterway Attributes and a Vessel Reliability Failure), and Accident|WA, VOE (Accident given Waterway Attributes and Vessel Operational Errors) were introduced earlier, in Section 3.

Primary Expert Judgment Questionnaires

lab - Relative Probability, Vessel Operational Error Given Vessel Attributes	$PR(VOE_j \vert VA_k)$
2 - Relative Probability, Vessel Reliability Failure Given Vessel Attributes	$PR(VRF_j \vert VA_k)$
3 - Relative Probability of an Accident Given Waterway Attributes and VRF	$PR(Accident_m \vert WA_L, VRF_j)$
3b - Relative Probability of Collision Given Waterway Attributes	$PR(Accident_m \vert$ WA,)
4ab -Relative Probability of Accident Given Waterway Attributes and VOE	$PR(Accident_m \vert WA_L, VOE_j)$

4.5.2 Expert Types Responding to Questionnaires

A matrix showing types of expert respondents is shown in the following table. Only people with a deep and current knowledge of the situations being posed were given particular questionnaires. For example, the experts answering questionnaire 2 were primarily TAPS trade chief engineers working in the TAPS fleet. When a motivational bias was thought to be present, as in questionnaire 1, where we were essentially asking how many human errors occurred on different types of tankers, groups indifferent to the bias (for example, pilots) were favored over competing segments of oil industry personnel.

	Total Number of Respondents	Pilots	Oil industry	Local	SERVS	Coast Guard
Initial Surveys	24	0	4	2	13	5
Questionnaire 1	13	11	2	0	0	0
Questionnaire 2	23	0	20	3	0	0
Questionnaire 3	24	0	16	8	0	0
Questionnaire 3b	11	1	2	8	0	0
Questionnaire 4a	23	0	23	0	0	0
Questionnaire 4b	23	0	23	0	0	0
Questionnaire 5	12	5	6	2	0	0
Questionnaire 6	9	5	3	1	0	0
Total	162	22	99	24	13	5

Gathering the expert judgment using the questionnaires required over two man months of actual interview time with experts. The support for the questionnaire process was evident in all groups participating even though the questionnaires were at times difficult and tedious.

The results of each subgroup were plotted graphically to show if significant differences in the judgments of experts were present in the responses and none were present. In fact, the degree of agreement between different groups in the maritime industry can only be described as remarkable.

The elicitations were performed in several ways. Oil company personnel were given questionnaires (usually one or two at a time) on vessels or in large groups of 6 to 22 experts in centralized areas stateside. SERVS personnel were given the questionnaires in groups of three on their vessels. Pilots went through the sessions in the pilot house in Valdez. The pilots usually took the questions by themselves or in groups of two. Local professionals, including USCG personnel, usually took the questionnaires in their offices or place of business, with the exception of the Cordova Fishermen, who had seven participants receive a session similar to the centralized oil company elicitation sessions in their union hall. In all cases, the confidentiality of the experts was guaranteed and the experts received an explanation of how the information was going to be used in the project. Names were never recorded and in some instances, when the sample was small, not even group affiliations were recorded.

4.53 Format of Primary Questionnaires

The graphic on the following page shows the format of the primary questionnaires. This is an actual question from questionnaire 3. In the graphic two similar scenarios are described. On the left is a situation where an inbound tanker greater than 150,000 DWT has just had a propulsion failure and is within 2 to 10 miles of a tug with tow in winds over 45 mph blowing onshore to the closest shore point with visibility greater than half a mile in Central Prince William Sound. The situation on the left includes an iceberg of bergy bit size or larger and on the right the iceberg is omitted. The question being asked of the expert is which situation (the one on the right, or the left) is more likely to result in a collision. In each question, only one attribute is changed to make the differences in the questions more accessible to the experts.

Scenario Example Questionnaire 3
(Prob of Collison|Waterway Attributes and Propulsion Failure)

Given a Propulsion Failure

Traffic Type: Tug with Tow

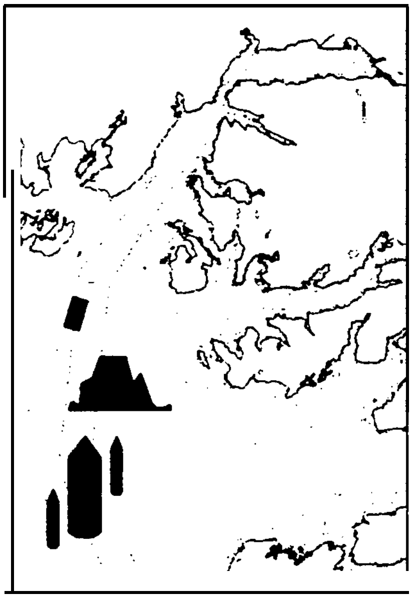
Traffic Proximity: Vessels 2 to 10 Miles

Tanker Size & Direction: Inbound more than 150 DWT

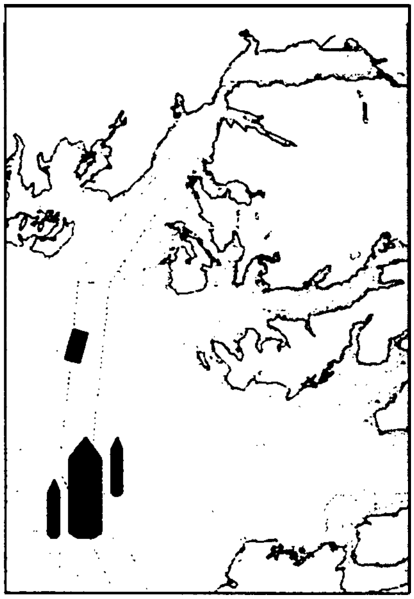
Wind Speed: More than 45

Wind Direction: Perpendicular/on Shore

Visibility: Greater than 1/2 mile



Bergy Bits within a mile

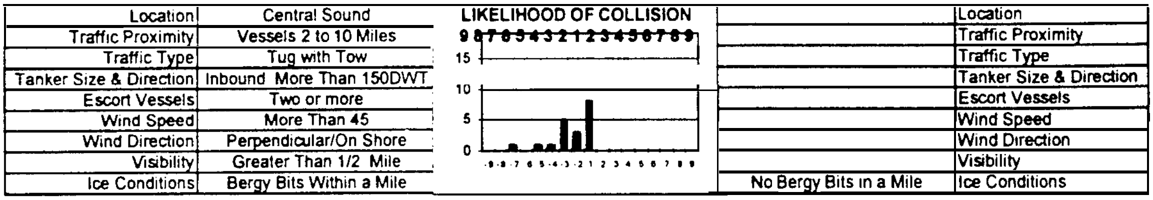


No Bergy Bits

The situation in the questionnaire is not posed graphically but is put in a booklet format with up to 150 separate questions like the one below. This question is identical to the graphic shown above. The situation on the left is completely defined. Only the attribute that has changed is shown for the situation on the right. If the attributes are left blank they are identical to the situation on the left.

Location	Central Sound	LIKELIHOOD OF COLLISION		Location
Traffic Proximity	Vessels 2 to 10 Miles	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Traffic Proximity
Traffic Type	Tug with Tow			Traffic Type
Tanker Size & Direction	Inbound More Than 150DWT			Tanker Size & Direction
Escort Vessels	Two or more			Escort Vessels
Wind Speed	More Than 45			Wind Speed
Wind Direction	Perpendicular/On Shore			Wind Direction
Visibility	Greater Than 1/2 Mile			Visibility
Ice Conditions	Bergy Bits Within a Mile		No Bergy Bits in a Mile	Ice Conditions

If the expert feels the situation on the left is much more likely to cause an accident, he or she would circle a large number on the left. If the situation on the right is felt to be more likely to result in a collision, then a number on the right would be circled. If the expert is indifferent, then the expert circles a 1. The magnitude of the number is related to the importance that that particular expert puts on the attribute that was changed. Below is a graphic of the actual data gathered for one of the questions in this study. The Geometric Mean of the expert responses is -1.93 which relates to a tendency for the experts to feel that the situation with the ice is more likely to result in a collision. A regression is then performed with respect to the exponential formulation of the risk equation (briefly explained in Section 3 and shown below) and on the geometric mean of the individual questions to determine the importance that the experts collectively assigned to each of the attributes.



Location	Central Sound		Location
Traffic Proximity	Vessels 2 to 10 Miles		Traffic Proximity
Traffic Type	Tug with Tow		Traffic Type
Tanker Size & Direction	Inbound More Than 150DWT		Tanker Size & Direction
Escort Vessels	Two or more		Escort Vessels
Wind Speed	More Than 45		Wind Speed
Wind Direction	Perpendicular/On Shore		Wind Direction
Visibility	Greater Than 1/2 Mile		Visibility
Ice Conditions	Bergy Bits Within a Mile	No Bergy Bits in a Mile	Ice Conditions

Enumerating the exponential yields

Relative Pr(Collision) = 3 13.2

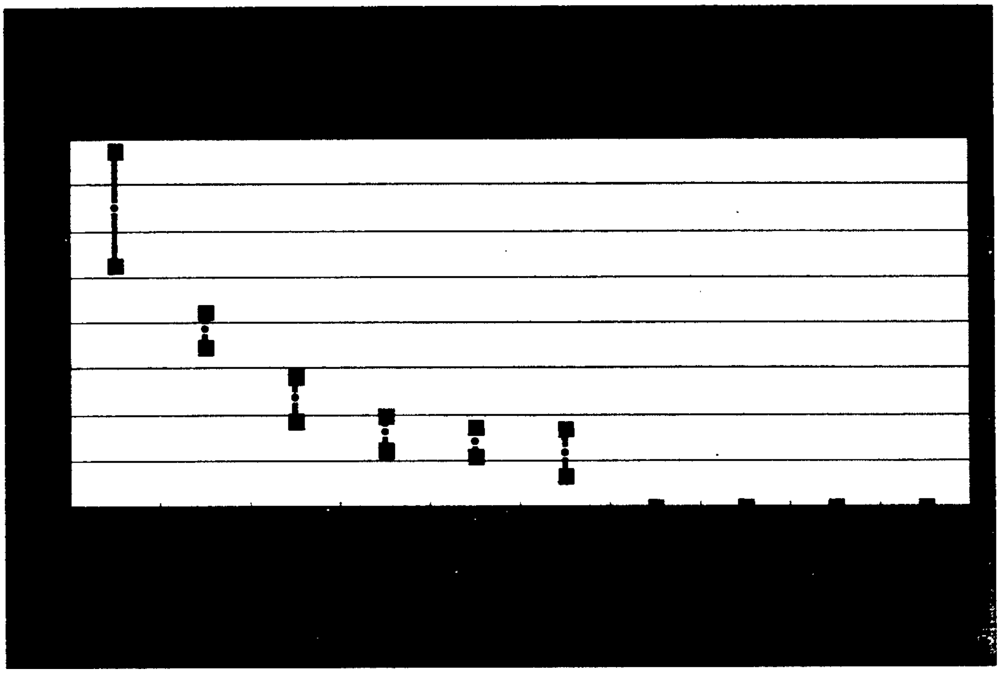
Relative Pr(Collision) = 136.0

$$\text{Pr(Collision(Propulsion Failure,WA)} = e\wedge^{\text{SUM(Bi * Xi)}}$$

4.5.4 Use of Expert Judgment in Simulation

By enumerating the exponential equation, it is possible to calculate the relative probability of an incident occurring from not only the questions asked but from every combination of attributes. In this case, approximately 50,000 combinations of waterway attributes for each failure type, not including vessel attributes, were possible. These simple equations were used in the simulation to calculate the probability of an incident occurring given sets of waterway attributes in PWS at five minute intervals.

It is possible to represent the relative contribution of different attributes to the probability of a collision by multiplying the beta value derived for each value by the difference between the maximum and minimum covariant values. Beta(I) * DeltaX(I). The graph below is a graphical representation of the importance of each attribute. The major limitation up to this point is that the values are related only to collisions caused by propulsion failures class of accidents.



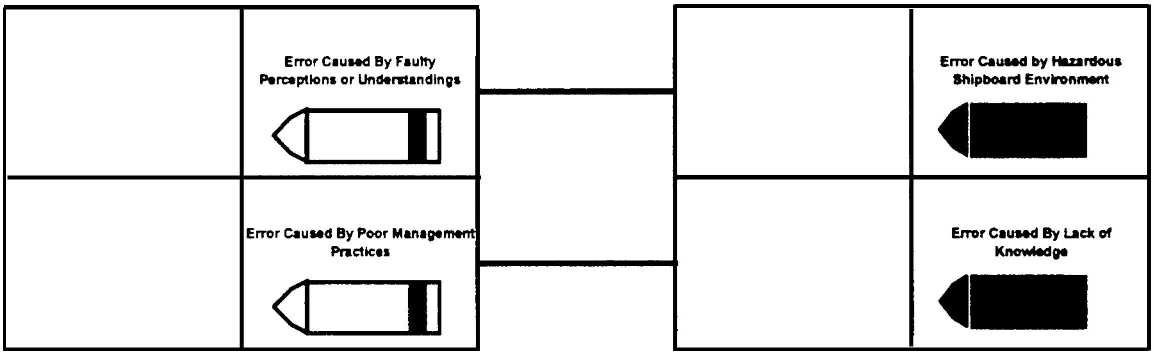
4.5.5 Calibration of Primary Questionnaire Results

In order to relate a large portion of the accidents given vessel reliability failures to each other (for example PR(grounding|propulsion failure,WA) to Pr(collision|steering failure, WA), another type of paired comparison questionnaire is required. These questionnaires, developed with the Bradley-Terry paired comparison method, ask experts to indicate which of two well defined events is more likely to take place in the next five minute period. On the following page, a questionnaire to calibrate the probability of all human error types with respect to each other given different vessel attributes is shown. In this formulation, two vessels are well defined and the most likely of every combination of comparisons of the five types of human errors and two vessel types are asked of several experts. The question being asked of the expert is which situation is more likely to take place in the next five minutes. If an error due to faulty perception or understanding is more likely on vessel B than a error caused by hazardous shipboard environment on vessel A, then an X is placed next to the column on the left. Only the first two questions are shown, but the questionnaires ran from 24 to 80 questions per section, with two sections in booklet 5 and 6. Booklets and questionnaires are contained in Technical Documentation Part II.

Example of Bradley Terry Paired Comparison Question

VESSEL A	
When Built	1965 - 1979
Vessel Size	More than 250,000 DWT
Material	HTS High Tensile Steel
Crew Type	U.S. Union Personnel
Officer Ser. On Vessel	0 to 1 years
Officer Ser. In Billet	0 to 1 years
% Below License	Greater than 40%
Bridge Team Stability	Less Than 1 Year
Officer Training	Individual
Management Type	Charter
Flag	United States

VESSEL B	
When Built	1965 - 1979
Vessel Size	100 to 150,000 DWT
Material	DH Mild Steel
Officer Crew Type	U.S. Company
Officer Ser. On Vessel	Greater than 1 years
Officer Ser. In Billet	Greater than 1 years
% Below License	Greater than 70%
Bridge Team Stability	Greater than 1
Officer Training	Individual & Team
Management Type	Oil Comp. Owned
Flag	United States



4.6 Management System Audits

Management System Audits were carried out using the management system audit questionnaire included in Technical Documentation Part II.

The development of this audit method is described in Technical Documentation Part III.

Management audits were carried out at the head offices of the following companies:

• ARCO Marine, Inc.	Long Beach, California
• Chevron Shipping Company	San Francisco, California
• SeaRiver Maritime, Inc.	Houston, Texas
• OMI Corporation, Inc.	New York, New York
• Marine Transport Lines	Weehawken, New Jersey
• Maritime Overseas Corporation	New York, New York
• Keystone Shipping Company	Bala Cynwyd, Pennsylvania
• MorMac Marine Transport, Inc.	Stamford, Connecticut

Furthermore, audits were carried out onboard 1-2 ships belonging to each of the above companies. depending on their number of ships in the PWS trade.

The results of the audits for each company were the combined score for shore-based and ship-based management.

The audit on the ship would, for instance, verify the existence and degree of implementation of management systems and procedures intended to be in place onboard the ship.

The management system audits resulted in the following scores out of 100 percent:

Highest Score:	88 percent
Average Score:	69 percent
Lowest Score:	51 percent

The performance of the PWS operators is shown in Figure 4.6-1.

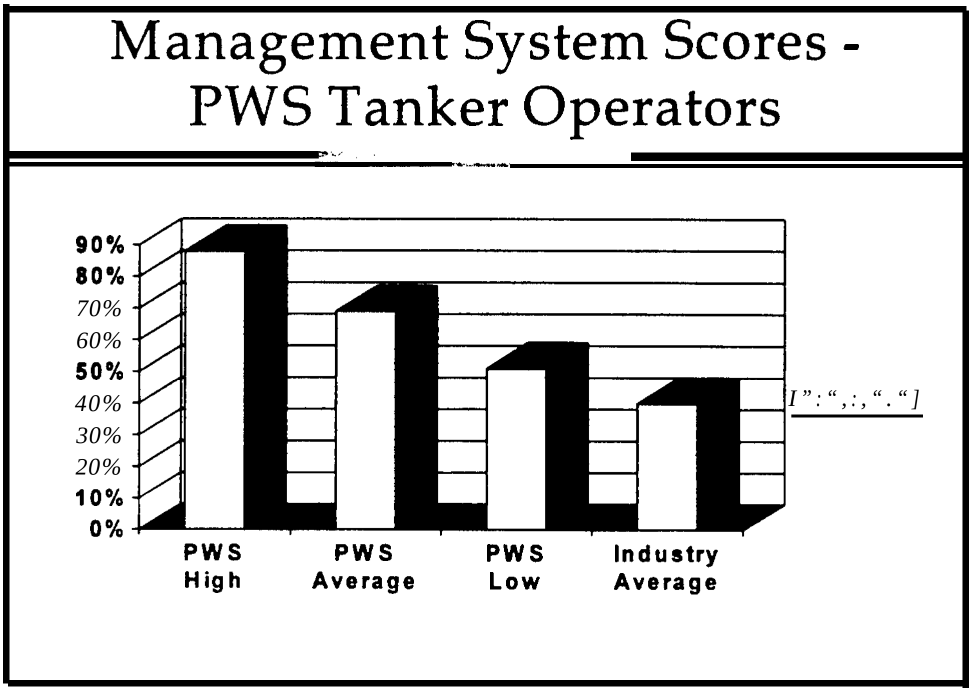


Figure 4.6.1
Management System Scores - PWS Tanker Operators

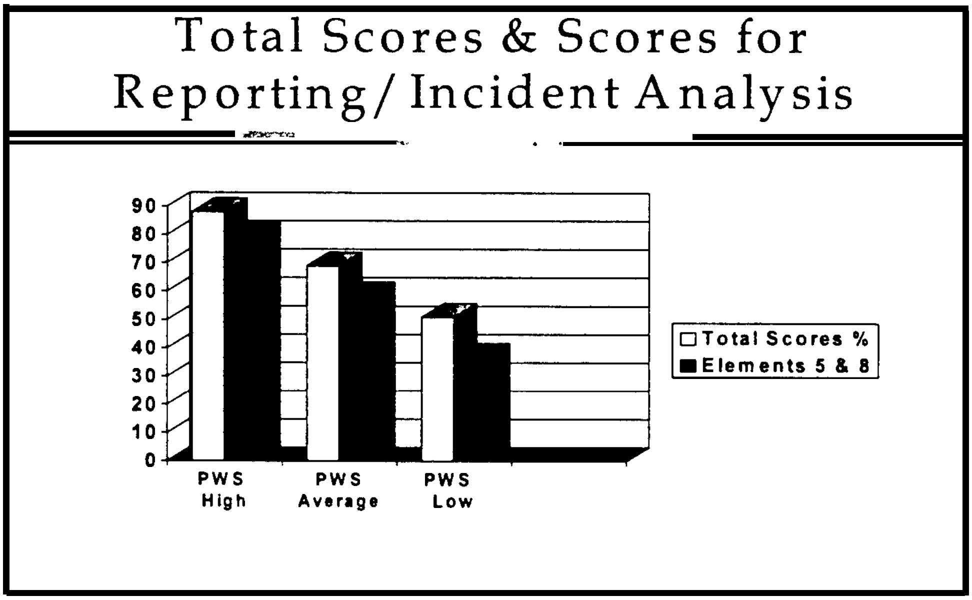


Figure 4.6-2
Total Scores & Scores for Reporting/Incident Analysis

A marine/waterways industry average was obtained from the International Loss Control Institute in Atlanta (for the same 14 management system elements as used in this study). It can be seen that the standard of management for PWS shipping companies compares well with this industry average, but that there is room for improvement, especially for the lowest scoring companies. This industry average is graphically depicted in Figure 4.6- 1.

One important aspect of the management audit was to establish the degree of confidence the study could have in the completeness of reported incidents from each shipping company. The results of the audit demonstrated a clear correlation between total management score and scores for the elements important to an effective failure reporting system. These elements (5 and 8 of the management audit) are concerned with practices for recordkeeping and incident analysis.

The scores for elements 5 and 8 are shown in Figure 4.6-2 compared to total management scores. On this basis, the project team decided to base the calculation of failure rates on the companies with the best management scores, having established that those companies had the most stable and mature systems for failure reporting and analysis.

4.7 Prince William Sound Traffic Data, Vessel Traffic System and Tug Data

Interactions between tankers and surrounding vessels play a central role in the overall system risk. Vessel types included in PWS traffic analysis included:

- Fishing boats,
- Fen-y/ Tour Boats,
- Tankers,
- SERVS Vessels,
- Cruise Vessels, and
- Tugs With Tow

A major contributor to traffic interactions in the PWS is the geographical layout and the rules that control navigation. The rules for navigation were obtained from the national, state, and USCG regulations. A chart representation of the geographical layout for the PWS was obtained from the USCG VTS in Valdez, Alaska. In addition, the VTS data and interviews with the local community provided some 99 plots of vessel routes which were used in both the simulation and MARCS model (for example see Figure 4.7-l).

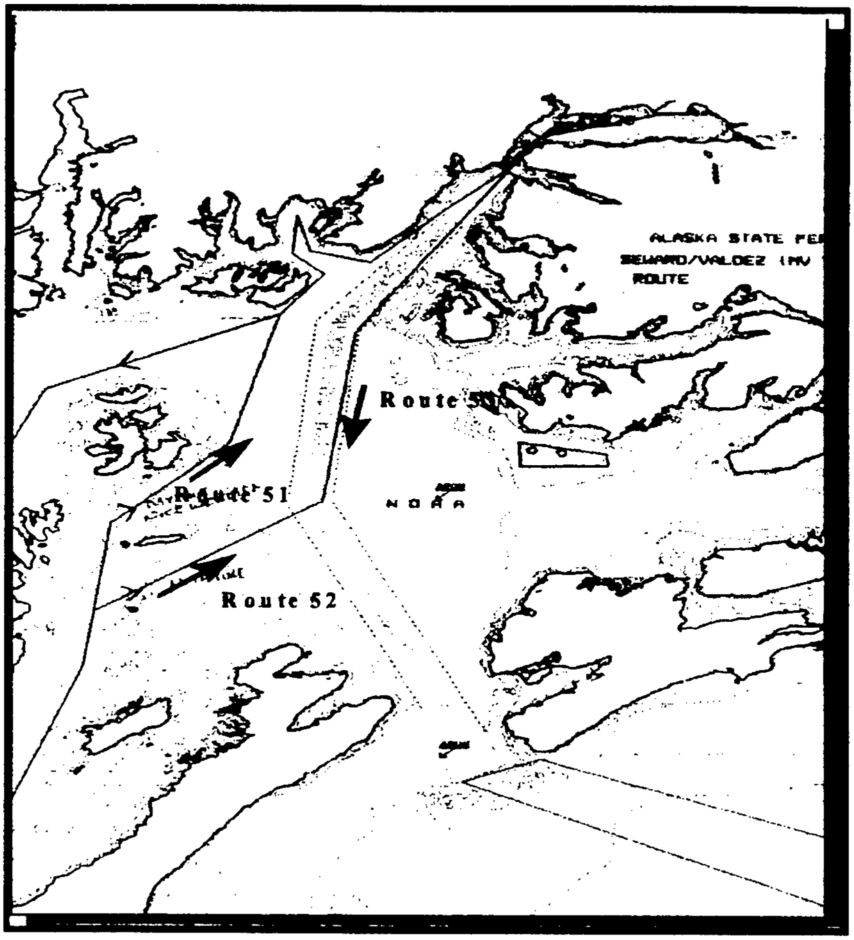


Figure 4.7-l. Routes 51,52,53 Seward - Valdez Ferry Routes

Vessel transit data came from many sources in the Prince William Sound community. SERVS vessels maintain logs for tanker escort transits that provide information on the total number of tanker transits per year. The SERVS data from mid 1989 through November of 1995 was used in this study. The USCG provided both paper logs of vessel transits by vessel types and date\time and graphical print outs of transit routes. The logs were used to verify the overall number of transits of each vessel type and to determine individual tankers' arrival and departure rates to the port and the average amount of time spent at berth for different size tankers. The number of times that tankers go to anchorage is determined by the weather and traffic restrictions on navigation through Hinchinbrook Entrance and the Narrows and was checked against the paper logs and verified by USCG personnel.

Determining which tankers call on the Alyeska Terminal and their mean inter arrival times was an iterative process. The starting data point for the baseline tanker fleet was USCG VTS logs from the first six months of 1995. In addition, the SERVS logs give the exact number of times each vessel called on port Valdez along with arrival and departure times and the amount of time spent at berth and the anchorage. This snapshot of traffic was not sufficient to determine the baseline tanker fleet because of several problems. Some vessels typically in the fleet were in dry dock being serviced. Other vessels had been retired due to OPA 90 double hull / age restrictions. Other vessels no longer called on the port due to dropping supply and economic competition between carriers.

The baseline taken from the first half of 1995 was shown to the steering committee for comment. Changes were made in the baseline, including vessels previously excluded and excluding vessels no longer in the fleet. The resulting fleet and mean inter arrival times (MIAT), shown in Table 4.7-1, is capable of carrying 1.56 million barrels of crude oil per day on average. Tanker routes and speeds are controlled by transit regulations. These rules are completely covered in the base case description.

SERVS vessels are vessels that escort tankers through PWS while laden with crude oil. Typically, two vessels are required per tanker but often size and wind restrictions require that three escort vessels be used. The SERVS vessel allotments are described in depth in the Base Case and Risk Reduction Methodology sections of the report and are assigned at tanker departure in the simulation.

Table 4.7-1, Baseline Tanker Fleet PWS Simulation

Vessel	Baseline Trips	Baseline MIAT
ARCO ALASKA	20	18.25
ARCO ANCHORAGE	32	11.41
ARC0 CALIFORNIA	21	17.38
ARCO FAIRBANKS	32	11.41
ARCO INDEPENDENCE	23	15.87
ARCO JUNEAU	9	40.56
ARC0 SPIRIT	19	19.21
ARCO TEXAS	26	14.04
CHESAPEAKE TRADER	30	12.17
CHEVRON MISSISSIPPI	30	12.17
SEARIVER BATON ROUGE	25	14.60
SEARIVER BENICIA	19	19.21
SEARIVER LONG BEACH	20	18.25
SEARIVER NORTHSLOPE	19	19.21
SEARIVER PHILADELPHIA	27	13.52
SEARIVER SAN FRANCISCO	25	14.60
DENALI	25	14.60
KENAI	25	14.60
PRINCE WILLIAM SOUND	27	13.52
TONSINA	25	14.60
BT ALASKA	25	14.60
OVERSEAS ALASKA	30	12.17
OVERSEAS ARCTIC	0	0.00
OVERSEAS BOSTON	23	15.87
OVERSEAS CHICAGO	22	16.59
OVERSEAS OHIO	23	15.87
OVERSEAS JUNEAU	23	15.87
OVERSEAS NEW YORK	23	15.87
OMI COLUMBIA	23	15.87

Commercial fishing vessel traffic accounts for more transits in PWS than any other category of vessels. Yet hard data on fishing vessel movements does not exist and can only be approximated due to variations in run sizes, market conditions and environmental factors. Several members of the PWS community contributed much effort in characterizing the fishing vessel activity. Data for the fishing vessel traffic model came from formal written questionnaires, official Alaska Department of Fish and Game catch data, Commercial Fisheries Entry Commission (CFEC) records and interviews with members of the fishing and fish processing industry. This data and all estimated boat crossings used for the model are contained in a report by Blake (1995). Fishing vessels include all craft used for commercial fishing including fish tenders which collect fish from the fishing grounds and return to a port, and floating fish processors which also collect fish from the fishing grounds and process them as appropriate.

The significant fishing vessel interactions can be grouped into 11 different seasons:

1) Eastern District Salmon Purse Seine
2) Western PWS Salmon Purse Seine
3) PWS Salmon Gillnet
4) Herring Seine Season
5) Herring Gillnet Season
6) Herring Bait and Food
7) Herring Roe on Kelp Pounding
8) Herring Roe on Kelp Diving
9) Pollock Trawl Fishery
10) Black Cod & Pacific Cod Long Line Fishery
11) Halibut Long Line Fishery

Ferry vessel transit information was obtained from schedules published in the 1996 Alaskan Mileposts. Routes were taken directly from the VTS plots of typical paths followed throughout the 1996 season. Actual start times of the vessels servicing the PWS were scheduled into the arrival program and the ferries were assigned to the appropriate routes. Ferries were assigned speeds of 14 to 16 mph.

Tour boat traffic was modeled from VTS plots. When the VTS plots were made, quantities of vessel taking each route were included in the margins. The data also provided beginning and ending dates and approximate start times for the vessel routes. This information was used to assign the appropriate number of vessels at the correct times. The tour boats run primarily from late May through early September and starts are limited to those days only. The tour vessels do not run every day due to demand. Tour vessels are some of the faster vessels and are assigned a velocity of 15 to 22 mph.

Cruise vessel traffic is a significant and increasing portion of the traffic in the PWS. The industry is competitive and dynamic which makes estimating future traffic difficult to simulate. The USCG vessel traffic logs and plots provided a comprehensive picture of the traffic in 1995. The same traffic was used throughout the twenty five year simulation run. Cruise vessels are among the faster vessels in the PWS and are assigned a 15 to 21 mph speed unless otherwise directed regulations.

Several types of traffic are included in the tug with tow category. Log barge traffic contributes the bulk of the transits. Several of the small communities on the PWS get deliveries of fuel oil and other consumable via **barges** and this traffic is also modeled. The traffic routes and quantities were taken directly from VTS logs and plots for 1995. Some oceangoing barges duck inside Montague Island to take advantage of the relatively calmer water and these transits are also included in the model. The vessel speeds were assigned values from 6 to 12 mph. The barges do not run on schedules and can arrive in the PWS any time of year and all times of day, unlike the fishing, ferry and cruise vessels.

4.8 Environmental Data

Environmental data was obtained from two main sources, SERVS transit data logs from 1990-l 995 and the National Oceanic and Atmospheric Administration (NOAA) buoys for 1995. The SERVS logs contain information on wind speed, wind direction, sea height, precipitation and visibility taken at three locations during each escort transit; the Narrows, Naked Island, and Seal Rocks. In addition, presence and size of ice in each of twelve locations (including the traffic lanes) in PWS is recorded per transit. The Buoys contain information on wind speed, wind direction, sea height, and visibility on a half hourly basis at Potato Point, Central Prince William Sound (Buoy 46060) and Seal Rocks (Buoy 46061). This data was used to develop univariate and bivariate probability models for the weather used in both MARCS and the systems simulation.

As with all of the data gathering processes undertaken in the PWS Risk Assessment, the collection, clean up, and analysis of the weather data was a considerable undertaking. However, uncertainties in the weather data still exist for several reasons.

- Weather data for the Buoys could only be obtained for the base case year and even then, the Potato Point Buoy was inoperable for a large portion of that year.

- Weather data from SERVS was obtained in a per transit rather than per time unit basis.

- The weather for the entire Prince William Sound had to be modeled from data obtained at six locations in Prince William Sound. Particularly important, and currently not available, is the actual weather information at both the Narrows and Hinchinbrook Entrance where closure decisions are to be made.

For the most part, the study had to accept the data shortcomings that were present. Models were developed in an effort to capture as much of the dependencies in the weather as were possible to measure from the data. In addition, 10 years (1986-1996) of wind speed and wind direction data from Middleton Island was obtained from Mr. Vince Patrick, of the Prince William Sound Science Center, for comparison with the data from Buoy 46061 for weather sensitivity analysis. This will be reported in a separate future appendix.

5.0 Base Case Results

5.0 Base Case Results

5.1 Format of Base Case Results

This chapter provides a detailed analysis of the baseline risk of the Prince William Sound oil transportation system. The base case is defined as the existing calling fleet operating under 1995 system rules and restrictions. Historical data from 1995 describing weather (wind, visibility), ice conditions, current, vessel size and speed, traffic density and traffic pattern were used to create base case data bases. The complete base case definition is contained in Section 3-10 and Section 1.3 of the Technical Documentation Part I .

Base case system risk is described in terms of three parameters: (1) accident frequency, or the statistical number of accidents per year within a defined area, (2) accident consequence expressed, or the potential average oil outflow in tons per year within a defined area, and (3) frequency--consequence relationships described by an oil outflow distribution showing the statistical frequency for discrete size ranges of potential oil outflows. These frequency and consequence results are expressed in five ways:

- for each of six accident types (collision, drift grounding, powered grounding, fire and/or explosion, foundering, structural failure), at each of the seven geographical subareas (Port Valdez, the Narrows, Valdez Arm, Central Sound, Knowles Head anchorage, Hinchinbrook Entrance, Gulf of Alaska), for each season. A seventh accident type, allisions can only occur at the Valdez Marine Terminal and are reported only for Port Valdez;

- for each of the seven subareas, summed over all accident types and seasons;

- for each of the seven accident types summed over all subareas and seasons;

- for each season, summed over all subareas and accident types; and

- for the system as a whole, summed over all subareas, all seasons, and all accident types.

The significant impact on the baseline risk of existing risk reduction measures such as escorts, pilotage, closure conditions, extended VTS coverage, and drug and alcohol testing can be inferred from the results described in this chapter. The decrease in system risk that may be attributed to these interventions is explicitly calculated in the assessment of existing and proposed risk reduction measures described in Chapter 7.

5.2 Reconciliation of Risk Results from Methodologies

Chapter 3, Methodologies for Assessment of Risk, described the integration of the four methodologies used in the Prince William Sound Risk Assessment. Fault trees, the static Marine Accident Risk Calculation System (MARCS), and the dynamic system simulation/regression methodology were used to estimate the frequencies of accidents. As described in Chapter 3 and in the Technical Documentation Part TV, these three models used common traffic image, environmental (geographical, weather, visibility, ice), and historical vessel failure rates data as inputs to the modeling process. The fourth model, the oil outflow model described in the Technical Documentation Part TV, Section 4.4, was used to estimate the consequences of accidents predicted by the other three models. Since risk was defined, for the purposes of the PWS Risk Assessment, as the risk of oil outflow, the analysis focused primarily on the outbound transits of laden tankers. The application of each of the three frequency assessing models to outbound laden tankers is shown in Table 5.2-l. Since the project scope specified the domain of concern as “20 miles before Hinchinbrook to Valdez and return”, the contribution to the base case risk due to inbound tanker transits was modeled in the system simulation/regression as shown in Table 5.2-2. Accidents involving inbound tankers are a potentially significant source of oil outflows since bunker fuel is 2-3 percent of the cargo carrying capacity of the tanker. These accidents could also result in loss of life, injury, and extensive damage.

Table 5.2-l
Application of Risk Models to Accident/Location Scenarios For Outbound Laden Tankers

	Port	**Narrows**	**Arm**	**Central PWS**	**Hinchinbrook Entrance**	**Gulf of Alaska**	**Knowles Head Anchorage**
Collisions	M/FT ss	M/FT ss	M/FT ss	M&T ss	M/FT ss	M/FT ss	M/FT ss
Drift Grounding	MCS SS	MCS ss	MCS ss	MCS ss	MCS ss	MCS ss	MCS ss
Powered Grounding	FT SS	FT ss	FT ss	FT ss	FT ss	FT ss	FT ss
Fire and/or Explosion	M/FT	M/FT	M/FT	M/FT	M/FT	M/FT	M/FT
Foundering	M/FT ss	M/FT ss	M/FT ss	M/FT ss	M/FT ss	M/FT ss	M/FT ss
Structural Failure	M/FT ss	M/FT ss	M/FT ss	M/FT ss	M/FT ss	M/FT ss	M/FT ss
Allision	FT	-					

Where:

MCS = MARCS model calculation

M/FT = MARCS model calculation using fault tree calculation of conditional probability of accident

SS = System simulation calculation calibrated against MARCS model output and historical data

FT = Fault Tree

As shown in Table 5.2-1, the DNV predicted drift grounding accident frequencies were calculated using the MARCS model alone and the accident frequencies for powered grounding and allision were calculated using the fault tree model alone. The statistical accident frequencies for collisions, foundering, fire and explosion, and structural failure were calculated using a combined fault tree/MARCS approach. Where MARCS and the fault tree were integrated, the situational exposure (time in system, weather) and interactions (traffic) were calculated by MARCS; the conditional probability of an accident occurring were calculated from the fault trees (See Technical Documentation Part IV, Sections 4.1 and 4.2 for complete technical description).

Table 5.2-2
Application of Risk Models to Accident/Location Scenarios for Inbound Ballast or Partially Laden Tankers

	Port	**Narrows**	**Arm**	**Central PWS**	**Hinchinbrook Entrance**	**Gulf of Alaska**	**Knowles Head Anchorage**
Collisions	SS	ss	ss	ss	ss	ss	ss
Drift Grounding	ss	ss	ss	ss	ss	ss	ss
Powered Grounding	SS	ss	ss	ss	ss	ss	ss
Fire and/or Explosion	-		-				
Foundering	SS	ss	ss	ss	ss	ss	ss
Structural Failure	SS	ss	ss	ss	ss	ss	ss
Allision	-		-				

Detailed analysis of two potentially significant base case risk scenarios were completed.

1. A fault tree model of the closely coupled laden tanker-tethered tug system in the Narrows identified factors that could significantly increase the base case risk due to this specific operation.

2. The fault tree and the system simulation were both used to provide a detailed analysis of the critical scenario of a laden tanker maneuvering in ice during an outbound transit.

Sections 5.3, 5.4, and 5.5 provide a structured and integrated summary of the base case risk results. Section 5.3 presents a description of the statistical accident frequencies and oil outflows by accident types (the seven accident types are defined in Section 3.2), and accident scenarios (a scenario is an accident type at a specific location) for outbound laden tankers. Section 5.4 provides a brief description of the component of system risk due to inbound tankers.

Section 5.5 contains a detailed description of the location and seasonal dependencies for collisions, grounding, and structural failures. The results presented in these sections are further documented in Technical Documentation Part V, Section 5.4 which contains complete summarized MARCS/Fault Tree and System Simulation results. Detailed results from each model are also contained in Technical Documentation Part V. The summary of significant system risks presented in Section 5.6 provides the foundation for the discussion of risk reduction measures in Chapter 6.

5.3 Description of Statistical Accident Base Case Frequencies and Potential Oil Ouflows for Outbound Laden Tankers

5.3.1 Comparison of Accident Types and Accident Scenarios

This section describes base case risk in terms of statistical accident frequencies and potential accident oil outflows. These statistical frequencies and oil outflows are presented for seven accident types (collision, drift grounding, powered grounding, structural failure/foundering, fire/explosion, and allision, for seven accident locations (Port Valdez, the Narrows, the Arm, Central PWS, Hinchinbrook Entrance, the Gulf of Alaska, and

Knowles Head anchorage), and for thirty six accident scenarios (accident types at specific locations). Statistical frequencies are presented in two ways: the statistical number of accidents/year expressed in scientific notation (0.001 accidents/year = 1.0e-3 accidents/year) and the corresponding return time expressed in years (0.001 accidents/year = 1 accident0000 years, or a return time of 1,000 years). Potential average oil outflows are expressed in tons of oil released per year.

Two values are presented for each reported frequency and outflow--the value obtained from the DNV fault tree or fault tree/MARCS model calculation and the value obtained from the GWU system simulation. *Since each of the values presented is the point estimate calculated by a particular model and each model result has its own range of uncertainty, the two numbers cannot be interpreted as a statistical confidence interval.* The independent calculation of similar results does, however, provide assurance that the calculations are complete, accurate, and consistent. In all but a few accident scenarios, the range of answers produced by very different modeling techniques are within a half an order of magnitude (a factor of 5). In most cases the answers are within a quarter of an order of magnitude (a factor of 2.5). Where major differences in results do occur, they can be traced to difference in assumptions and definitions used in the modeling approaches.

This high degree of agreement between the models in spite of the very different modeling approaches used reflects the care taken to ensure common data and common assumptions and provides assurance in the validity of the results. The results presented in Sections 5.2, 5.3, and 5.4 are integrated from the Fault Tree, MARCS, and system simulation output contained in Technical Documentation Part V, Sections 5.1 through 5.4.

The use of multiple models in the calculation of accident frequencies captures the strength of each approach and compensates for the limits inherent in each model. This recognition that there is no optimal method of risk assessment is a unique strength of the Prince William Sound Risk Assessment. As will be shown below and in Chapter 7, the use of all three models helps to ensure that no significant source of risk is overlooked and that risk inducing counter effects introduced into the system by risk reduction measures are detected. The fault tree was used specifically to provide a close up picture of the Narrows, of allisions with the terminal berth, and of maneuvering in ice. The results of the examination of the Narrows revealed a major source of risk in the current system as described in

Section 5.3.2. The results of the ice navigation examination are discussed in Chapter 7. The system simulation revealed the dynamic interactions of many existing and proposed interventions into the system and was used to calculate the small but relatively significant risk due to accidents involving inbound tankers. Considering the impact of proposed risk reduction interventions on inbound as well as outbound traffic ensures that a risk reduction measure does not merely shift the risk from one area of the system to another. These system interactions are described in the risk reduction evaluation contained in Chapter 7.

Each modeling methodology contributes unique insights into the system. The MARCS contains a detailed disabled tanker save model that considers the precise geographic location of accidents and the capabilities of assisting tugs. MARCS can therefore model the geographic dependencies saving a tanker from drift grounding. The locations identified by the simulation are the locations of the triggering event, (i.e., propulsion failure) not necessarily the location of the subsequent accident (i.e., drift grounding). Fault Tree and MARCS parameters can be changed to represent escort vessels not currently in the system (for example, enhanced capability tugs); the expert judgment approach used in the system simulation is restricted by the domain of experience of the participating experts. The simulation captures dynamic interactions not captured by the static fault tree or the static MARCS model. The fault tree provides a multiple level causal analysis not possible in MARCS and restricted to three levels in the system simulation technique. The elicitation of judgment from Prince William Sound maritime experts for use in the system simulation compensates for the lack of relevant accident and causal data. The fault trees use the judgment of DNV experts where historical data does not provide the basis for estimating causal frequencies or probabilities.

5.3.2 A Potential High Risk Scenario: Powered Grounding in the Narrows due to Human Error on the Tethered Tug

The fault tree detailed analysis of powered grounding in the Narrows (Technical Documentation Part V, Section 5.3) identified the powered grounding of a laden tanker in the Narrows caused by an error or failure on the tethered tug, under certain operating conditions as a potentially high risk scenario. The predominant risk in this scenario (statistical frequency of 3.0e-02 groundings per year) is introduced into the system by the combination of a tightly coupled configuration (tethered tug, engine engaged) with no external or internal vigilance capable of identifying and correcting human error or incapacitation on the tug. Since the solution to this potential hazard is straightforward and procedural (i.e., the establishment of written formal procedures), and is likely to have been implemented prior to the publication of this report, this scenario is not included in the discussion of the base case risk in Sections 5.2 and 5.4.

The detailed analysis of this key accident scenario is contained in Technical Documentation Part V, Powered Grounding in the Narrows: Fault Tree Model Close up on Tugs in the Narrows. The sources of uncertainty in the risk results calculated by the fault tree are described in Technical Documentation Part V. The alternative operating procedures that will potentially eliminate this risk spike are discussed in Technical Documentation Part V and are summarized in Chapter 7, Assessment of Effectiveness of Risk Reduction Measures. When the tanker is isolated from the human and mechanical errors on the tug, the dominant branch in the fault tree describing a powered grounding in the Narrows becomes the branch describing a grounding caused by lack of ship control (from loss of steering other than hard-over rudder failure, loss of propulsion or human failure). If the risk due to grounding caused by the tethered tug is reduced through the implementation of formal procedures, the statistical frequency of a powered grounding in the Narrows in the base case is reduced to 1.8E-03 (an average return time of 555 years).

5.3.3 Statistical Frequencies of Accident Types and Accident Scenarios

5.3.3.1 Allisions

As stated in Section 5.2, seven accident types were examined in the risk analysis. Allisions are only possible in Port Valdez. the location of the Valdez Marine Terminal. The risk of allisions was examined through fault tree analysis. The risk of oil spill due to impact with the terminal berth in Port Valdez was assessed as follows for inbound, partially loaded tankers:

- The risk of spillage of crude oil is negligible since the oil in partially loaded tankers is normally located in the center tanks protected by the side tanks; and

- The risk of spillage of bunker oil is negligible as this oil is assumed to be located in tanks outside berth impact points.

The calculated probability from the fault tree analysis for allision of laden tankers is 1.7e-04 per departure, corresponding to a frequency of 0.11 per year. This frequency includes all impacts, independent of the severity of the impact. The calculated potential oil outflow resulting from the allision of a fully loaded outbound tanker is negligible. The complete analysis supporting this finding is contained in Technical Documentation Part V. The basic points of this analysis are as follows:

- The energy necessary to cause a hull penetration of a tanker in an allision is assumed to be 15 Mega Joules (this corresponds to a 100,000 DWT tanker hitting the berth impact point at 1 knot speed);

- The hull of a tanker with a displacement of 100,000 DWT could be penetrated in an allision at closing speeds exceeding 1 knot. The hull of a tanker with a displacement of 200,000 DWT could be penetrated in an allision at closing speeds exceeding 0.7 knots;

- Tankers smaller than 150,000 tons are not permitted to leave the berth when winds are 40 knots or greater. Tankers larger than 150,000 DWT are not permitted to leave berth when winds are 30 knots or greater;

- A wind of 40 knots will produce a drift speed of 1.2 knots for a 100,000 DWT tanker. A wind of 30 knots will produce a drift speed of 0.9 knots for a 200,000 DWT. Tankers will not, however, develop this drifting speed within a short time of departure from berth. Therefore, the maximum closing velocities will not exceed the velocity required for hull penetration; and

- In order for an allision to occur during departure, a failure would have to occur on the tanker and also on at least one of the two docking tugs.

The case of an allision of an outbound tanker with a different berth (i.e., a tanker departing berth 4 and striking berth 3) due to human error or mechanical failure was not considered.

5.3.3.2 Results by Accident Type

In the description of results that follows, the model results for foundering and structural failure were combined for both the MARCS and system simulation results. This was done for two reasons: (1) founderings are rare events and can be considered as subsets of structural failure, (2) the MARCS and system simulation used different definitions to distinguish structural failure from foundering accidents.

The statistical frequency of occurrence for accidents involving outbound laden tankers in the base case for the five remaining accident types are shown in Table 5.3-2. The statistical accident frequency in Table 5.3-2 is the statistical frequency for all accidents, regardless of whether or not the accident has the potential to spill oil.

Each accident type has a different potential to rupture a cargo or bunker tank and to spill oil. In particular, a large percentage of the collision interactions involve fishing vessels, tour boats, and other small vessels are not capable of producing the collision energy required to penetrate a tankers hull. It was assumed that one half of the remaining collisions (those when the tanker is the striking vessel) also would not produce an oil outflow due to the location of protective spaces forward of a tankers cargo tanks. The percentage of grounding accidents that would not produce oil outflow depends upon the composition of the fleet (the proportion of double hull, double bottom vessels) and the location of the predicted grounding. The percentage of accidents with the potential for oil outflow is shown for each accident type in the third column of Table 5.3-2. The effect of this differing proportion of oil outflow producing accidents for each accident type is shown in the description of potential oil outflows in Section 5.3.5.

Table 5.3-l
Accident Types for Outbound Tankers By Statistical Frequency of Occurrence

Accident Type	Accident Frequency Statistical Accidents Per Year	Percentage Of Accident Type With Potential For oil oufflow	Accident Return Time Average Time In Years
Collisions	1.6e-02 to 4.1e-02	26%	62 to 24 years
Powered Grounding	4.6e-03 to 7.2e-03	68%	169 to 139 years
Drift Grounding	4.6e-03 to 5.5e-03	69%	217 to 182 years
Structural Failure	1.5e-03 to 1.6e-03	95%[2]	648 to 615 years
Fire and Explosion’	9.4e-04	100%	1065 years
Total - All Accidents	2.8e-02 to 5.6e-02	75%	36 to 18 years

[1] Fire and Explosion values calculated by Fault Tree model only

‘Percentage based on IMO structural failure definition (a structural failure serious enough to effect the structural integrity of the vessel and to warrant repair at the next port of call) and IMO data.

The models predict that more than three quarters of the statistical accidents affecting outbound tankers are collisions. However, only 26 percent of these collisions have the potential for producing an oil outflow. If accidents that do not have the potential for producing oil spills are excluded from the analysis, the statistical accident frequencies for collisions, powered grounding, and drift grounding are all of the same order of magnitude. This exclusion of collisions with insufficient energy to penetrate the hull or grounding with insufficient energy to penetrate the inner hull of a double hull vessel is done prior to computing oil outflows. The potential oil outflows for the five accident types are more tightly grouped than are the statistical accident frequencies.

Note from Table 5.3-1 and Figure 5.3-2 that the model results agree at the accident level within a factor of two for the total statistical accident frequency and for the statistical frequency for all accident types except collision. As will be seen in the discussion of accident scenarios in Section 5.3.3.3, the dynamic simulation calculations show a significantly higher collision risk in the Port, Narrows, and Arm than does the static MARCS model due to the ability of the simulation to model the increased risk during periods of high traffic congestion due to system closures and fishing openers. Although most of these collision interactions are not potential oil outflow producing events, their consideration in the analysis is an important element in the development of risk reduction strategies.

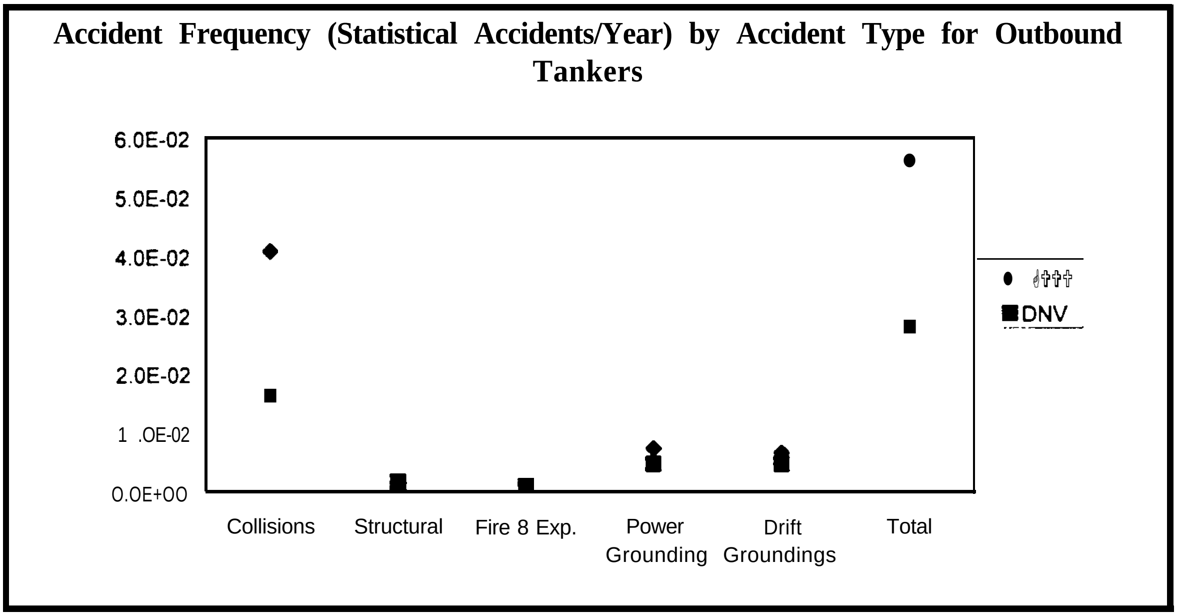

Accident Frequency (Statistical Accidents/Year) by Accident Type for Outbound Tankers

Figure 5.3-2

5.3.3.3 Results by Accident Scenario

The statistical accident frequencies and accident return times for the thirty five specific accident scenarios (accident type and location for accidents involving outbound laden tankers) are shown in Table 5.3-2. Three additional manipulations of the simulation results presented in Technical Documentation Part V were necessary to reconcile the system simulation and the MARCS results:

- The MARCS reports the locations of drift grounding as the location where the disabled vessel grounds. The drift grounding location reported in the system simulation is the location of the triggering propulsion or steering failure. The only place where this difference in modeling assumptions produce differing results was for propulsion or steering failures occurring in Central PWS resulting in a grounding of the tanker in the Hinchinbrook Entrance or the Knowles Head anchorage areas. The simulation drift grounding results were adjusted by allocating 50 percent of the grounding due to propulsion or steering failure in Central PWS to the Hinchinbrook Entrance location (which includes the North Shore of Montague Island). The basis for this assumption was the analysis of tides and currents (see Technical Documentation Part IV) which indicate that a net drift to the South could be expected approximately 50 percent of the time.

- A second adjustment was made necessary by differences in definitions between the two models. Since all laden tankers in the Narrows are accompanied by a tethered tug, MARCS defines any grounding due to loss of propulsion on a tanker as a powered grounding unless there is also a simultaneous failure on the tug (an extremely low probability event). The “drift grounding” reported by the system simulation are grounding preceded by a propulsion or steering loss in all locations. To ensure comparability between models, the grounding frequency and oil outflow reported in Technical Documentation Part V as “drift grounding in the Narrows” was reallocated to the Powered Grounding in the Narrows scenario. This adjustment was not made to the grounding in the Arm results due to the uncertainty in the proportion of time the tug is tethered to the tanker in the Arm.

- Third, since the area defined as the Gulf of Alaska in the base case definition (see Figure 3.3-l) does not include any land (Seal Rocks is in the Hinchinbrook Entrance area), a powered grounding in this area is virtually impossible. The powered grounding identified in the system simulation as occurring in the Gulf were reallocated to the Hinchinbrook Entrance area. The precise artificial boundaries created for the analysis were not obvious to the experts filling out the expert judgment elicitation questionnaires which provided the basis for the system simulation accident conditional probabilities.

The accident scenarios are listed in the descending order of their maximum accident frequency in Table 5.3-2, regardless of which model calculated the maximum frequency. The agreement between the models at the scenario level remains strong. The model results differ by more than a half order of magnitude (a factor of 5) for only four scenarios (indicated in bold in Table 5.3-2):

- The statistical frequency *ofpowered groundings in the Port and in the Central Sound* was calculated as negligible by the Fault Tree based on the assessment that the probability of a dangerous course in these areas was zero.

- *Drift Grounding in the Arm* is defined in MARCS and the Simulation differently. The MARCS calculation assumes that drift grounding cannot occur during the portion of the outbound transit in the Arm when the escort tug is tethered to the tanker; all grounding in this configuration are powered grounding. The system simulation does not differentiate, and includes all grounding due to propulsion or steering loss in the drift grounding category.

- Drift Groundings that occur in the Anchorage Zone due to propulsion failures in the Central Sound are included in the Drift Grounding-Anchorage Scenario in MARCS and in the Drift Grounding—Central Sound Scenario in the System Simulation/Regression.

Three other important scenarios, collisions in the Port, the Arm and the Narrows, differ by more than a factor of two. These differences are a reflection of the more precise modeling of the traffic interactions in and around the exclusion zone by the system simulation. The simulation captures the increased risk of collision resulting from traffic congestion due to closures, fishing openers, and other causes. The MARCS uses a static representation of the system and assumes average traffic densities which vary with position, but not with time.

The ranking given in Table 5.3-2 is displayed in Figure 5.3-3 where the respective frequencies produced by the MARCS and system simulation are shown. The interval between the two values shown shows the degree of agreement between the models. It is not to be interpreted as a statistical confidence interval about a point estimate.

The estimated percentage of accidents with the potential for resulting in an oil outflow is also shown for each accident scenario in column five of Table 5.3-2. Figure 5.3-4 shows that, based on the maximum calculated frequency, seven of the thirty five scenarios account for approximately 80 percent of total statistical accident frequency. Ten specific accident scenarios (accident type and location) involving outbound laden tankers in the base case have a frequency of occurrence predicted by at least one risk model to be greater than 1 .OE-03 (a return tune shorter than 1,000 years). Note that the four most likely accident scenarios are collisions in the Port, Narrows, Arm, and Central Sound, but that a relatively small percentage of the accidents in these accident scenarios (13 percent--31 percent) have the potential for resulting in an oil outflow. As a result, the difference between accident scenarios is less dramatic when they are compared on the basis of oil out-flows in Section 5.4.

An * in Table 5.3-2 indicates a negligible frequency (less than 1 .0E-07). Since outbound tankers rarely go to the anchorage, the probability for all accident types at the anchorage is negligible except for drift grounding (indicating that a tanker could have a failure in Central Prince William Sound and drift into the anchorage area). Negligible values for powered grounding in Port Valdez and in the Central Sound were calculated in the Fault Tree model based on the assumption that there were no dangerous courses and no maneuvering in these areas for outbound tankers.

Table 5.3-2

Accident Scenarios
Ranked by Statistical Frequency of Occurrence
(Accidents Ranked By Maximum Frequency)+

Accident Type	Location	Statistical Number Of Accidents Per Year	EXPECTED Return Time In Years	% With Oil Outflow Potential
Collisions	Port	5.2E-03--1.2E-02	193—80	26%
Collisions	Arm	3.3E-03--1.1E-02	301—91	25%
Collisions	Narrows	2.7E-03--1.1E-02	365—93	13%
Collisions	Central Sound	3.2E-03--4.5E-03	309—222	31%
Drift Grounding	Hinchinbrook	2.4E-03--3.4E-03	419—294	69%
Powered Grounding	Narrows	1.8E-03--3.1E-03	568—326	66%
Powered Grounding	Hinchinbrook	8.9E-04--1.8E-03	1123—564	70%
Drift Grounding	**Arm**	**1.7E-04--1.5E-03**	**659—5797**	66%
Collisions	Hinchinbrook	9.6E-04--1.5E-03	662—1040	37%
Powered Grounding	Arm	1.1E-03--1.2E-03	804--935	66%
Powered Grounding	**Port**	***--1.0E-03**	**972**	66%
Powered Grounding	**Central Sound**	***--9.9E-04**	**1012**	66%
Drift Grounding	Port	7.4E-04--9.3E-04	1073--1345	66%
Drift Grounding	Gulf	1.8E-04--8.4E-04	1189--5470	70%
Drift Grounding	**Central Sound**	**5.0E-05--8.2E-04**	**1220--20121**	**66%**
Collisions	Gulf	4.9E-04--7.2E-04	1385--2033	37%
Structural & Foundering	Central Sound	4.4E-04--5.4E-04	1865--2248	95%
Structural & Foundering	Hinchinbrook	2.4E-04--3.1E-04	3187--4238	95%
Fire & Explosion[1]	Central Sound	3.1E-04	3187.	100%
Structural & Foundering	Gulf	3.0E-04	3313--4242	95%
Structural & Foundering	Arm	2.4E-04--2.9E-04	3394---4198	95%
Structural & Foundering	Port	1.3E-04--2.2E-04	4525--7981	95%
Fire & Explosion[1]	Arm	1.8E-04.	55504	100%
Fire & Explosion[1]	Hinchinbrook	1.3E-04	7474	100%
Fire & Explosion[1]	Gulf	1.3E-04	7770	100%
Structural & Foundering	Narrows	1.1E-04	8926	95%
Fire & Explosion[1]	Port	9.6E-05	10471.	100%
Fire & Explosion[1]	Narrows	8.6E.05	11682	100%
Drift Grounding	Anchorage	*--8.2E-05	121951	66%

Accident Type	Location	Statistical Number Of Accidents Per Year	EXPECTED Return Time In Years	% With Oil Outflow Potential
Drift Grounding	Narrows	*--2.1E-06	476190	67%
Powered Grounding	Gulf	*	*	*
Collisions	Anchorage	*	*	*
Structural & Foundering	Anchorage	*	*	*
Fire & Explosion [1]	Anchorage	*	*	*
Powered Grounding	Anchorage	*	*	*

[1] Fire and Explosion values calculated by Fault Tree model only.

* Indicates value is less than 1 .Oe-07

+ Bold Font indicates a disagreement between models of a factor of 5 or more

Accident Frequencies (Statistical Number of Accidents/Year) by Accident Scenarios

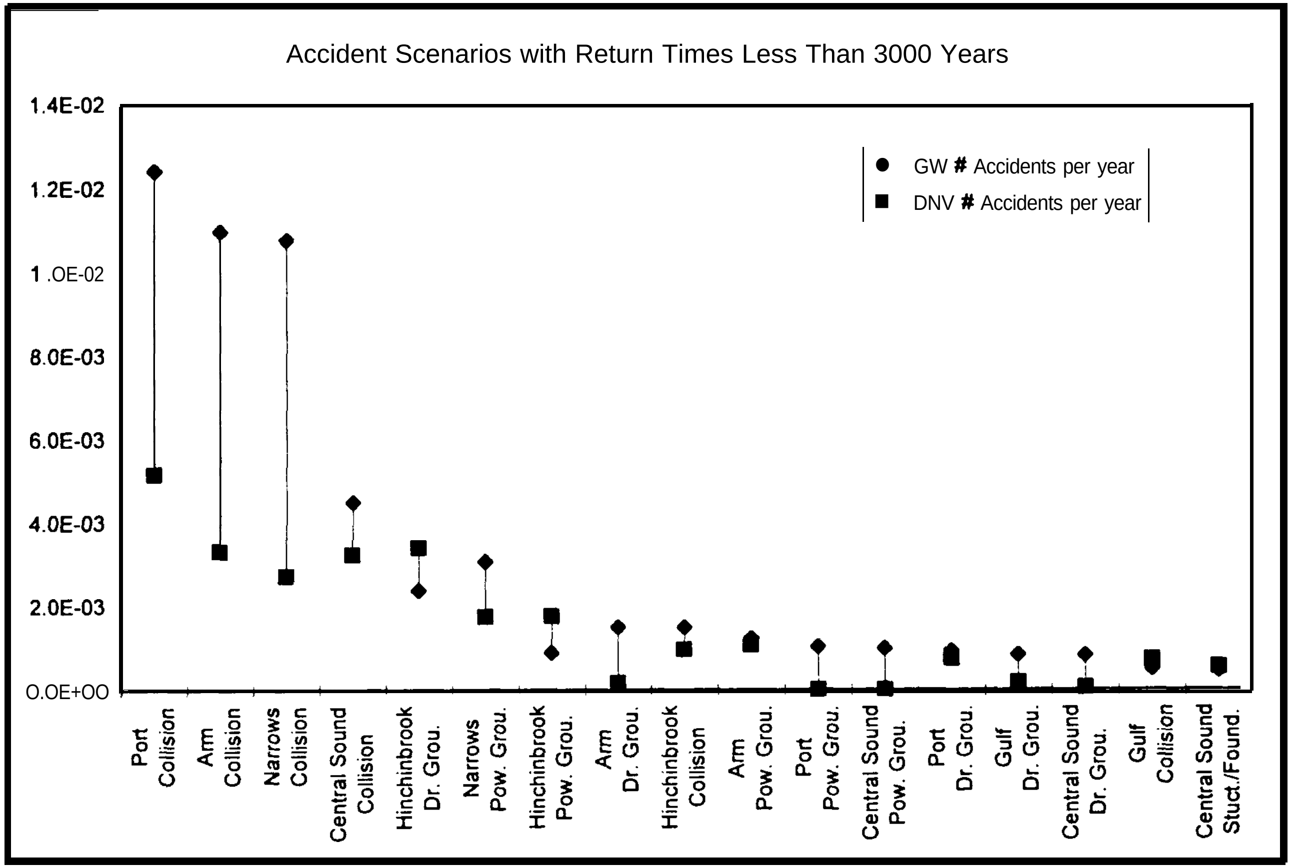
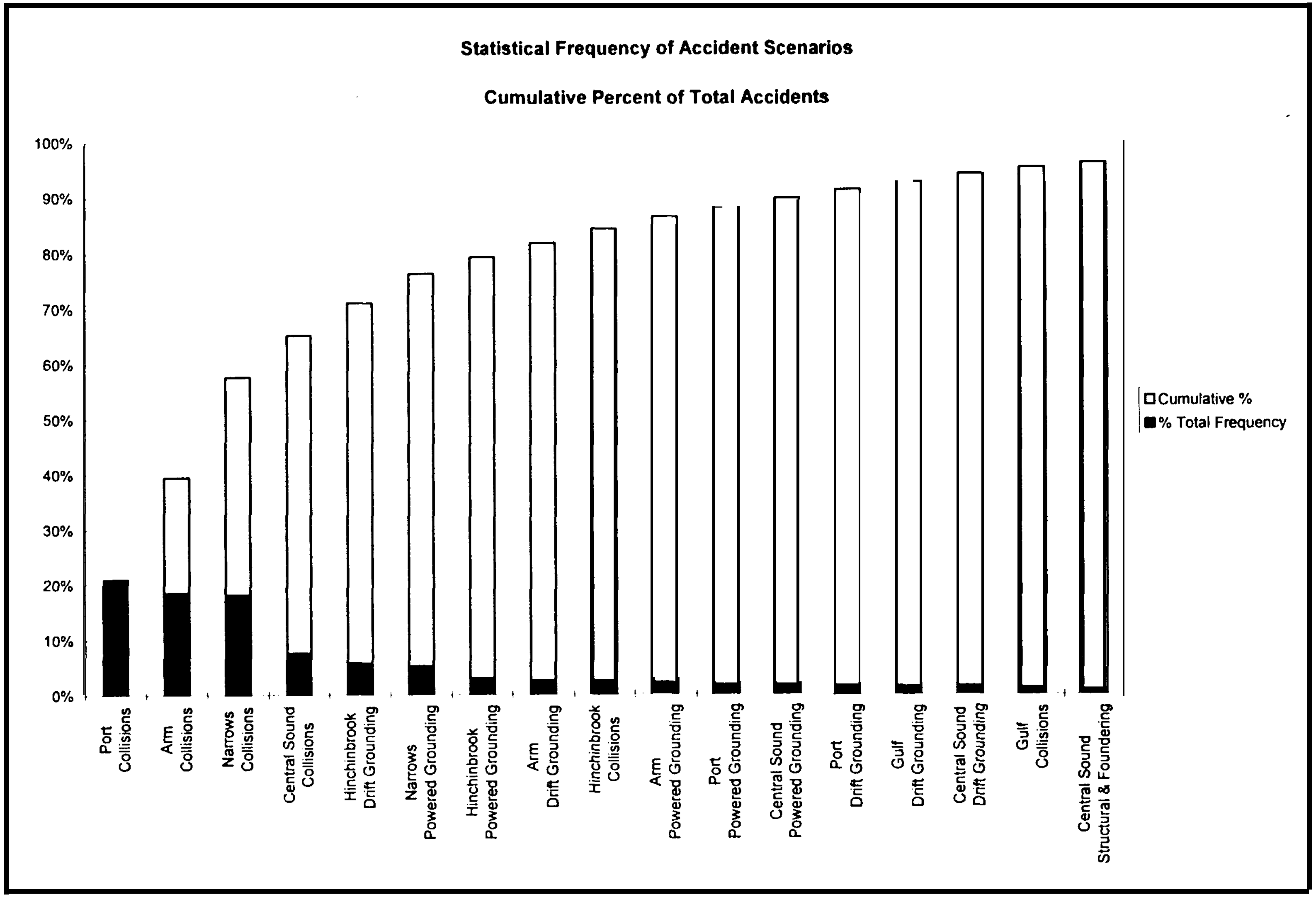


Figure 5.3-3


Statistical Frequency of Accident Scenarios

Cumulative Percent of Total Accidents

Figure 5.3-4

5.3.4 Oil Outflows by Accident Types

In Section 5.3.3, structural failures and fires and explosions were not among the dominant accident types as determined by the statistical frequency of occurrence. When using the potential average oil outflow as the descriptive parameter, structural failures and fires and explosions become significant. This is due to (1) all fires and explosion accidents and 95 percent of all structural failures have the potential for an oil outflow, and (2) the probability of the total loss of a vessel is higher for these accident types than it is for collisions or groundings.

The fact that a low proportion of collision accidents have the potential for an oil outflow results in the reversal of the relative ranking of collisions and groundings described for statistical accident frequencies. As seen in Table 5.3-3, the outbound oil outflow expected from groundings (117 to 250 tons/year) exceeds the oil outflow expected from collisions (75-180 tons/year) even though the statistical frequency of outbound collisions (1.6e-02 to 4.1e-02 collisions/year) is greater than the statistical frequency of groundings (9.2e-03 to 1.4e-02 groundings/year). Table 5.3-4 shows that the range of variation in oil outflows for all five accident types is a factor of 4.5. Comparing Figure 5.3-5 to Figure 5.3-2 illustrates this relative compression of results.

Table 5.3-3
Potential Average Oil Ouflows for Outbound Laden Tankers by Accident Type

Accident Type	Potential Oil Outflow
Collisions	75-180 tons/year
Drift Grounding	67--121 tons/year
Powered Grounding	50- 129 tons/year
Fire and Explosion[1]	40 tons/year
Structural Failure/ Foundering	27--52 tons/year
Total Oil Outflow--All Accidents	260--480 tons/year

[1] Fire and Explosion values calculated by Fault Tree model only

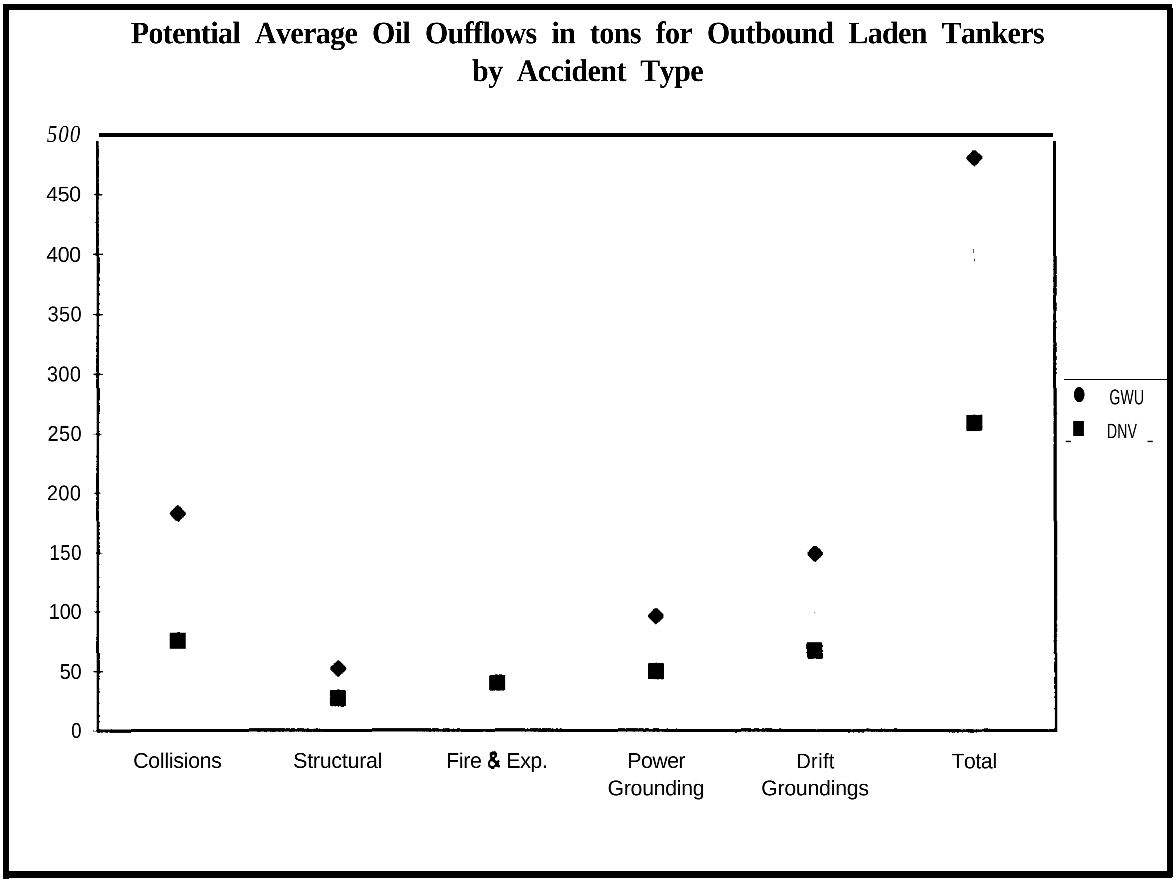


Figure 5.3-5

5.3.5 Oil Ouflows by Accident Scenarios

As expected, a description of system risk described by oil outflows by accident scenario provides a picture that is less dominated by a few significant risk scenarios than is the view that considers only the statistical frequencies of occurrence of accident scenarios. As shown in Table 5.3-4 and Figure 5.3-6, nineteen of the thirty five accident scenarios are predicted by at least one risk model to produce a potential average oil outflow of greater than 10 tons/year. Figure 5.3-7 shows that it takes 14 scenarios to account for 80 percent of the predicted total potential oil outflow in the base case compared with the 7 scenarios required to account for 80 percent of the statistical accident frequency.

The potential average oil outflow results show agreement between the modeling approaches similar to that described in the discussion of statistical accident frequencies. Results from two methodologies differed by more than a half order of magnitude (a factor of 5) for four scenarios indicated in bold font in Table 5.3-4. The variations in the powered grounding results for the Central Sound and Port Valdez and the drift grounding in the Arm and Central Sound were explained. A variation in model results appears in the drift grounding in the Gulf of Alaska potential oil outflow results that did not appear in the statistical accident frequency results. The MARCS model predicted oil outflow for drift grounding in the Gulf is almost a magnitude larger than that predicted by the system simulation. This result is the reflection of the MARCS ability to consider the operational characteristics of the assisting tug in the MARCS save model and suggests that mariners may have over estimated the ability of the escort vessel to prevent their tanker from grounding under adverse conditions.

Table 5.3-4
Potential Average Oil Outflow by Accident Scenario
Oil Outflows Ranked in order of maximum value

Accident Type	Location	Potential Average Oil Outflow Per Year In Tons
Collisions	Arm	15—64
Drift Grounding	Hinchinbrook	40—57
Powered Grounding	Narrows	14—49
Collisions	Port	25—38
Collisions	Central Sound	18—34
Powered Grounding	Hinchinbrook	20—27
Drift Grounding	**Gulf**	**3—26**
Drift Grounding	**Arm**	**1—25**
Powered Grounding	Arm	9—21
Collisions	Hinchinbrook	6—21
Powered Grounding	**Central Sound**	***--17**
Collisions	Narrows	7—17
Powered Grounding	**Port**	***--17**
Drift Grounding	Port	6—15
Structural & Foundering	Central Sound	9—15
Drift Grounding	Central Sound	*--14
Fire & Explosion[1]	Central Sound	*--13.
Structural & Foundering	Arm	4—10
Structural & Foundering	Hinchinbrook	5—8
Structural & Foundering	Gulf	5—8
Fire & Explosion[1]	Arm	8.
Structural & Foundering	Port	2—7
Collisions	Gulf	5—7
Fire & Explosion[1]	Hinchinbrook	6
Fire & Explosion[1]	Gulf	5.
Fire & Explosion[1]	Port	4
Structural & Foundering	Narrows	2—4
Fire & Exp. [1]	Narrows	4
Powered Grounding	Gulf	*
Drift Grounding	Anchorage	•
Drift Grounding	Narrows	*
Collisions	Anchorage	*

Accident Type	Location	Potential Average Oil Outflow Per Year In Tons
Structural & Foundering	Anchorage	*
Fire & Exp.[1]	Anchorage	*
Powered Grounding	Anchorage	*

[1] Fire and Explosion values calculated by Fault Tree model only

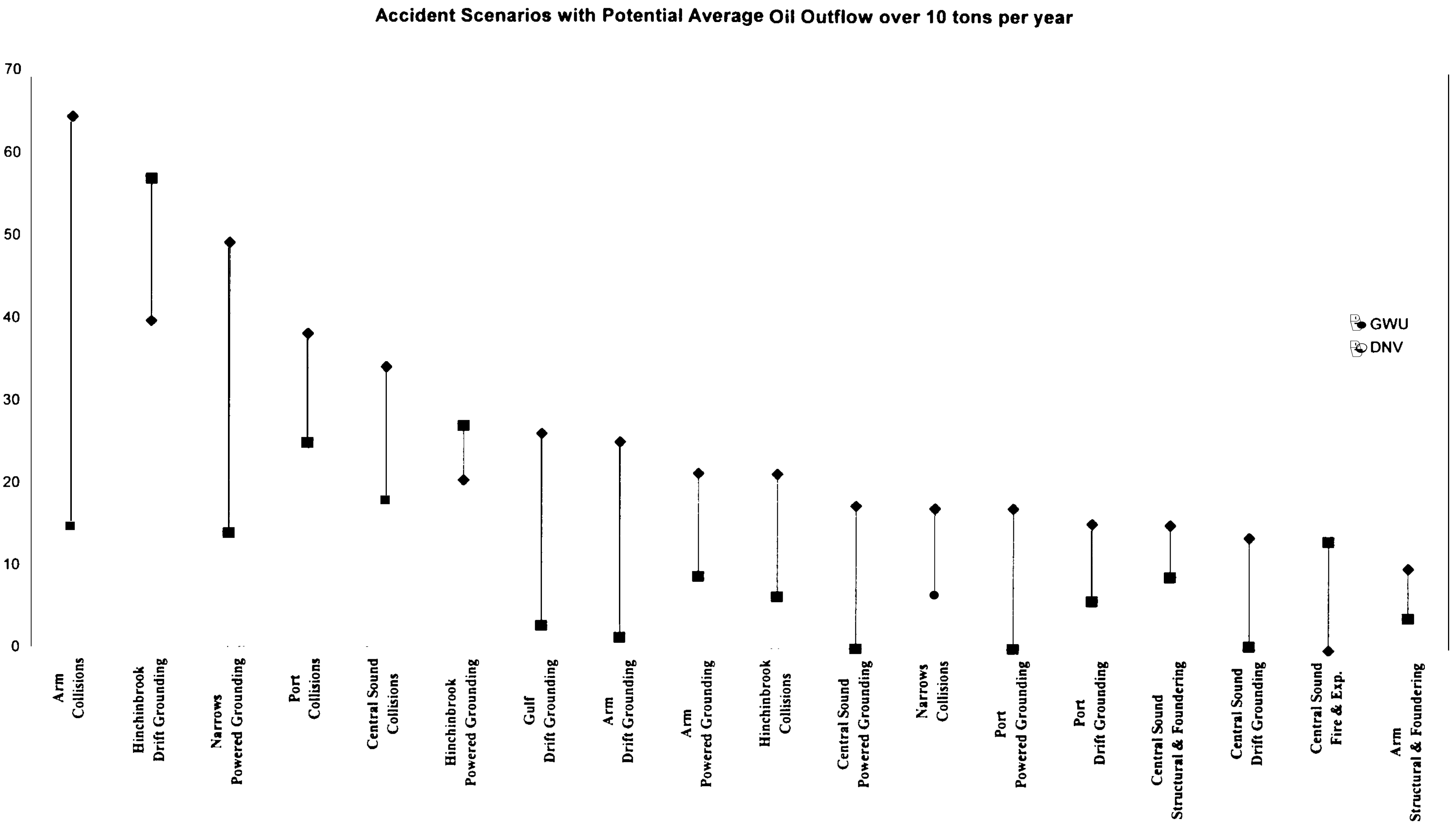

Accident Scenarios with Potential Average Oil Outflow over 10 tons per year
70
60
50
40
30
20
10
0
GWU
DNV
Arm Collisions
Hinchinbrook Drift Grounding
Narrows Powered Grounding
Port Collisions
Central Sound Collisions
Hinchinbrook Powered Grounding
Gulf Drift Grounding
Arm Drift Grounding
Arm Powered Grounding
Hinchinbrook Collisions
Central Sound Powered Grounding
Narrows Collisions
Port Powered Grounding
Port Drift Grounding
Central Sound Structural & Foundering
Central Sound Drift Grounding
Central Sound Fire & Exp.
Arm Structural & Foundering

Figure 5.3-6

Potential Average Oil Outflow by Accident Scenarios

Cumulative Percentage of Total Outflow

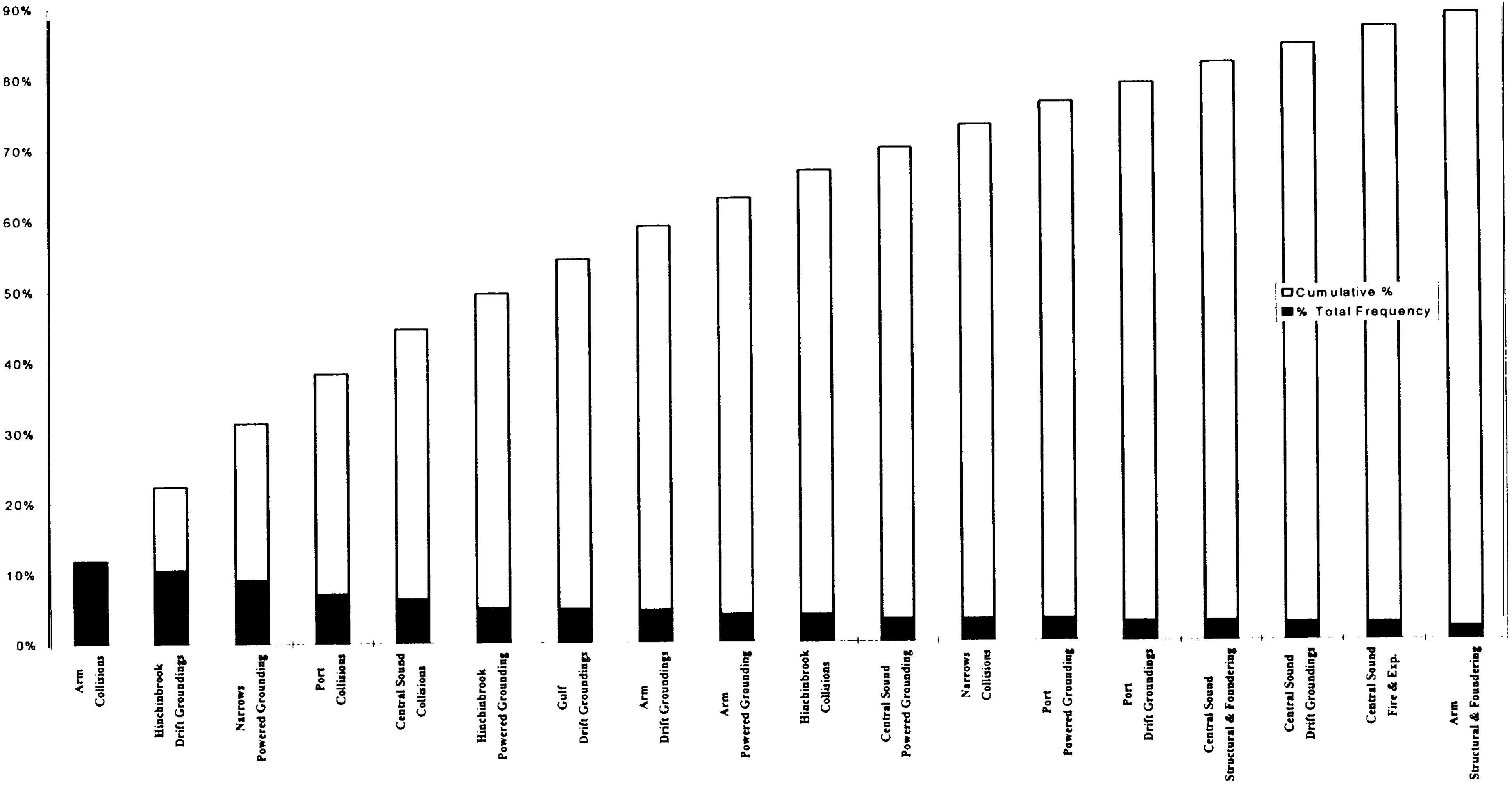


Figure 5.3-7

5.4 Discussion of Risk to Inbound Tankers

The project scope required the examination of risk of oil outflows from tankers, "from 20 miles before Hinchinbrook and return". The risk attributed to inbound tankers was calculated by the system simulation for two reasons:

- Although the inbound tankers are in ballast or partially laden, the cumulative oil outflow from accidents involving inbound tankers may be relatively significant, particularly as risk management initiatives reduce the risk of outbound transits.

- A full system simulation was developed to investigate the full systemic interactions of risk reduction interventions. Interventions in the system intended to reduce outbound risk can adversely effect the risk of inbound transits. (As will be shown in Chapter 7, this interaction between outbound and inbound risk does occur.)

As shown in Table 5.4-l and Figure 5.5.1-2, the statistical frequency of accidents involving inbound tankers is almost twice that of the statistical frequency of accidents involving outbound tankers. This is not surprising, since inbound tankers are not escorted and, by diverting to the anchorage, spend more time in the system. Note that in Table 5.4-1, for inbound tankers drift grounding are more likely than are powered grounding. The inverse was true for outbound tankers, showing the benefit of escort vessels for outbound tanker transits.

Table 5.4-l
Accident Types for Inbound Tankers
By Statistical Frequency of Occurrence

Accident Type	Accident Frequency Statistical Accidents Per Year	Accident Return Time Average Time In Years
Collisions	6.0E-02	17
Drift Grounding	3.1E-02	32
Powered Grounding	1.2E-02	84
Structural Failure	1.7E-03	60
Total - All Accidents	1 .OE-0 1	10

Oil outflows for inbound tankers were calculated assuming that bunkers and partial cargoes would be lost only in the case of total loss of the vessel. As shown by Table 5.4-2, the potential average oil outflow due to accidents involving inbound tankers is only approximately 6 percent of the potential oil outflow expected from accidents involving outbound tankers. However, the only outbound accident scenarios that exceed this potential volume of oil, 30 tons/year, are drift grounding at Hinchinbrook, powered grounding in the Narrows, and collisions in the Arm, Port, and Central Sound. The drift grounding accident type is predicted to result in a potential average oil outflow per year of 15 tons. Table 5.3-4 shows that this potential average oil outflow is relatively significant when compared to the potential oil outflows for outbound scenarios.

Table 5.4-2
Potential Average Oil Outflows for Inbound Tankers by Accident Type

Accident Type	**Potential Average Oil outflow**
Collisions	**9** tons/year
Drift Grounding	15 tons/year
Powered Grounding	**5.5** tons/year
Structural Failure/ Foundering	1.5 tons/year
Total Oil Outflow--All Accidents	**30** tons/year

5.5 Discussion of Specific Accident Types

Additional insight into the base case risk may be gained by examination of specific accident types. Knowledge of the differing location and seasonal dependence of accident types is an important element of risk management. The sections below discuss the seasonal and location dependencies for collisions, power and drift grounding, and structural failures. The discussion of outbound location dependencies is taken from the MARCS/FT and system simulation results and draws wherever possible on the analysis of historical incident and accident data contained in Chapter 4. The discussion of inbound location dependencies and the description of seasonal dependencies is based on the system simulation results.

Fires and explosions were considered by the fault tree model as independent of location and season.

Validating risk models of rare events using historical data is difficult. While the sparse historical record does not provide an adequate basis for testing validity, it does provide a basis for assessing the reasonableness of model results. Three comparisons can be made:

- comparing predicted PWS accident frequencies with historical accident rates;
- comparing predicted PWS accident frequencies with worldwide accident rates; and
- comparing PWS predicted incident rates with historical incident rates.

The analysis predicts a return time of 24 to 62 years for collisions (see Table 5.3-2) involving outbound tankers, and 75 to 108 years for grounding (combining the drift and powered groundings statistical frequencies in Table 5.3-2) of outbound tankers in PWS with the current system safeguards. Since the pipeline opened in 1975, there has been one inbound tanker collision with ice and one tanker grounding. (See Section 4.1.5). Note that the PWS statistical accident frequency per year values shown in Table 5.3-l were converted to statistical accidents/mile in order to make this comparison.

Additional insight can be gained by examining the triggering incidents for which historical data is available--those mechanical failures that could have resulted in accidents and oil outflows. The failure rates predicted by the models (l-2 propulsion or steering failures per year) are consistent with the number of failures calculated from the product of the failure rates described in Section 4.4 (determined from data analysis and industry survey) and the expected annual tanker mileage in PWS (determined from the number of tanker transits in the base case determined in Section 3.10.2). The number of failures predicted by the models is also consistent with the historical data summarized in Section 4.1.5. Although these consistency checks are not tests of validity, they do provide a basis for ensuring that the models were properly calibrated.

5.5.1 Location and Seasonal Dependence for Collisions

Figure 5.5. l-l and 5.5.1-2 show that the expected collisions involving outbound or inbound tankers in Prince William Sound are concentrated in the Port, Narrows, and Arm. These are the areas most effected by traffic congestion caused by management of the exclusion zone and are the only areas where fishing openers conflict with tanker traffic. Figure 5.5.1-3, however shows that most of the collisions with outbound tankers in the Port and the Narrows will not produce oil outflows, making the Arm the location of the greatest potential oil outflow due to collisions. Figure 5.5.1-4 indicates that the most common vessel type involved in a collision with an outbound or inbound tanker is a fishing vessel. The second most likely vessel to be involved in a collision with a tanker is a SERVS vessel not engaged in an escort. Figure 5.5.1-5 indicates that the potential oil outflows from collisions involving other tankers and SERVS vessels exceeds that from fishing vessels. These distribution of collision by vessel type shows the impact of traffic congestion on accident frequency as modeled by the system simulation. Figure 5.5.1-6 indicates that the collisions are a seasonally dependent accident. Not surprisingly, the statistical frequency of collisions and the potential average oil outflow due to collisions are greatest during the summer months, peaking during the July and August tourist and commercial fishing seasons.

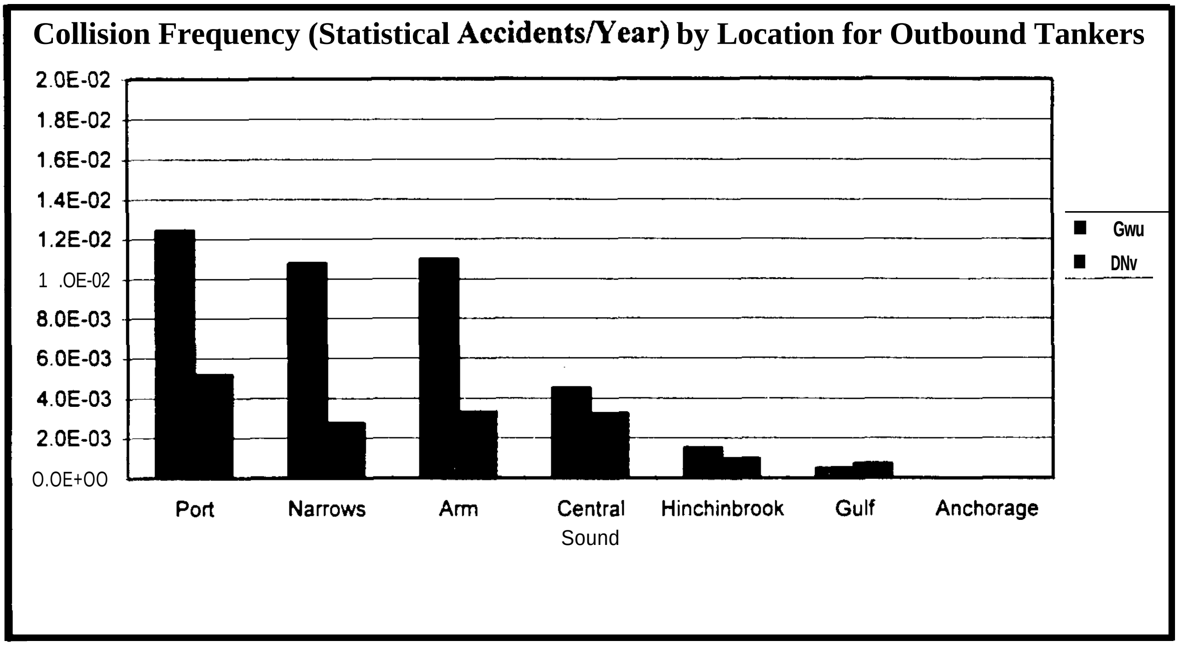


Figure 5.5.1-1

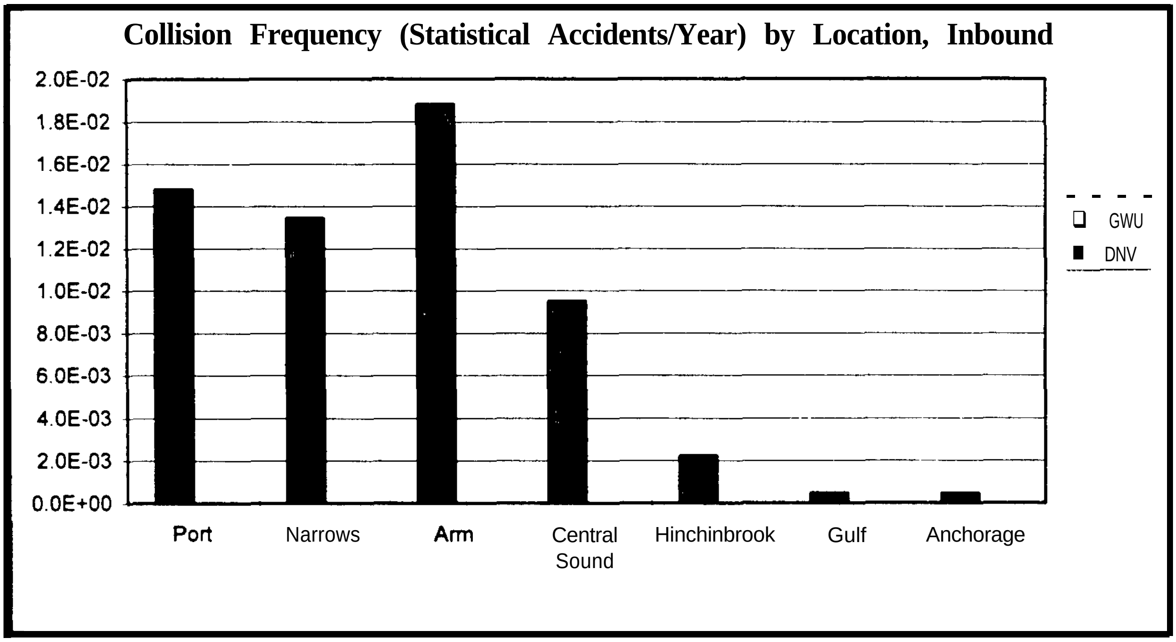


Figure 5.5.1-2

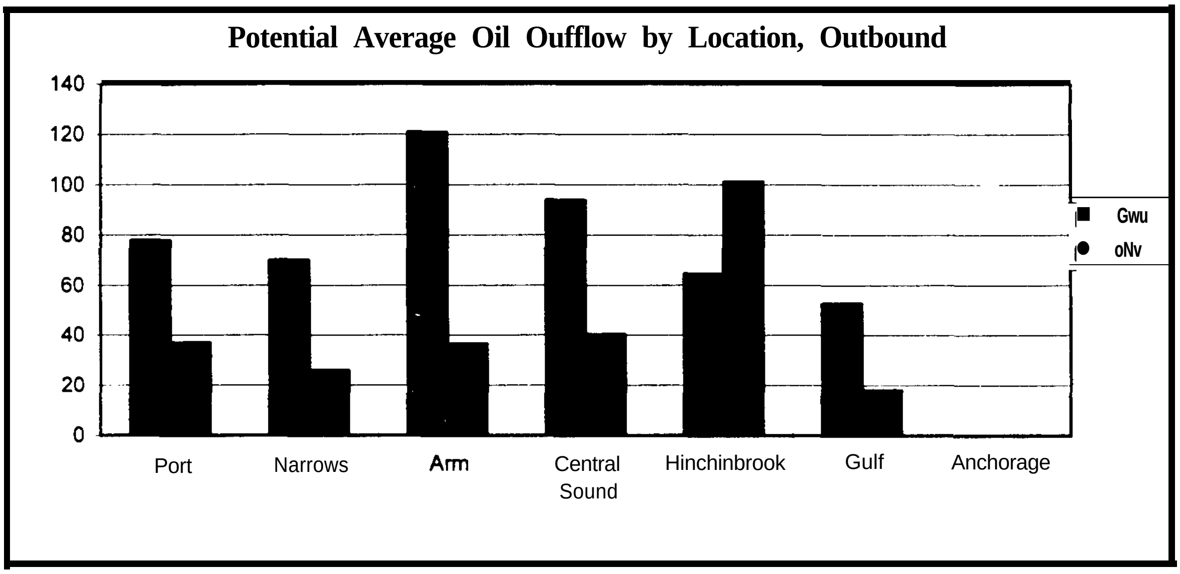

Potential Average Oil Ouflow by Location, Outbound

Figure 5.5.1-3

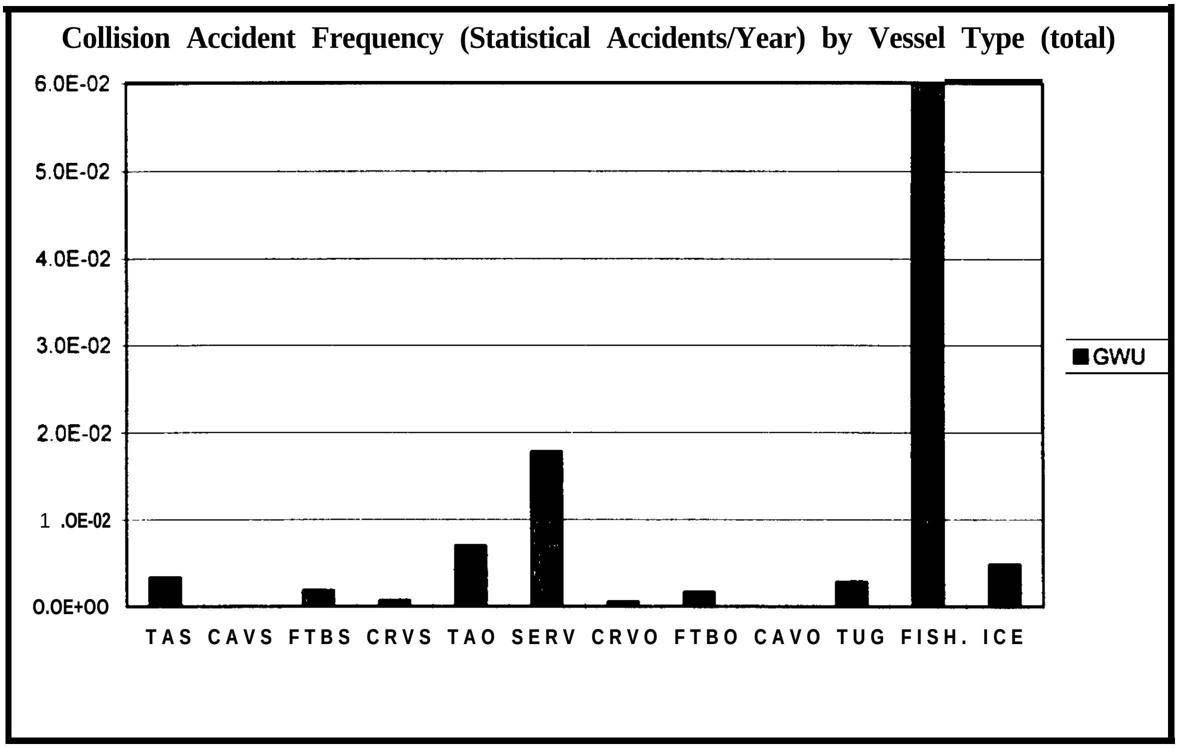


Figure 5.5.1-4

KEY:

TAS : Tanker same direction
CAVS : Cargo vessel same direction
FTBS : Ferry/Tour same direction
CRVS : Cruise Vessel same direction
TAO : Tanker opposite direction
SERV : Escort Vessel
CRVO : Cruise Vessel opposite direction
FTBO : Ferry/Tour opposite direction
CAVO : Cargo vessel opposite direction
TUG : Non Escort Tug
Fish : Fishing vessel
Ice : Ice

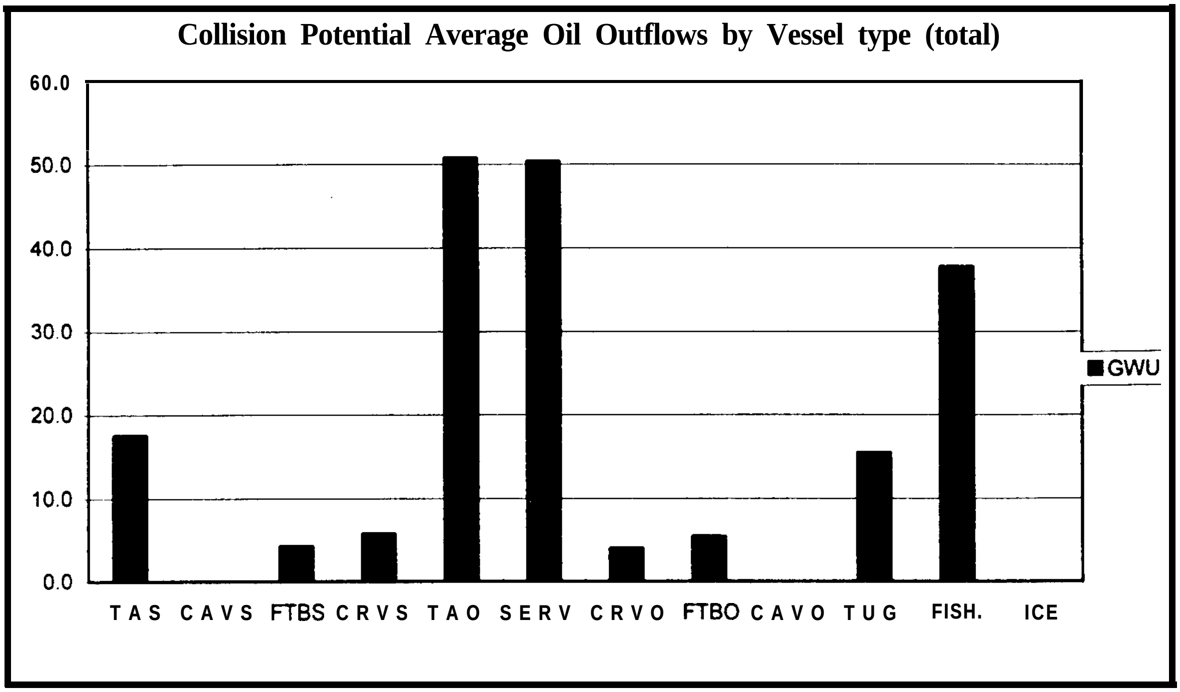


Figure 5.5.1-5

KEY:

TAS : Tanker same direction
CAVS : Cargo vessel same direction
FTBS : Ferry/Tour same direction
CRVS : Cruise Vessel same direction
TAO : Tanker opposite direction
SERV : Escort Vessel
CRVO: Cruise Vessel opposite direction
FTBO : Ferry/Tour opposite direction
CAVO: Cargo vessel opposite direction
TUG : Non Escort Tug
Fish : Fishing vessel
Ice : Ice

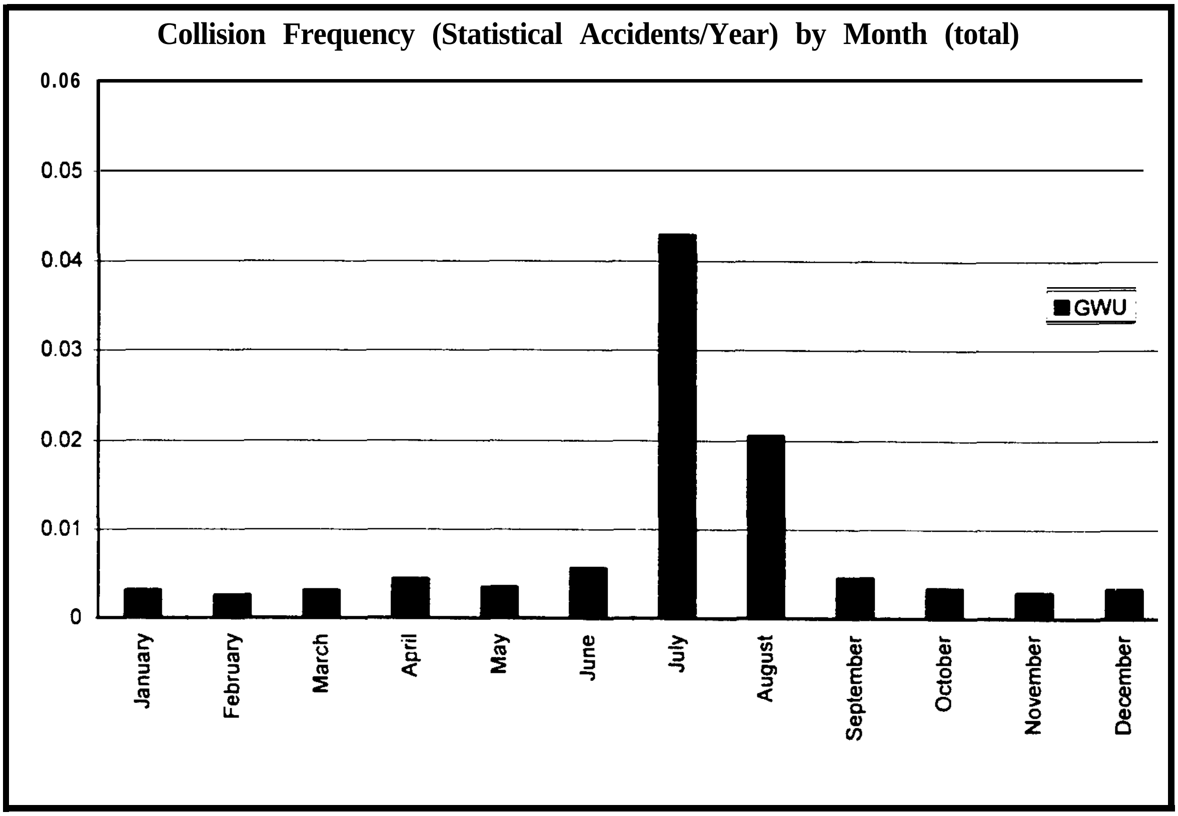


Figure 5.5.1-6

5.5.2 Location and Seasonal Dependence for Grounding

Drift groundings are defined as groundings triggered by a steering failure or power failure that disables a tanker. Powered groundings are defined as groundings caused by human error or navigational system failure. All groundings when a tug is tethered to the tanker are considered powered groundings unless the tug has a simultaneous loss of propulsion or steering. As stated in Section 5.3, the MARCS and system simulation implemented these definitions and assumptions in slightly different ways. As explained in Section 5.3, the location for drift grounding is defined as the location of the eventual grounding in the MARCS model and the location of the triggering failure in the system simulation. Accordingly, the output of the system simulation has been adjusted where possible to obtain consistent results for powered and drift grounding.

Figure 5.521 shows that between 60 and 78 percent of all predicted drift grounding involving outbound tankers will occur in the Hinchinbrook

Entrance--Gulf of Alaska area reflecting the decreased effectiveness of escort tugs in the more hostile environment outside of PWS. Figure 5.5.2-2 shows that the statistical frequency of drift grounding for inbound tankers is more than five times greater than the statistical frequency for outbound tankers; a difference that is accounted for by the presence of escort vessels for outbound tankers. The potential inbound tanker drift grounding are more dispersed by location, but the most probable areas for a drift grounding for an inbound tanker are Hinchinbrook Entrance, Central Sound, and Valdez Arm.

Figure 5.5.2-3 shows that powered grounding of outbound tankers are more evenly distributed between the Narrows, Arm, Hinchinbrook Entrance, and Port Valdez. Again, the method of defining locations in the system simulation produces an apparent conflict with the fault tree result in that the simulation predicts a significant statistical frequency for powered grounding in the Central Sound. If a human error occurred in Central PWS, however, a resulting powered grounding would occur in the Hinchinbrook Entrance area.

Figure 5.5.2-4 and 5.5.2-5 show that drift groundings and powered groundings show differing seasonal dependencies. The drift grounding frequencies are independent of season, reflecting the relative seasonal independence of the steering and propulsion failures that are the triggering incidents for drift groundings. As discussed in Section 4.1.5, the seasonal distribution of the historical propulsion and steering failures which could have been triggering events for a drift grounding is relatively uniform, showing a slight, but insignificant seasonality. Steering failures have been slightly more likely to occur in the summer and fall; propulsion failures slightly more likely to occur during the fall and winter. Powered grounding frequencies are predicted by the simulation to increase in the summer months, consistent with the increase in maneuvering required by traffic and ice conditions.

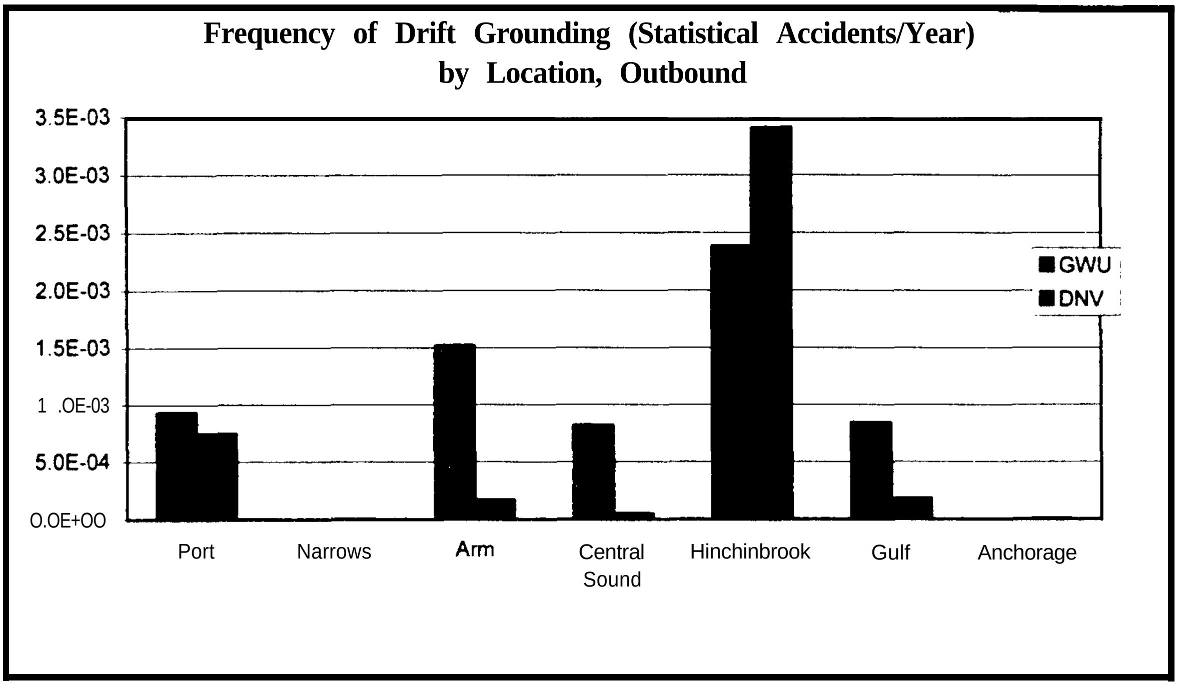


Figure 5.5.2-1

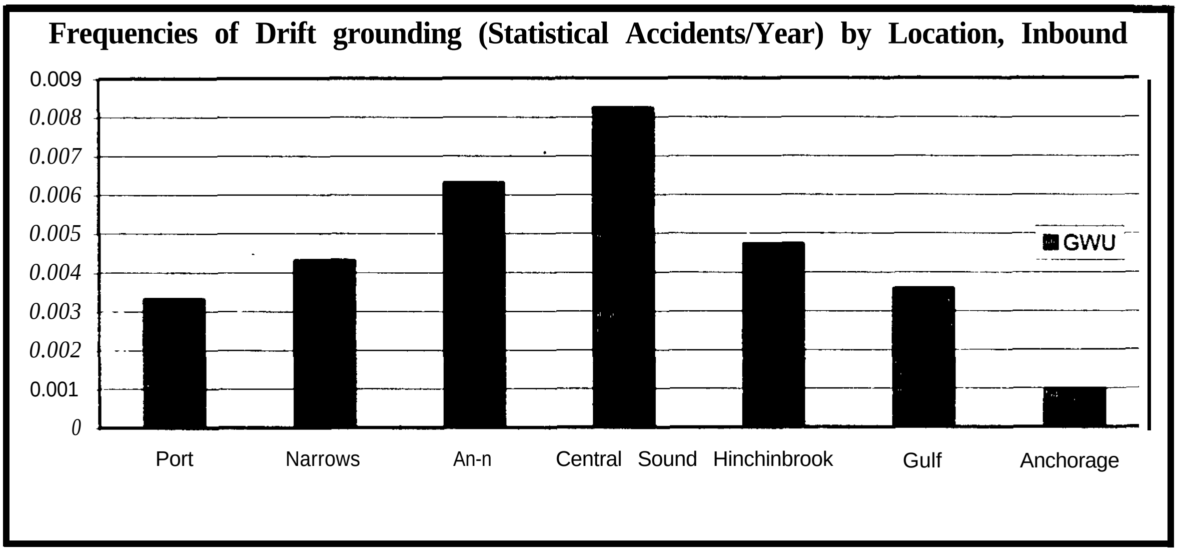


Figure 5.5.2-2

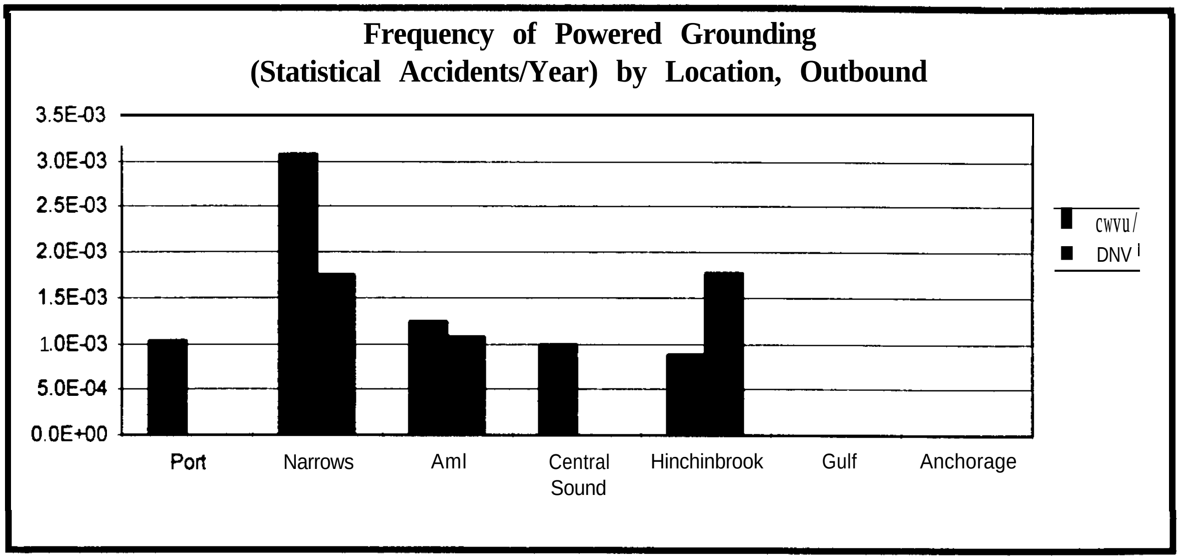

Frequency of Powered Grounding (Statistical Accidents/Year) by Location, Outbound

Figure 5.5.2-3

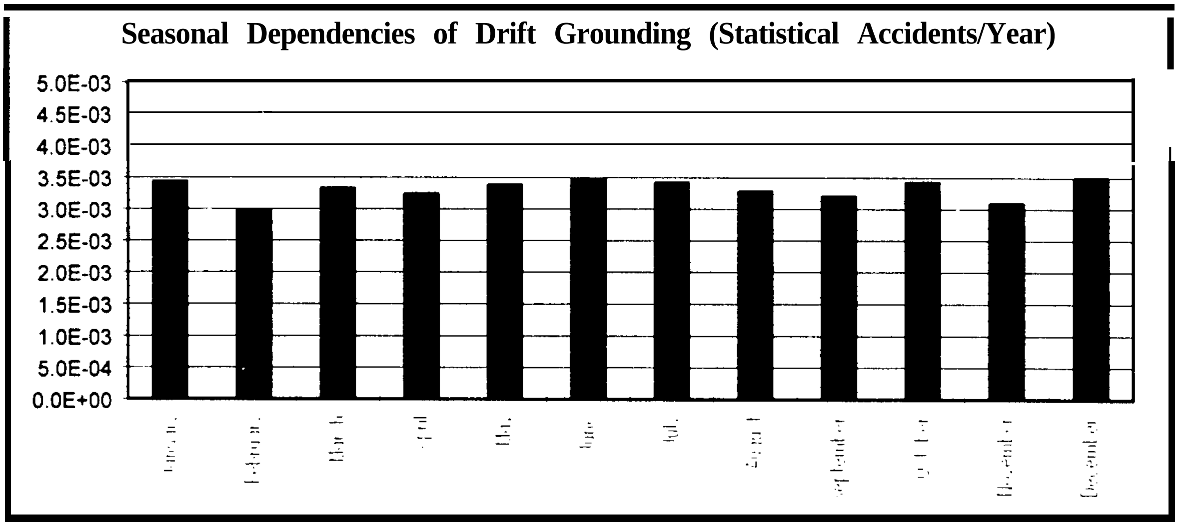

Seasonal Dependencies of Drift Grounding (Statistical Accidents/Year)

Figure 5.5.2-4

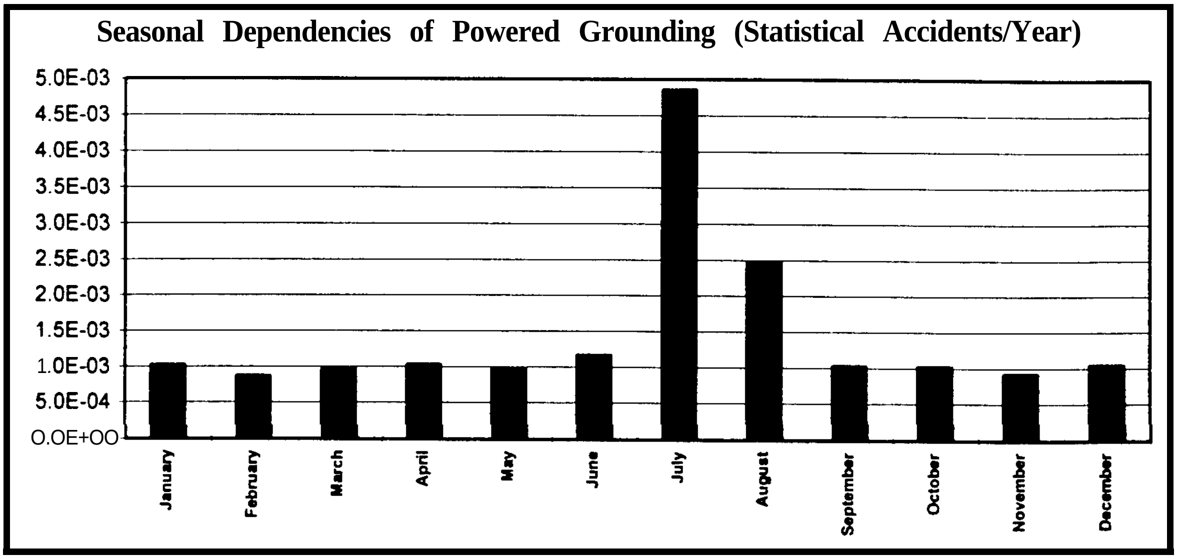


Figure 5.5.2-5

5.5.3 Location and Seasonal Dependence for Structural Failures

Structural failures are dependent upon time exposure in the system and the wind and weather conditions experienced. As shown in Figure 5.5.3-1, this dependence results in a distribution of structural failures that almost reflects the time spent by an outbound tanker in each area of the system. The distribution does, however, reflect the increased probability of structural failure per unit of exposure (time/mile) in the Gulf of Alaska or Hinchinbrook Entrance. Similarly, Figure 5.5.3-2 shows that the system simulation predicts that structural failures are more likely to occur in the winter months. This distribution corresponds to the actual seasonal variation with 82 reported structural failure incidents described in Section 4.15, Figure 4.2b.

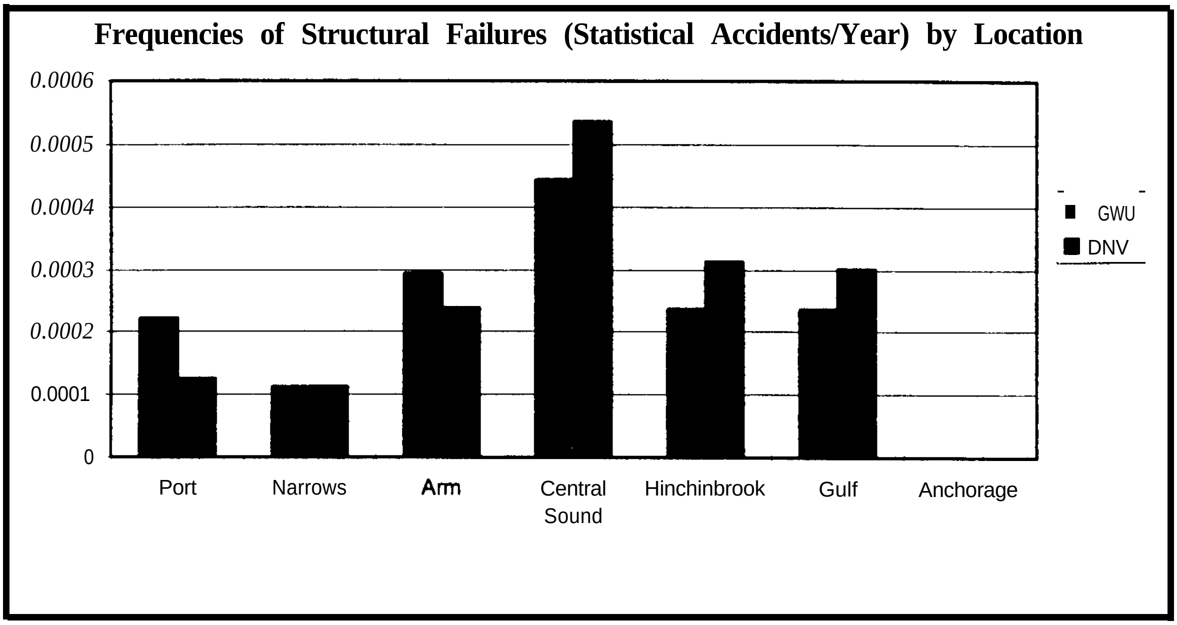


Figure 5.5.3-l

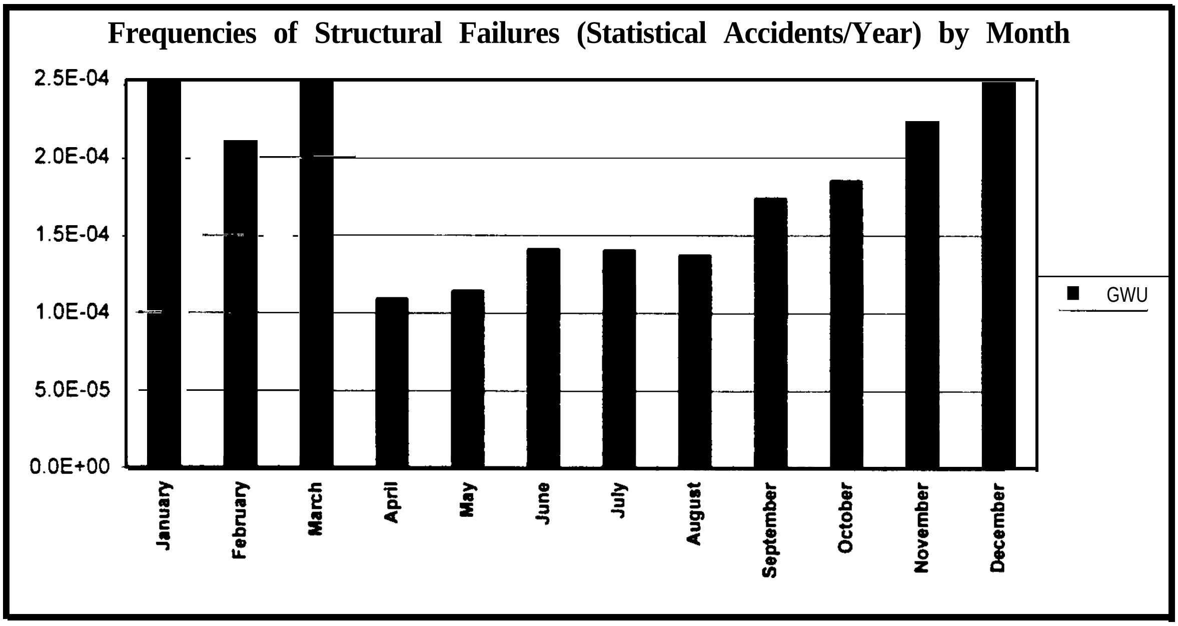


Figure 5.5.3-2

5.6 Analysis of Risk Reduction Potential

The dominant accident scenarios in the modified base case as per Table 5.3-2 (where the tethered tug is assumed to operate with the clutch disengaged) are collisions in the Port, Narrows, Arm, and Central Prince William Sound, drift grounding at Hinchinbrook Entrance and the Gulf of Alaska, and powered grounding in the Narrows, at Hinchinbrook Entrance, and in Valdez Arm. Targeting these risk scenarios has several strategic implications. A reduction in the frequency of drift grounding can be achieved by one or more of the following three methods:

- The reduction in frequency of the triggering propulsion or failure;
- The improvement in the save capability of escort and standby vessels; and
- The reduction of the exposure of tankers to conditions where escort vessels are unable to save a disabled tanker.

Powered groundings are primarily the result of human error. The effects of human error are reduced by: (1) preventing the occurrence of the error, or (2) detecting and correcting the error through external or internal vigilance. As discussed in Section 5.2, the dominant cause of powered grounding in the Narrows in the base case was human error on the tethered tug. Removing this error by establishing formal procedures that decouple the tanker from the effects of an error or failure on the tug renders the next dominant cause for power groundings in the Narrows to be exposure to human error on the tanker.

Collisions are reduced by reducing hazardous interactions or by lowering the probability that a collision will occur when an interaction takes place. In PWS, this implies that traffic management rules that consider the effects of traffic congestion and procedures that minimize human error will be effective.

Targeting specific accident scenarios will not be an optimal risk management strategy if the objective is to minimize the potential of oil outflows due to accidents. Table 5.3-4 shows that the range of predicted potential average oil outflows of accident scenarios varies by slightly more than one order of magnitude (4 tons/year to 64 tons/year). As shown in Table 5.3-2, the statistical accident frequencies for these same scenarios varies by approximately four orders of magnitude. This indicates that a prevention strategy that effectively targets a few high frequency accident scenarios will not be as effective in reducing oil outflows. For example, a utopian strategy that totally eliminated the risk of collision involving laden tankers in the Port, Arm, Narrows and Central Sound, the risk of drift grounding of laden tankers at Hinchinbrook Entrance and the risk of powered grounding of outbound tankers in the Narrows would reduce the statistical outbound accident frequency by approximately 85 percent. The reduction in potential oil outflow, although significant, would be approximately 50 percent of the total potential oil outflows from accidents involving outbound tankers. The oil outflow from accidents involving inbound tankers would not be affected.

The fact that half of the potential oil outflows in PWS are associated with a large number of very different scenarios indicates that an effective risk management strategy must have broad systemwide elements. Chapter 6 describes the develop ment of a framework for classifying and testing specifically targeted and broad systemic risk reduction interventions. The results of the analysis of these measures are described in Chapter 7.

5.7 MARCS/Fault Tree And System Simulation Results

The results described in Sections 5.3 through 5.6 were integrated from the results produced by the MARCS/FT and system simulation approach. The integrated risk results and comparison between results from each model are provided in Technical Documentation Part V, Section 5.4.

Detailed descriptions of results from each model are provided in Technical Documentation Part V, Section 5.1 for the simulation, Section 5.2 for the MARCS Model and in Section 5.3 for the fault tree models.

Modeling assumptions and uncertainties for each model are provided in Technical Documentation Part IV.

6.0 Risk Reduction Evaluation

6.0 Risk Reduction Evaluation

6.1 The Analysis And Evaluation Process

Two of the objectives of the Prince William Sound Risk Assessment project were to (1) identify, evaluate, and rank proposed risk reduction measures, and (2) to develop a risk management plan and risk management tools that can be used to support a risk management program. In order to make the system safer, risk reduction measures that significantly reduce system risk had to be identified and implemented. A logical and valid process for identifying, analyzing, and evaluating risk reduction measures was, therefore, an essential component of the PWS Risk Assessment. The eight step process shown in Figure 6. l-l and described below was developed to meet this need.

Step l--Collect risk reduction measures. Risk reduction measures were identified from three primary sources:

1. The public record -- Written comments on draft legislation and regulations (VTS, OPA 90, Pilotage, etc.) and contingency plans and public hearing records contained many suggested changes that have not been implemented.

2. Prior studies and reports -- Reports such as the 1990 Alaska Oil Spill Commission Report, the Federal and State Exxon Valdez On Scene Commander's reports, and two prior risk analyses of Prince William Sound provided another set of risk reduction measures.

3. The steering committee -- Members of the steering committee provided risk reduction measures that had been generated by their organizations.

Step 2-Group risk reduction measures by function. The 162 risk reduction measures identified in Step 1 were organized by creating a three level functional decomposition that categorized the measures based on functional implementation objectives. The objectives of the functional decomposition were to provide an understandable and logical presentation of the risk reduction measures that would ensure the evaluation of all critical measures without allocating extensive time on interventions that have little or no impact. The upper level of the classification consisted of the following five functional objectives.

1. Externally control and support vessel movement.
2. Improve human performance of shipboard personnel.
3. Improve ships by design, construction, or modification.

4. Improve external prevention and enforcement systems.
5. Improve emergency capability.

The second level of the functional hierarchy consisted of 16 sub categories, the third level of 43 functional types. Each of 162 risk reduction measures was assigned a Category, sub category and type classification. The resulting risk reduction measure listing and classification, is shown in Technical Documentation Part IV.

Step 3-Edit and review risk reduction measures. The members of the steering committee were asked to review the list of risk reduction measures, to identify redundancies and errors, and to comment on the following:

1. Completeness -- Are all the measures you submitted contained on the list?

2. Logical structure -- Do the definitions of categories, sub categories, and types make sense?

3. Logical consistency -- Are the measures assigned to the correct categories, sub categories, and type?

The revised list of measures produced by this review process is contained in Table A-IA, in Technical Documentation Part IV. Table A-1A compares the revised list of 117 edited and corrected risk reduction measures with the original 162 measures.

Step 4--Group risk reduction measures by performance. In order to test risk reduction measures, the risk reduction measures had to be converted to a form consistent with modeling parameters. The intended effects of the risk reduction measures on the system had to be identified before the appropriate modeling changes could be determined. A six stage framework based on the concept of the causal chain, developed for maritime risk assessment by Harrald (1995) based on earlier work by Baisuck and Wallace (1979), was used as a basis for this re-classification of risk measures. As shown in Figure 6.1-2, risk interventions can affect the system by influencing stages in the causal chain in one or more of the following six ways:

1. Decrease frequency of root or basic cause events.

2. Decrease frequency of immediate cause (triggering) events.

3. Decrease exposure to hazardous situations.

4. Intervene to prevent an accident if an incident (error or failure in hazardous situation) occurs.

5. Reduce consequences (oil outflows in the PWS case) if an accident occurs.

6. Reduce the impact of consequences (ameliorate impact of oil spills in PWS Risk Assessment case).

Category 6, reducing the impact of an oil spill once it occurs, is beyond the scope the PWS Risk Assessment. The remaining five categories were used as the basis for the risk reduction re-classification. The format of a three level decomposition was preserved. The second level of the new hierarchy contains nine sub categories and the third level contains 36 types.

Step 5--Identify risk measures in place in the base case, minimum safeguard case, and maximum safeguard case. The risk measures currently in place were identified using system documentation (VTS Users Manual, VTS Operating Manual, Vessel Escort and Response Plan), regulations, and laws. Procedures followed by shippers, the USCG, and Alyeska/SERVS not formally established were ascertained through interviews. A detailed description of these requirements is contained in the base case definition document. Risk reduction measures that could not be changed from the base case without changing regulations or laws that applied nationally or internationally were identified by the contract team. A minimum safeguard case was established based on this analysis. Additional safeguards above the base case were defined in operational terms. The results of this analysis performed in Steps 4 and 5 are shown in Table A-2, in Technical Documentation Part IV. Table 2 defines base case, minimum case, and additional safeguards above the base case for each of the 36 performance based risk reduction type classifications. Table A-2 was presented to the Steering Committee for comment and correction.

Step 6-Relate performance measures to model parameters. Evaluating risk reduction measures using the PWS Risk Assessment models (fault tree, system simulation, MARCS) required analysts to determine how the effect of each type of risk reduction measure could be represented in the language of one or more of the risk models. Table A-3, in Technical Documentation Part IV, shows how risk reduction measure types can be represented and which evaluations are conceptually possible using the PWS Risk Assessment models.

Step 7--Develop evaluation plan. The evaluation plan was based on the concept, previously stated, of using the hierarchical decomposition to ensure that critical areas were evaluated and valuable time was not allocated to evaluating marginal interventions. The resulting plan is shown in Figure 6.1-3. The assessment of the base case (Case A) risk was the basis for all risk reduction evaluations. Risk reduction measures in place in the base case are described in the Base Case Definition (see Section 3.10). Note that Figure 6.1-3 indicates two versions of the Base Case: Case A and Case Al. Case Al is the base case with formal procedures for the tethered tug in the Narrows described in Chapter 5 and is the case against which all other risk reduction measures are compared. Risk reduction measures in the minimum safeguard case (Case B) and the maximum safeguard case (Case C) and all other cases tested are described in Table 6-l through Table 6-17. The model changes required to implement each risk reduction case are shown in Table 6-l 8. The risk reduction evaluation then proceeded in three phases:

1. In phase one of the risk reduction evaluation, the system risk resulting from the minimum safeguard case and the maximum safeguard case were assessed. Comparing the base case results to the minimum and maximum cases provided a valuable assessment of the relative effectiveness of measures already in place in the baseline case. The risk reduction measures removed or adjusted to produce the minimum safeguard case (Case B) are shown in Table 6-1. A minimum external safeguard (no closure conditions, no escorts) case assuming the existing fleet is operated and managed in the Base Case is defined in Table 6-2. Table 6-3 defines a no escort/base case fleet case. The risk reduction measures included in the maximum safeguard case (Case C) are shown in Table 6-4. Risk reduction measures that could not be implemented in the maximum safeguards case are shown in bold in Table 6-4. Table 6-5 defines a maximum external safeguard case, assuming the fleet is managed and operated as in the base case.

2. In phase two of the risk reduction evaluation, the system risk was assessed when groups of measures represented by each of the five general categories listed in Step 4 (the top level of the hierarchy in Figure 6-3) were implemented producing Cases 1,2,3,4 and 5. The measures implemented in each of these cases are listed in Tables 6-6 through 6-12. (Note that there are two versions of both Case 1 and Case 5). The changes to the models that were made to represent these changes are listed as Cases 1 through 5 in Table 6-25. Risk reduction measures that are not represented by the changes in model parameters are highlighted in bold type (with a reference to reasons provided in Section 6.2) in Tables 6-6 through 6-12.

3. In phase three of the risk reduction measure evaluation, the system risk was assessed when smaller changes are made to the system. The effect of the implementation of groups of measures composed of subgroups or types or individual risk reduction measures were assessed. The risk reduction measures represented by these changes and the risk model parameter changes made to represent these interventions are shown in Tables 6- 13 through 6-24 (Cases 1.1, 1.2, 1.1.1, 1.1.2, 1.1.3, 3.1, 3.1.1, 3.2, 3.2A, 3.3, 4.1, 4.2). Model changes required to implement these interventions are also shown in Table 6-25.

Step 8--Produce risk results. The risk models were adapted, appropriate computer runs were performed, and results were obtained as described in Chapter 7.

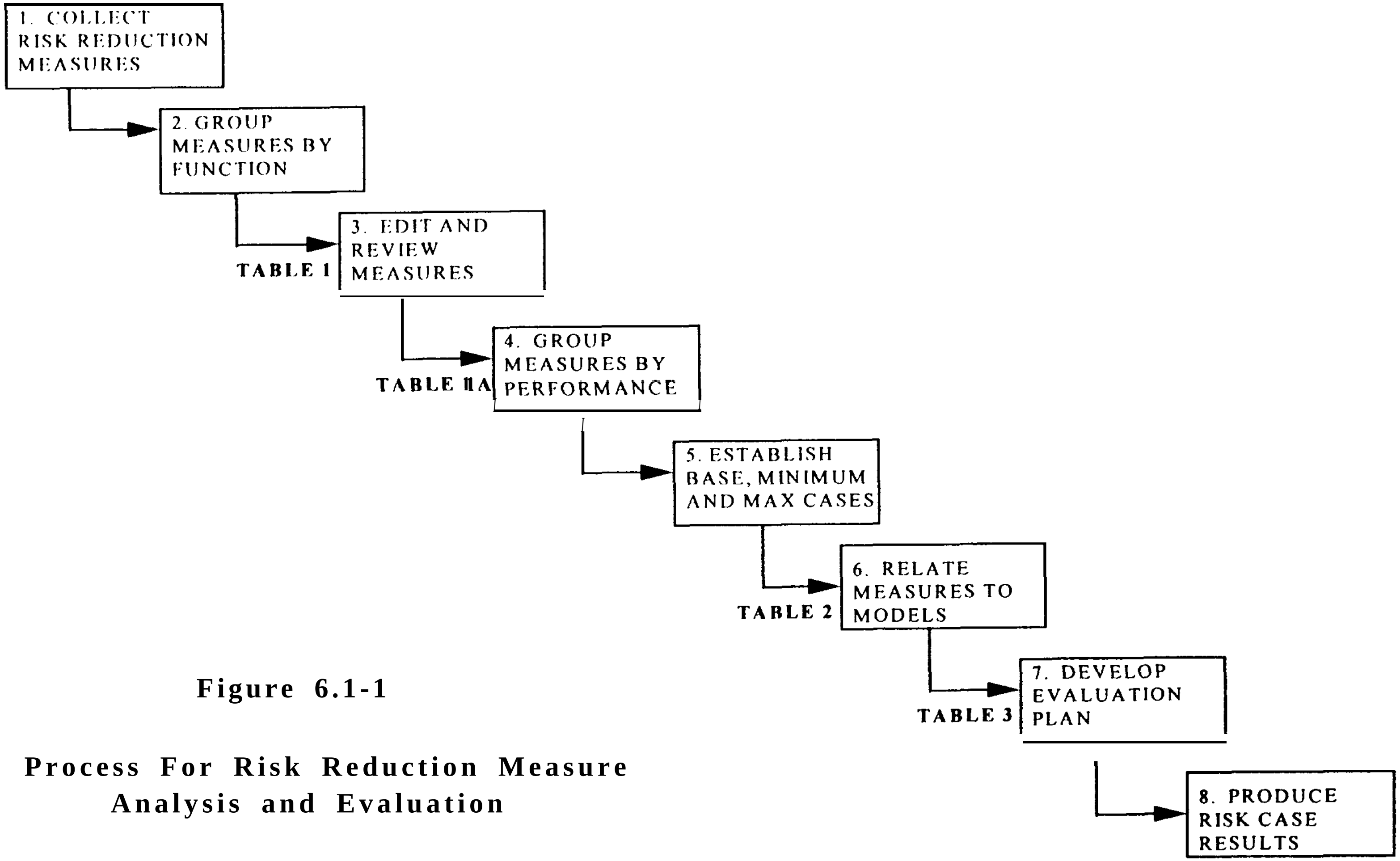


Figure 6.1-1

Process For Risk Reduction Measure Analysis and Evaluation

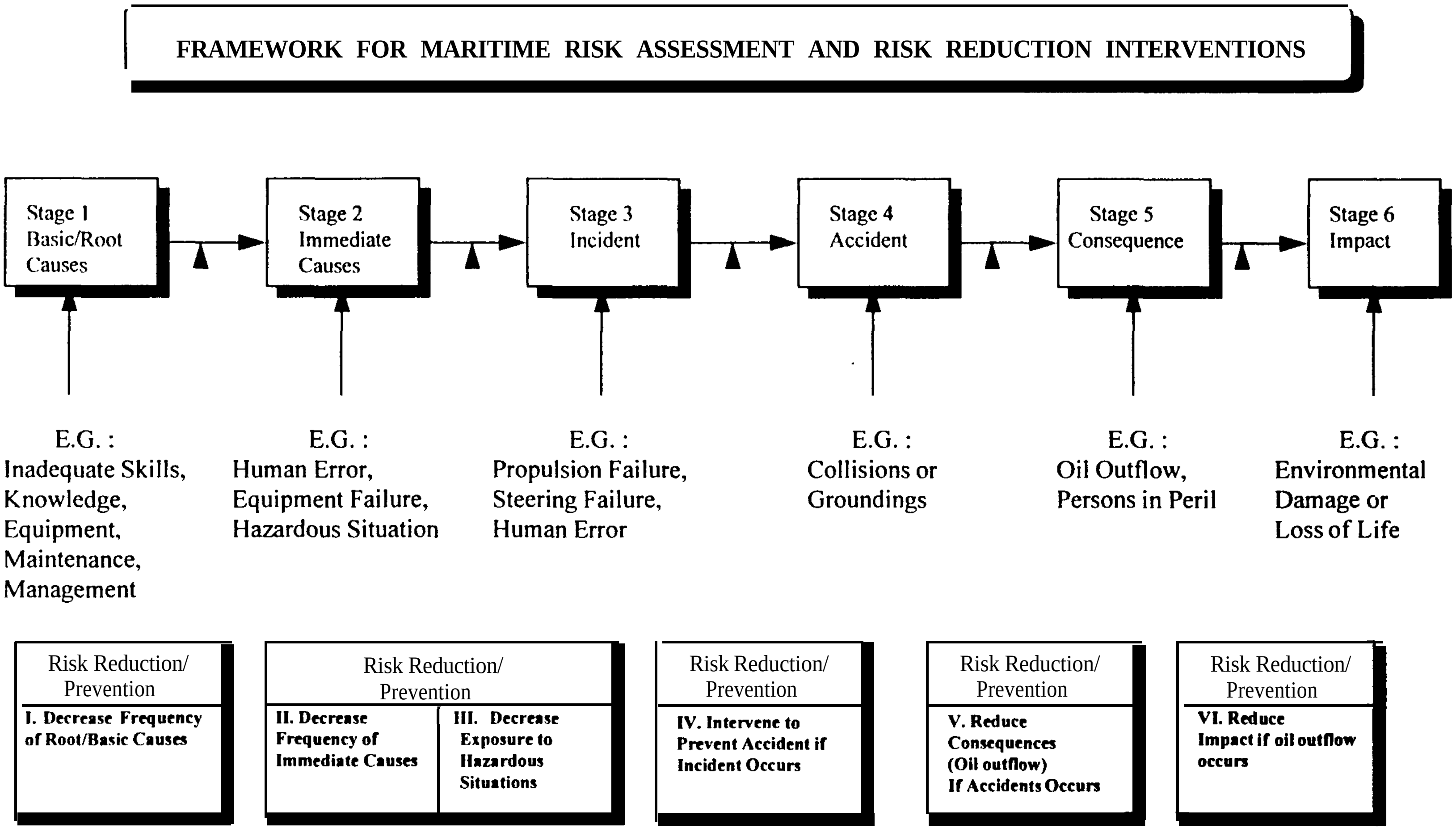

FRAMEWORK FOR MARITIME RISK ASSESSMENT AND RISK REDUCTION INTERVENTIONS
Stage 1 Basic/Root Causes
Stage 2 Immediate Causes
Stage 3 Incident
Stage 4 Accident
Stage 5 Consequence
Stage 6 Impact
E.G. : Inadequate Skills, Knowledge, Equipment, Maintenance, Management
E.G. : Human Error, Equipment Failure, Hazardous Situation
E.G. : Propulsion Failure, Steering Failure, Human Error
E.G. : Collisions or Groundings
E.G. : Oil Outflow, Persons in Peril
E.G. : Environmental Damage or Loss of Life
Risk Reduction/ Prevention
I. Decrease Frequency of Root/Basic Causes
Risk Reduction/ Prevention
II. Decrease Frequency of Immediate Causes
III. Decrease Exposure to Hazardous Situations
Risk Reduction/ Prevention
IV. Intervene to Prevent Accident if Incident Occurs
Risk Reduction/ Prevention
V. Reduce Consequences (Oil outflow) If Accidents Occurs
Risk Reduction/ Prevention
VI. Reduce Impact if oil outflow occurs

Figure 6.1-2

Structure For Evaluation of Effectiveness of Risk Reduction Measures

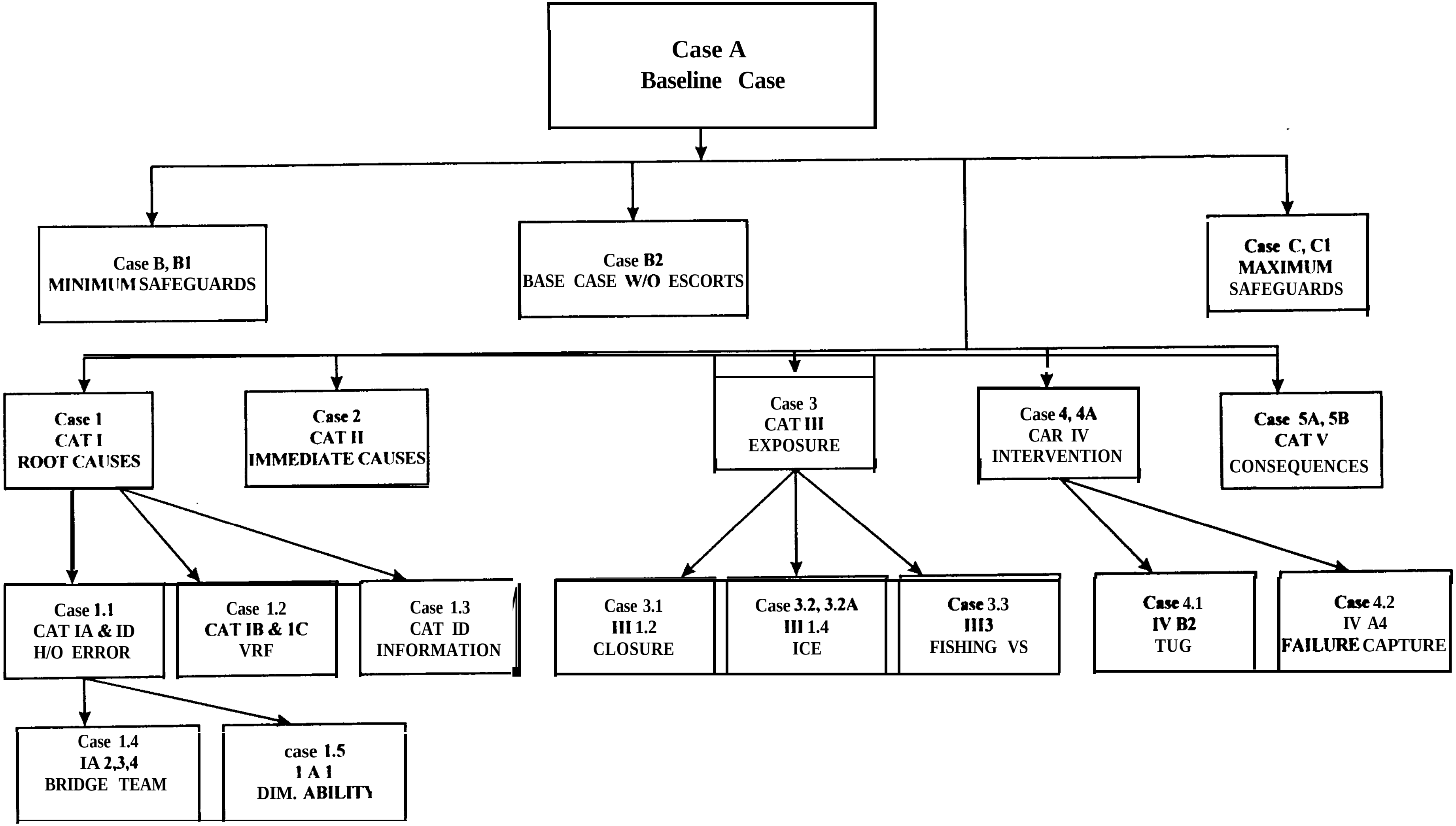


Figure 6.1-3

6.2 Risk Reduction Cases Evaluated

Not all risk reduction measures specified as part of the cases listed in Tables 6-l through 6-24 below were modeled as the cases were implemented (see Section 6.3 and Chapter 7). The tables indicate which of the following reasons were the basis for omitting each specific proposed risk reduction measure from the analysis:

> ‘Models are currently incapable of capturing the level of detail specified.
> ‘Data are not available to determine the values of modeling parameter changes.
> [3]Measure was not tested in case indicated since it is redundant with other measures included in the case. It was, however, tested as an independent case.
> [4]Decision made to test in follow on analysis, if significant benefit is indicated.
> ‘Equivalent risk reduction measure tested, see Chapter 7.

Table 6-1--CASE B
Minimum Safeguard Case (Changes From The Base Case)

RISK REDUCTION MEASURE CATEGORY	**CHANGES FROM BASE CASE**
I. Decrease frequency of root cause events	IA. Human and Organizational Error
	1. Random drug tests for masters instead of testing each voyage
	3. IMO STCW manning standards for vessels
	6. Crew stability equal to company with maximum turnover in base fleet
	IB. Vessel Reliability Failures
	1. Entire fleet scores equal to minimum shipper score on IMSRS
	ID. Better decision making information
	1. Remove ADSS equipment
	2. Remove vessel traffic control (VTS communications)
	3. Disestablish Bligh Reef Light tower
	4. Disestablish weather buoys
	6. Discontinue VTC relay of ice information

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of immediate causal events	IIA. Internal and External Vigilance 1. Two officers on bridge, no pilot beyond Valdez Arm
III. Decrease exposure to hazardous situations	1. Remove all transit restrictions except exclusion zone in the Narrows 2. Eliminate all VTSA rules except TSS and Exclusion Zone 3. Increase fishing vessels transit by 10 percent
IV. Improve ability to intervene to prevent accident if incident occurs	IVA. Error recognition and recovery 1. Tankers transit at sea speed (14 kts) in sound and Arm, 10 kts in Narrows IVB. Improve external save capability 1. No escort vessels 2. No tethered tug in Narrows 3. No standby ERVs at Hinchinbrook and Naked Island
V. Reduce Consequences if accident occurs	

Table 6-2--CASE B.1
Minimum Safeguard with Base Case Parameters

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
III. Decrease exposure to hazardous situations	1. Remove all transit restrictions except Exclusion Zone in the Narrows 2. Eliminate all VTSA rules except TSS and Exclusion Zone
IV. Improve ability to intervene to prevent accident if incident occurs	IVA. Error recognition and recovery 1. Tankers transit at sea speed (14 kts) in sound and Arm, 10 kts in Narrows IVB. Improve external save capability 1. No escort vessels 2. No tethered tug in narrows 3. No standby ERVs at Hinchinbrook and Naked Island

Table 6-3--CASE B.2
Base Case Without Escort Vessels

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
IV. Improve ability to intervene to prevent accident if incident occurs	IVA. Error recognition and recovery 1. Tankers transit at sea speed (14 kts) in sound and Arm, 10 kts in Narrows IVB. Improve external save capability 1. No escort vessels 2. No tethered tug in narrows 3. No standby ERVs at Hinchinbrook and Naked Island

Table 6-4--CASE C
Maximum Safeguard Case (Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	IA. Human and Organizational Error 1. Drug test escort masters, pilot, tanker bridge team and engine room watch prior to transit 2. More restrictive work hour standards (75 percent of OPA 90 standards) 3. Extra mate on tanker, Chief mate as not watchstander, additional ABS on tanker as expert helmsman 4. All shipping companies adopt ISM code, SERVS and Southwest Alaska Pilots Association adopt equivalent standards 5. Bridge team stability of entire fleet equal to best performers 6. Require integrated bridge team training with pilot, interactions with ERV IB. Vessel Reliability Failures 1. All vessels equal to best performers on IMSRS IC. Detect Hazardous Conditions 1. Entire fleet equal to best performers on IMSRS and expert judgment questionnaires

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
	ID. Better Decision Making Information 1. ADSS on all vessels, failure alarms on all navigational equipment, assume perfect navigation information available, side scan sonar on all vessels 2. Expand VTS radar coverage to cover entire VTSA, VTC plot ADSS on all vessels required to participate in VTSA, perfect information on location of hazards available 3. RACON on Bligh Reef and Naked Island, perfect navigational information available 4. Real time weather reporting at Hinchinbrook, Middle Rock. Real time current reporting in the Narrows Perfect information on weather and current available 5. Electronic charts available and used on all tankers. Redundancy of all navigational equipment. Perfect information available to fix ships position. 6. VTS/SERVS real time reporting of ice conditions. Side scan sonar on tankers. Perfect information available on ice conditions.
II. Decrease frequency of immediate causal events	IIA. Internal and External Vigilance 1. **Standard job descriptions on 2nd officer, standard pilot-master and escort briefings'**

RISK REDUCTION MEASURE CATEGORY	**CHANGES FROM BASE CASE**
	2. Third officer on the bridge when transiting Hinchinbrook, Narrows, or ice 3. State pilots embark/disembark at Hinchinbrook, port closed when pilots unable to board
II. Decrease exposure to hazardous situations	1. Decrease closure conditions in Narrows by 10 kts wind, ½ m visibility Decrease Hinchinbrook closure conditions by 15 kts wind and by **6 ft wave conditions**[2] Close entire system when Narrows is closed Daylight transits only in ice Assume perfect information of hazardous situations 2. Extend one-way zone to 146 35' W Extend TSS to 20 miles offshore **Establish TSS for westbound traffic, establish one-way zone through Hinchinbrook**[4] 3. Control fishing vessel, tanker interactions **by limiting tanker transits during openers or scheduling openers.**[5] Require fishing vessels to participate in VTS. 4. Require ice transit to be at 6 kts with ice lights on tankers

RISK REDUCTION MEASURE CATEGORY	**CHANGES FROM BASE CASE**
V. Improve ability to intervene to prevent accident if incident occurs	**WA. Error Recognition and Recovery** **1. Range on speeds in Narrows, Arm and Central Sound. Choose optimal speed for each area**[4] **2. Perfect information available to detect tank leak, inert gas leak, and navigation equipment failure’** **3. Person and TV camera on steering flat through Narrows’** **4. All vessels provide redundancy in system that will prevent 50 percent of all steering and propulsion failures**[3] [VB. Improve External Save Capability **1. Enhanced towing training program for ERVS and escorts, rapid deployment emergency towing package on all tankers (bow and stern)**[4] 2. Propeller disengaged on tethered tug. Two mates on the bridge of tethered tug, tug with enhanced power and maneuverability 3. Enhanced escort capability--tug capable of holding and towing tankers under all conditions. Increase power and maneuverability; **provide three tugs for docking and undocking of tankers**[4] **4. Increase crew stability on tugs through dedicated crews**[4]

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
	5. Revise escort program: preposition enhanced escort tug at Hinchinbrook, escort to 60 49"N (through Narrows and Am), proceed without escorts to 60 27', escort through Hinchinbrook, provide enhanced capability tug vessel at Hinchinbrook
V. Reduce Consequences if accident occurs	1. **Require hydrostatic loading of all single hull tankers, and for wing tanks only on double bottom tankers**[3] 2. Replace fleet with double hull tankers, require bunkers to be inside of double hull

Table 6-5--CASE Cl
Maximum Safeguard Case With Base Case Parameters

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
III. Decrease exposure to hazardous situations	1. Decrease closure conditions in Narrows by 10 kts wind, ½ m visibility Decrease Hinchinbrook closure conditions by 15 **kts** wind and **by 6 ft wave conditions**[2] Close entire system when Narrows is closed
IV. Improve ability to intervene to prevent accident if incident occurs	Enhanced escort capability--tug capable of holding and towing tankers under all conditions

Table 6-6--Case 1
Root Cause -Improved Human/Organizational Performance Case
(As Modeled In The System Simulation-Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
. Decrease frequency of root cause events	IA. Human and Organizational Error 1. Drug test escort masters, pilot, tanker bridge team and engine room watch prior to transit 2. More restrictive work hour standards (75 percent of OPA 90 standards) 3. Extra mate on tanker, Chief mate as not watchstander, additional ABS on tanker as expert helmsman 4. All shipping companies adopt ISM code, SERVS and Southwest Alaska Pilots Association adopt equivalent standards 5. Bridge team stability of entire fleet equal to best performers 6. Require integrated bridge team training with pilot, interactions with ERV IB. Vessel Reliability Failures 1. All vessels equal to best performers on IMSRS IC. Detect Hazardous conditions 1. Entire fleet equal to best performers on IMSRS and expert judgment questionnaires ID. Better decision making information

RISK REDUCTION MEASURE CATEGORY	CHANGES-FROM BASE CASE
	1. ADSS on all vessels, failure alarms on all navigational equipment, assume perfect navigation information available, side scan sonar on all vessels 2. Expand VTS radar coverage to cover entire VTSA, VTC plot ADSS on all vessels required to participate in VTSA, perfect information on location of hazards available 3. RACON on Bligh Reef and Naked Island, perfect navigational information available 4. Real time weather reporting at Hinchinbrook, Middle Rock. Real time current reporting in the Narrows. Perfect information on weather and current available 5. Electronic charts available and used on all tankers. Redundancy of all navigational equipment. Perfect information available to fix ships position 6. VTS/SERVS real time reporting of ice conditions. Side scan sonar on tankers. Perfect information available on ice conditions

Table 6-7--Case 1A
Improved Human And Organizational Performance
(As modeled in Fault Tree/MARCS--Changes from the Base Case)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	IA. Human and Organizational Error 1. Drug test escort masters, pilot, tanker bridge team and engine room watch prior to transits 2. All shipping companies adopt ISM code, SERVS and Southwest Alaska Pilots Association adopt equivalent standards 3. Require integrated bridge team training with pilot, interactions with ERV IB. Vessel Reliability Failures 1. All vessels equal to best performers on IMSRS IC. Detect Hazardous Conditions 1. Entire fleet equal to best performers on IMSRS and expert judgment questionnaires
II. Decrease frequency of immediate causal events	IIA. Internal and External Vigilance 1. Standard job descriptions on 2nd officer, standard pilot-master and escort briefings
IV. Improve ability to intervene to prevent accident if incident occurs	IVA. Error Recognition and Recovery 2. Perfect information available to detect tank leak, inert gas leak, and navigation equipment failure

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
	IVB. Improve External Save Capability 1. Enhanced towing training program for ERVS and escorts, rapid deployment emergency towing package on all tankers

Table 6-8-Case 2
Immediate Cause/Improved Vigilance Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
II. Decrease frequency of immediate causal events	IIA. Internal and External Vigilance 1. **Standard job descriptions on 2nd officer, standard pilot-master and escort briefings** [1] 2. Third officer on the bridge when transiting Hinchinbrook, Narrows, or ice 3. State pilots embark/disembark at Hinchinbrook, port closed when pilots unable to board

Table 6-9 Case 3
Reduced Exposure To Hazardous Situation Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGESFROM BASE CASE
[II. Decrease exposure to ıazardous situations	1. Decrease closure conditions in Narrows by 10 kts wind, ½ m visibility Decrease Hinchinbrook closure conditions by 15 kts wind and **by 6 ft wave conditions** [2] Close entire system when Narrows is closed Daylight transits only in ice Assume perfect information of hazardous situations 2. Extend one-way zone to 146 35' W Extend TSS to 20 miles offshore **Establish TSS for westbound traffic, establish one-way zone through Hinchinbrook** [4] 3. Control fishing vessel, tanker interactions **by limiting tanker transits during openers or scheduling openers."** Require fishing vessels to participate in VTS. 4. Require ice transit to be at 6 kts with ice lights on tankers

Table 6-10--Case 4
Intervention/Revised Escort Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
IV. Improve ability to intervene to prevent accident if incident occurs	**IVA. Error Recognition and Recovery** 1. **Range on speeds in Narrows, Arm and Central Sound. Choose optimal speed for each area**[4] 2. **Perfect information available to detect tank leak, inert gas leak, and navigation equipment failure’** 3. **Person and TV camera on steering flat through Narrows’** 4. **All vessels provide redundancy in system that will prevent 50 percent of all steering and propulsion failures (TESTED SEPARATELY AS CASE 4.2)**[3] IVB. Improve External Save Capability 1. **Enhanced towing training program for ERVS and escorts, rapid deployment emergency towing package on all tankers (bow and stern)**[4] 2. Propeller disengaged on tethered tug. Two mates on the bridge of tethered tug. tug with enhanced power and maneuverability 3. Enhanced escort capability--tug capable of holding and towing tankers under all conditions. Increase power and

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
	maneuverability; **provide three tugs for docking and undocking of tankers**[4] 4. **Increase crew stability on tugs through dedicated crews**[4] 5. Revise escort program: preposition enhanced escort tug at Hinchinbrook, escort to 60 49"N (through Narrows and Arm), proceed without escorts to 60 27', escort through Hinchinbrook, **provide enhanced capability tug at Hinchinbrook**[3] **(ENHANCED CAPABILITY TUG AT HINCHINBROOK ENTRANCE IN PREPOSITIONED ESCORT CASE TESTED SEPARATELY AS CASE 4A.)**

Table 6-11--Case 5A
Consequences-Double Hull Fleet Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
V. Reduce Consequences if accident occurs	1. Replace fleet with double hull tankers, require bunkers to be inside of double hull

Table 6-12--Case 5B
Consequences--Hydrostatic Loading Of Single Hull Vessel Case
(Changes From The Base Case)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
V. Reduce Consequences if accident occurs	Require hydrostatic loading of all single hull tankers, and for wing tanks only on double bottom tankers

Table 6-13--Case 1.1
Reduced Human Error Case (Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	IA. Human and Organizational Error 1. Drug test escort masters, pilot, tanker bridge team and engine room watch prior to transit 2. More restrictive work hour standards (75 percent of OPA 90 standards) 3. Extra mate on tanker, Chief mate as not watchstander, additional ABS on tanker as expert helmsman 4. All shipping companies adopt ISM code, **SERVS and Southwest Alaska Pilots Association adopt equivalent standards'** 5. Bridge team stability of entire fleet equal to best performers 6. Require integrated bridge team training with pilot, interactions with ERV ID. Better Decision Making Information 1. ADSS on all vessels, failure alarms on all navigational equipment, assume perfect navigation information available, side scan sonar on all vessels 2. Expand VTS radar coverage to cover entire VTSA, VTC plot ADSS on all vessels required to participate in VTSA, perfect information on location of hazards available

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
	3. RACON on Bligh Reef and Naked Island, perfect navigational information available **4.** Real time weather reporting at Hinchinbrook, Middle Rock. Real time current reporting in the Narrows. Perfect information on weather and current available **5.** Electronic charts available and used on all tankers. Redundancy of all navigational equipment. Perfect information available to fix ships position **6.** VTS/SERVS real time reporting of ice conditions. Side scan sonar on tankers. Perfect information available on ice conditions

Table 6-14-Case 1.2
Reduced Vessel Failure Case (Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	IB. Vessel Reliability Failures 1. All vessels equal to best performers on IMSRS

Table 6-15--Case 1.1.1
Improved Navigation And Training Information Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	ID. Better Decision Making Information 1. ADSS on all vessels, failure alarms on all navigational equipment, assume perfect navigation information available, side scan sonar on all vessels 2. Expand VTS radar coverage to cover entire VTSA, VTC plot ADSS on all vessels required to participate in VTSA, perfect information on location of hazards available 3. RACON on Bligh Reef and Naked Island, perfect navigational information available 4. Real time weather reporting at Hinchinbrook, Middle Rock. Real time current reporting in the Narrows. Perfect information on weather and current available 5. Electronic charts available and used on all tankers. Redundancy of all navigational equipment. Perfect information available to fix ships position 6. VTS/SERVS real time reporting of ice conditions. Side scan sonar on tankers. Perfect information available on ice conditions

Table 6-16--Case 1.1.2
Improved Management And Crew Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	IA. Human and Organizational Error 2. More restrictive work hour standards (75 percent of OPA 90 standards) 3. Extra mate on tanker, Chief mate as not watchstander, additional ABS on tanker as expert helmsman 4. All shipping companies adopt ISM code, **SERVS and Southwest Alaska Pilots Association adopt equivalent standards'** 5. Bridge team stability of entire fleet equal to best performers

Table 6-17--Case 1.1.3
Reduced Diminished Ability Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
I. Decrease frequency of root cause events	IA. Human and Organizational Error 1. Drug test escort masters, pilot, tanker bridge team and engine room watch prior to transit

Table 6-18--Case 3.1
Stricter Closure Condition Case
(Changes From The Base Case)
(Changes Indicated In Bold Not Implemented In Models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
111. Decrease exposure to hazardous situations	Decrease closure conditions in Narrows by 10 kts wind, ½ m visibility Decrease Hinchinbrook closure conditions by 15 kts wind and **by 6 ft wave conditions**[2] Close entire system when Narrows is closed Daylight transits only in ice Assume perfect information of hazardous situations 2. Extend one-way zone to 146 35’ W Extend TSS to 20 miles offshore **Establish TSS for westbound traffic, establish one-way zone through Hinchinbrook**[4]

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
III. Decrease exposure to hazardous situations	Decrease Hinchinbrook closure conditions by 15 kts wind and **by 6 ft wave conditions**[2]

Table 6-20--Case 3.2
Revised Ice Procedures Case (Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
III. Decrease exposure to hazardous situations	1. Daylight transits only in ice 4. Require ice transit to be at 6 kts Remain in lanes during ice conditions, reduce speed rather than maneuver in ice to eliminate dangerous courses (MODELED INDEPENDENTLY AS CASE 3.2A)

Table 6-21--Case 3.2A
Revised Ice Procedures Case (Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
III. Decrease exposure to hazardous situations	1. Created dependable ice reporting system 2. When ice is reported, use pre-determined course outside of lanes (toward Bligh Reef). Do not maneuver, maintain 10 kts

Table 6-22--Case 3.3
Revised Fishing Vessel Tanker Rules Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
III. Decrease exposure to hazardous situations	3. Control fishing vessel, tanker interactions by limiting tanker transits during openers or scheduling openers. Require fishing vessels to participate in VTS

Table 6-23--Case 4.1
Improved Tethered Tug Procedures Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
IV. Improve ability to intervene to prevent accident if incident occurs	2. Propeller disengaged on tethered tug 75 percent of time. Two mates on the bridge of tethered tug, tug with enhanced power and maneuverability, range on tug speeds (5,6,8 kts) 3. Enhanced escort capability--tug capable of holding and towing tankers under all conditions. Increase power and maneuverability; operate in indirect mode in Narrows, range on tug speed (6,8, 10 kts) **provide three tugs for docking and undocking of tankers**[4] **4. Increase crew stability on tugs through dedicated crews**[4]

Table 6-24--Case 4.2
Reduce Steering & Propulsion Failure Rate Case
(Changes From The Base Case)
(Changes indicated in bold not implemented in models)

RISK REDUCTION MEASURE CATEGORY	CHANGES FROM BASE CASE
IV. Improve ability to intervene to prevent accident if incident occurs	IVA. Error Recognition and Recovery 4. All vessels provide redundancy in system that will prevent 50 percent of all steering and propulsion failures

6.3 Model Parameter Changes Required To Implement Risk Reduction Cases

The risk reduction measures in the minimum safeguard case and maximum safeguard case and in each of the cases listed described in Tables 6-1 through 6-24 had to be translated into changes in modeling parameters in each risk model before their impacts could be evaluated. Two versions of the base case, three cases with current risk reduction measures removed (two versions of the minimum risk reduction case and a no escort case), two versions of a maximum intervention case, and twenty risk reduction intervention cases were modeled. The results of this analysis are described in Chapter 7. The cases tested in each model (Fault tree, MARCS, System Simulation) and the modeling rules used to translate risk reduction measures to model parameter changes are described in Table 6-25. The modeling rules for the System Simulation, Fault Tree Model, and MARCS referred to in the table are described in the text following the table.

Table 6-25
Risk Reduction Cases Related To Modeling Rules

RISK REDUCTION CASE (Refer to Tables *1-22* for definitions)	SYSTEM SIMULATION	MARCS	FAULT TREE MODEL
A. BASE CASE	Defined in Sec 3.10	Defined in Sec 3.10	Defined in Sec 3.10
A. 1 BASE CASE with improved tethering procedures	–	Defined in Sec. 3.10 with rules 17,18 for tethered tug	Defined in Sec. 3.10 with rules 17,18 for tethered tug

RISK REDUCTION CASE (Refer to Tables 1-22 for definitions)	SYSTEM SIMULATION	MARCS	FAULT TREE MODEL
B. (Minimum Safeguard Case) Table 6-I	Rules A, B Rules 1,2,3	Rules A, B Rules 10,11,12	
B. 1 Minimum Safeguard Case with Base Case Parameters Table 6-2	Rules A,B	Rules A,B	
8.2 Base Case without escort vessels Table 6-3	Rule A	Rule A	
C. Maximum Safeguard Case Table 6-4	Rules C,D,E,F1 Rules 4,6,7,8,9	Rules C, F2 Rules 10,11,12,20	
C. 1 Maximum Safeguard Case with Base Case Parameters Table 6-5	Rules C,F	Rules C, F	
1. Improved Human and Organizational Performance Table 6-6	Rules 4,6,7,8		
1 .A Improved Human and Organizational Performance Table 6-7		Rule 20	
2. Improved Vigilance Table 6-8	Rule 9		

RISK REDUCTION CASE (Refer to Tables 1-22 for definitions)	SYSTEM SIMULATION	MARCS	FAULT TREE MODEL
3. Reduced Exposure Table 6-9	Rules C, D, E		
4. Revised Escort-Intervention Table 6-10	Rule F1	Rules F1	
4.A Revised escort-intervention case with enhanced capability tug at Hinchinbrook Entrance		Rule F2	
5.A (Consequences--Double Hulled Fleet) Table 6-11	Rule 13	Rule 13	
5.B (Consequences--Hydrostatic Loading for single hull vessels) Table 6-12	Rule 14	Rule 14	
1.1 Reduced Human and Organizational error Table 6-13	Rules 6,7,8		
1.2 Reduced vessel reliability failures (all ship in fleet equal to best) Table 6-14	Rule 4		

RISK REDUCTION CASE (Refer to Tables 1-22 for definitions)	SYSTEM SIMULATION	MARCS	FAULT TREE MODEL
1.1.1 Improved training and navigation information Table 6-l 5	Rule 7		
1.1.2 Improved Bridge Team Management Table 6- 16	Rule 8		
1.1.3 Reduced Diminished Ability Table 6- 17	Rule 6		
3.1 Stricter closure conditions Table 6-l 8	Rule C	Rule C	
3.1.1 Stricter closure at Hinchinbrook Ent. Table 6-l 9	Rule C1		
3.2 Revised Ice Procedures--limited maneuvering , reduced speed Table 6-20	Rule D		Rule D, Rule 15
3.2A Revised Ice Procedures--alternate course, improved ice reporting Table 6-2 1			Rule 16
3.3 Revised Fishing vessel/tanker interaction rules Table 6-22	Rule E		

RISK REDUCTION CASE (Refer to Tables l-22 for definitions)	SYSTEM SIMULATION	MARCS	FAULT TREE MODEL
4.1 Tug in indirect mode in Narrows Table 6-23			Rule 19
4.2 Reduce steering and propulsion failures by 50 percent Table 6-24	Rule 5		

6.3.1 Rules For Changes To System Simulation And MARCS Situational Parameters

Rule A:	ESCORT (Simulation, MARCS) Remove Escort Program
Rule B:	CLOSURE (Simulation, MARCS) Remove Closure Conditions in Narrows and Hinchinbrook Entrance
Rule C:	CLOSURE (Simulation, MARCS) Decrease Closure Conditions by 10 kts at Narrows, 15 kts at Hinchinbrook Entrance, extend one-way zone to 146 35'W.
Rule Cl:	CLOSURE AT HINCHINBROOK ENTRANCE (Simulation) Close Hinchinbrook Entrance at 30kt wind to laden tankers > 150,000 DWT.
Rule D:	ICE (Simulation, MARCS) Ice transits at 6 kts, daylight only.
Rule E:	FISHING (Simulation) Coordinate Fishing Vessel\Tanker Interactions. Hold tanker transits if more than 20 fishing vessels in Narrows. Clear fishing vessels if four tankers in inbound or outbound queue.

Rule F: ESCORT (Simulation, MARCS)
Revised Escort Program. Tankers at Sea Speed in Central Sound. Prepositioned Escort Tug at Hinchinbrook, Escort through Narrows, Hinchinbrook, not in Sound; Standby Vessels for Central Sound.

Rule F1: Escort at Hinchinbrook equivalent to best currently available tug.

Rule F2: Escort tug at Hinchinbrook has enhanced capability.

6.3.2 Changes To Simulation, MARCS, And Fault Tree Input Parameters Relative To Base Case Values

Rule 1: INCREASE VESSEL RELIABILITY FAILURE PARAMETERS (VRF) (Simulation, MARCS)
Increase Vessel Reliability Failures. Number of Incidents in Anchor rescaled to the same number of incidents in Non-Anchor group per VRF.

Rule 2: INCREASE VESSEL OPERATIONAL ERROR PARAMETERS (VOE) (Simulation)
Increase Diminished Ability by 10 percent : VOE 1.1 * 1.1
Increase Lack of Training by 10 percent : VOE1.3 * 1.1
Increase Poor Management Practices by 20 percent : VOE1.4 * 1.2
Increase Faulty Perceptions by 20 percent : VOE1.5 * 1.2

Rule 3: CHANGE VESSEL ATTRIBUTES TO WORST CASE (Simulation)
Set Vessel Attribute 8 (Bridge-Stability) for all vessels to worst in fleet.
Set Vessel Attribute 9 (Off-train) for all vessels to worst in fleet.
Set Vessel Attribute 10 (Management-type) for all vessels to worst in fleet.

Rule 4: DECREASE VRF
(Simulation, MARCS)
Decrease Vessel Reliability Failures. Number of Incidents in Non-Anchor group rescaled to the same number of incidents in Anchor group per VRF.

Rule 5: DECREASE VRF (Rule 4 & Rule 5 are mutually exclusive)
(Simulation, MARCS)
Reduce Propulsion and Steering Systems by capturing 50 percent of failures
Reduce Propulsion Failures : Pr(Propulsion failure)*0.5
Reduce Steering Failures : Pr(Steering Failure)*0.5

Rule 6: DECREASE VOE (part A)
(Simulation)
Decrease Diminished Ability by 10 percent : VOE1. 1 * 0.9

Rule 7: DECREASE VOE (part B)
(Simulation)
Decrease Lack of Training by 20 percent : VOE1.3 * 0.8
Decrease Poor Management Practices by 20 percent : VOE1.4 * 0.8
Decrease Faulty Perceptions by 20 percent : VOE1.5 * 0.8

Rule 8: CHANGE VESSEL ATTRIBUTES TO BEST CASE
(Simulation)
Set Vessel Attribute 8 (Bridge-Stability) for all vessels to best in fleet.
Set Vessel Attribute 9 (Off-train) to best in fleet.
Set Vessel Attribute 10 (Management-type) to best in fleet.

Rule 9: INCREASE INTERNAL VIGILANCE (simulation)
In Central Prince William Sound Hinchinbrook Entrance and Gulf--3 officers on bridge instead of 2;
Decrease Diminished Ability : Pr(VOE1.1)*0.6
Decrease Hazardous Shipboard Environment: Pr(VOE1.2)*0.6
Decrease Lack of Training : Pr(VOE1.3)*0.6
Decrease Poor Management Practices : Pr(VOE1.4)*0.6
Decrease Faulty Perceptions : Pr(VOE1.5)*0.6

In Port, Narrows and Valdez Arm-- 4 officers on bridge instead of 3:

Decrease Diminished Ability : Pr(VOE1.1)*0.6
Decrease Hazardous Shipboard Environment: Pr(VOE1.2)*0.6
Decrease Lack of Training : Pr(VOE1.3)*0.6
Decrease Poor Management Practices : Pr(VOE1.4)*0.6
Decrease Faulty Perceptions : Pr(VOE1.5)*0.6

Rule 10: MARCS model human and organizational performance equivalents for rules Simulation Rules 2,3,4,5,7,8. Based on Fault Tree changes defined by Rule 20:
Adjust MARCS collision avoidance collision probabilities
Adjust MARCS structural failure frequency factors
Adjust MARCS fire and explosion frequency factors

Rule 11: INCREASE INTERNAL VIGILANCE (Fault Tree/MARCS)
Adjust fault tree internal vigilance parameter

Rule 12: INCREASE EXTERNAL VIGILANCE (Fault Tree/MARCS)
Adjust fault tree external vigilance parameter

Rule 13: Decrease Oil outflow (oil outflow model)
Entire Fleet Double Bottoms in oil outflow model

Rule 14: Decrease Oil outflow (oil outflow model)
All Single Hull Ships Hydrostatically Loaded in oil outflow model, number of vessel transits increased to account for loss of tonnage.

Rule 15: Ice maneuvering (Simulation/Fault Tree)
Remain in traffic lanes during ice conditions, reduce speed to 6 kts rather than maneuver in ice. Reduce number of course changes and reduce number of dangerous courses in Fault Tree to zero, increase exposure time by assuming speed in ice is 6 kts, decrease tanker-ice collision impact in oil outflow model.

Rule 16: Ice maneuvering (Fault Tree)
When ice is observed in or close to the tanker lane, tanker plans a course change toward Bligh Reef to avoid ice. Tanker maintains speed on alternative course (1 Okts). This procedure is dependent of a reliable ice reporting system.

Rule 17: Tethered tug in Narrows Procedures (Fault Tree)
Tethered tug dragged with clutch disengaged in 3/4 of all transits, reducing impact of branch of Fault Tree describing grounding caused by failure on the tug by making probability that clutch is engaged equal to 0.25.

Rule 18: Internal Vigilance on tethered tug (Fault Tree)
Add internal vigilance on tug, change probability that internal vigilance fails from 1 to same value as 2 persons on the bridge

Rule 19: Tug model and transit speed in Narrows (Fault Tree)
Adjust Fault Tree to compare tug in tethered and indirect modes by adjusting grounding caused by failure on tug parameter to 1 .O for tethered tug engaged, and 0.25 for clutch disengaged: 0.10 for tug in indirect mode. Compare at speeds of 5,6, and 8 kts by adjusting exposure time in Fault Tree.

Rule 20: Enhance human and organizational performance (Fault Tree)
Multiply following fault tree Basic event probabilities/frequencies by 0.8 (see Technical Documentation Part V the base case values of the parameters).

Powered Grounding Fault Tree Basic Events:

24 Serious Rudder Failure on ship
30 Failure of the internal vigilance on the tanker with respect to incapacitation
32 Failure of the internal vigilance on the tanker with respect to substandard human performance
34 Technical radar failure
35 Substandard human performance on the tanker in good visibility
36 Substandard human performance on the tanker in poor visibility
37 Officer on watch on tanker being absent
38 Officer on watch on tanker being absorbed
39 Officer on watch on tanker being injured or ill
40 Officer on watch on tanker being asleep
41 Officer on watch on tanker being intoxicated
42 Propulsion Failure
43 Steering Failure
44 Course is set over the ground, but not corrected for wind and current, due to substandard human performance

Collision Fault Tree Basic Events:

3*	Steering Failure on "own" ship
4*	Engine failure on "own" ship
7	Technical radar failure on "own" ship
13	Internal vigilance with respect to incapacitation fails on "own" ship
15	Substandard human performance related to navigation in good visibility on "own" ship
16	Internal vigilance with respect to substandard human performance fails on "own" ship
17	Substandard human performance related to navigation in poor visibility on "own" ship
23	Officer on watch on tanker being absent
24	Officer on watch on tanker being absorbed
25	Officer on watch on tanker being injured or ill
26	Officer on watch on tanker being asleep
27	Officer on watch on tanker being intoxicated

*These values not reduced by 20 percent, but replace with corresponding best case values (i.e., failure rate for all vessels in fleet = best vessels)

Structural Failure Fault Tree Basic Events:

4	Inspection failure (detection of cracks)
7	Inspection failure (detection of corrosion)
10	Weather routing not effected
12	Strain measuring system not applied, or not being paid attention to
13	Failure of good seamanship regarding speed/heading
15	Normal dynamic load and excessive static load (overloading)

6.4 Risk Reduction Technical Documentation

Technical Documentation Part IV documents the process of collecting and structuring the risk reduction measures evaluated in the PWS Risk Assessment. The following tables are included in Technical Documentation Part IV.

Table 1: RISK REDUCTION MEASURES GROUPED BY FUNCTIONAL CATEGORY, SUB CATEGORY AND TYPE (FEBRUARY 1996)

Table 1A: FINAL DRAFT OF EDITED RISK REDUCTION MEASURES GROUPED BY FUNCTIONAL CATEGORY, SUB CATEGORY AND TYPE

Table 2: EDITED RISK REDUCTION MEASURES GROUPED BY PERFORMANCE CATEGORY, SUB CATEGORY, AND TYPE (JULY 1996)

Table 3: PERFORMANCE MEASURES FOR BASE CASE, MINIMUM SAFEGUARD CASE AND ADDITIONAL SAFEGUARDS ABOVE BASE CASE AND MODELING PARAMETERS EFFECTED

REFERENCES

Baisuck, A. and W. A. Wallace. 1979. “A Frameworks for analyzing marine accidents” Marine Technology Society Journal. 13:5. pp. 8-14.

Harrald, John R. 1996. *Port and Waterway Risk Assessment Guide for the U.S. Coast Guard.* Institute for Crisis and Disaster Management, The George Washington University, Washington, D.C.

7.0 Assessment of Effectiveness of Risk Reduction Measures

7.0 Assessment of Effectiveness of Risk Reduction Measures

7.1 Overview of Evaluation Process

The base case risk results defined in Table 5.3-1 and Table 5.3-3 are summarized in Table 7.1-1 for reference purposes. Results in this chapter are presented as they were in Chapter 5. The statistical expectation of accident frequencies is stated in two ways: as the expected number of accidents/year expressed in scientific notation (0.001 accidents per year = 1.0e-3 accidents/year) and/or the expected return time expressed in years (0.001 accidents/year = 1 accident per 1,000 years, or a return time of 1,000 years). Potential average oil outflows are expressed as the statistical expectation of tons of oil released per year. This potential oil outflow is a statistical point estimate of the long run average oil outflow based on the long run average accident frequency and oil outflow curves for each accident type. A 100,000 ton oil outflow associated with an accident with a return time of 1,000 years would, for example, result in a potential yearly oil outflow of 100 tons.

Table 7.1-1
Expected Frequency of Occurrence and Potential Oil Outflow
by Accident Types for Outbound Tankers

Accident Type	Outbound Accident Frequency Statistical Accidents Per Year	Inbound Accident Frequency Statistical Accidents/Year	Potential Average Oil Outflows tons/year (outbound + inbound)
Collisions	1.6e-02 to 4.1e-02	6.0e-02	75-189
Powered Grounding	4.6e-03 to 7.2e-03	1.2e-02	50-135
Drift Grounding	4.6e-03 to 5.5e-03	3.1e-02	67-136
Structural Failure	1.5e-03 to 1.6e-03	1.7e-02	27-54
Fire and Explosion[1]	9.4e-04	NA	40
Total-All Accidents	2.8e-02 to 5.6e-02	1.0e-01	260-511

[1] Fire and Explosion values calculated by Fault Tree model only

‘Percentage based on IMO structural failure definition (a structural failure serious enough to effect the structural integrity of the vessel and to warrant repair at the next port of call) and IMO data.

Changes in risk due to system interventions are described relative to these base case results in sections 7.2 and 7.3. The change in expected accident frequency and potential oil outflows due to a hypothetical risk reduction measure would be calculated for using system simulation results as shown in the following example:

Base Case System Risk:

Expected Accident Frequency	5.6e-02
Potential Oil Outflow	511 tons

System Risk after Implementation of Risk Intervention:

Revised Expected Accident Frequency	3 .0e-2
Revised Potential Oil Outflow	440 tons

Percent Change from Base Case in Expected Accident Frequency:

$$(3.0-5.6)/5.6 \approx - 46\ \%$$

Percent Change from base case in Potential Oil Outflow:

$$(440-511)/511 \approx - 14\%$$

Section 7.4 discusses the effect of multiple risk reduction interventions and concludes with an estimation of a theoretical best case based on risk reduction measures evaluated. Section 7.5 describes the calculation of the minimum safeguard case risk, representative of the level of risk in PWS if all existing safeguards were removed. Risk reduction measures currently in place in the base case are responsible for mitigating most of the risk identified in the minimum safeguards case. The summary in Section 7.6 concludes that safeguards currently in place have removed approximately 75 percent of the risk that would exist if the system operated without these safeguards and that the risk reduction measures under consideration may be able to reduce the residual risk by approximately 75 percent.

Chapter 6 described the process of collecting, editing, and structuring potential risk reduction interventions. This process resulted in the definition of test criteria for eighteen specific risk reduction cases. These eighteen cases were evaluated by the system simulation and/or MARCS/Fault Tree models by implementing the parameter changes as defined in Section 6.3 and shown in Table 6-25. The cases analyzed provided a test of interventions in each of the five stages of the causal chain defined in Figure 6.1-2. The cases were defined and evaluated in a manner as shown in Figure 6.1-3 to ensure that the analysis did not overlook any potentially significant area of risk reduction or spend valuable time analyzing insignificant interventions. The risk reduction cases evaluated and the models used in their evaluation are listed in Table 7.1-1, classified by performance objective. A summary of the results of this analysis are presented in Section 7.2 and 7.3. Three other risk reduction cases consisting of combinations of these measures were analyzed and are described in Section 7.4. Two cases defined by the removal of current risk reduction measures were also analyzed and are described in Section 7.5: a no escort vessel case; and a minimum safeguard case. Complete detailed risk reduction evaluation results are contained in Technical Documentation Part V, Section 5, *Integrated Risk Reduction Evaluation* and Section 6, *Comparison of Common Cases Analyzed by G WU and DNV.*

Table 7.1-1
Risk Reduction Cases Evaluated Based On Structure Developed In Chapter 6

INTERVENTIONS	RISK REDUCTION CASES EVALUATED	
Stage I Interventions: Reduce basic or root causes.	*Case 1.*	Improve human and organizational performance (SS)
	case 1.1	Reduce human and organizational error (M/FT, SS)
	Case 1.1.1	Improve training and navigation information (SS)
	Case 1.1.2	Improve bridge team management (SS)
	Case 1.1.3	Reduce incidence of diminished ability (SS)
	Case 1.2	Reduce vessel reliability failures (M/FT, SS)
Stage II Interventions: Decrease frequency of immediate (triggering) events	Case 2	Improve internal vigilance. (SS)
Stage III Interventions: Decrease exposure to hazardous situations.	Case 3	Reduce exposure to hazardous weather, ice, traffic conditions (SS)
	Case 3.1	Impose stricter closure conditions (M/FT, SS)
	Case 3.1.1	Impose stricter closure conditions at Hinchinbrook Entrance (SS)
	Case 3.2	Revise ice navigation procedures (FT,SS)
	Case 3.3	Revise fishing vessel/tanker interaction rules (SS)
Stage IV Interventions: Intervene to prevent accidents ifincidents occur.	Case 4	Revise escort program using pre-positioned tugs (M/FT,SS)
	Case 4A	Revise escort program, pre-position enhanced capability tug at Hinchinbrook Entrance (M/FT, SS)
	Case 4.1	Tug in indirect mode in Narrows: (FT)
	Case 4.2	Capture/correct 50% of all steering and propulsion failures (M/FT)
Stage V Interventions: Reduce oil outflow if accidents occur.	Case 5A	Replace entire fleet with double hulled tankers.(M/FT)
	Case 5B	Hydrostatically load all single hulled vessels in existing fleet (M/FT)

Where SS = GWU regression/system simulation and M/FT = DNV MARCS and Fault Tree

7.2 Evaluation of Risk Reduction Cases

7.2.1 Evaluation of Risk Reduction Categories

The five stages of risk reduction interventions described in Section 7.1 are mutually exclusive since they correspond to interventions at distinct and separate points in the causal chain as shown in Figure 6.1-2. The multiple risk reduction interventions, therefore, have a compounding effect. A reduction in incidents achieved by interventions in Stages I and II will result in a commensurate reduction in accident frequency. If additional "downstream" Stage III or IV interventions are also implemented, they will further reduce the accident frequency.

The total effect of interventions made at separate stages is, therefore, the product of the effect of these interventions. Figure 7.2-l shows three equivalent approaches to achieving a 40 percent reduction in oil outflows. In the first case, root causes (human error and mechanical failures) are reduced by 40 percent and no other interventions are made. This broad systemwide intervention reduces incidents, accidents and oil outflows. It may be hard to achieve and even harder to verify successful implementation of this intervention. In the second case, system interventions such as VTS and escort vessels prevent 40 percent of all incidents from becoming accidents, but do not reduce the number of incidents that occur in the system. These interventions may be easy to verify, but it may be difficult to capture 40 percent of all incidents. In the third case, a 10 percent reduction is achieved at each stage. The result is a 27 percent reduction in incidents, a 34 percent reduction in accidents, and a 41 percent reduction in oil outflows. Multiple risk reduction interventions in the same stage, however, may not have a compounding impact since they tend to affect the same causal factors.

Interventions in Stages I, II, and V are systemic and tend to reduce the effects of all accident types and scenarios. Interventions in Stages III and IV tend to be targeted at specific accident types or accident scenarios. As will be discussed, some targeted interventions that reduce the expected frequency of specific accident scenarios can cause changes that increase the risk of other scenarios and can increase system risk.

Comparing the risk reduction effect of the maximum intervention possible in each category provides two basic factors for risk management planning. First, the comparison will provide focus to the risk management plan by showing which types of interventions provide significantly more risk reduction potential than others. Secondly, the evaluation of the maximum risk reduction potential in each category will show if there are any categories where additional interventions are unlikely to achieve significant reductions.

The ability of the models to capture all the risk reduction measures proposed is limited, as discussed in Chapter 6. This is particularly true for those measures addressing human and organizational causal factors at the beginning of the causal chain. The changing of a Stage V intervention (i.e., double hulls) can be directly modeled in both the system simulation and MARCS. Similarly, the changing of system rules and procedures (escorts, closures) and traffic patterns are accurately and completely modeled using the simulation. Human and organizational interventions (i.e., better training, reduced incapacitation) must be indirectly modeled. Estimates of how much these changes affect the parameters that represent human error were made based on limited historical data and modeling assumptions based on the technical and professional expertise of the project team. However, the specific measures that have been modeled provide a reasonable basis for evaluating the potential effects of each stage. The cases used to model each stage and the results obtained are described in the sections below and in Section 7.3. These cases follow the higher hierarchical structure represented in Figure 6.1-3 used to categorize the more than 117 edited risk reduction measures described in Technical Documentation Part IV. The five top level cases correspond to all the risk reduction interventions in each of the five intervention stages shown in Figure 6.1-2.

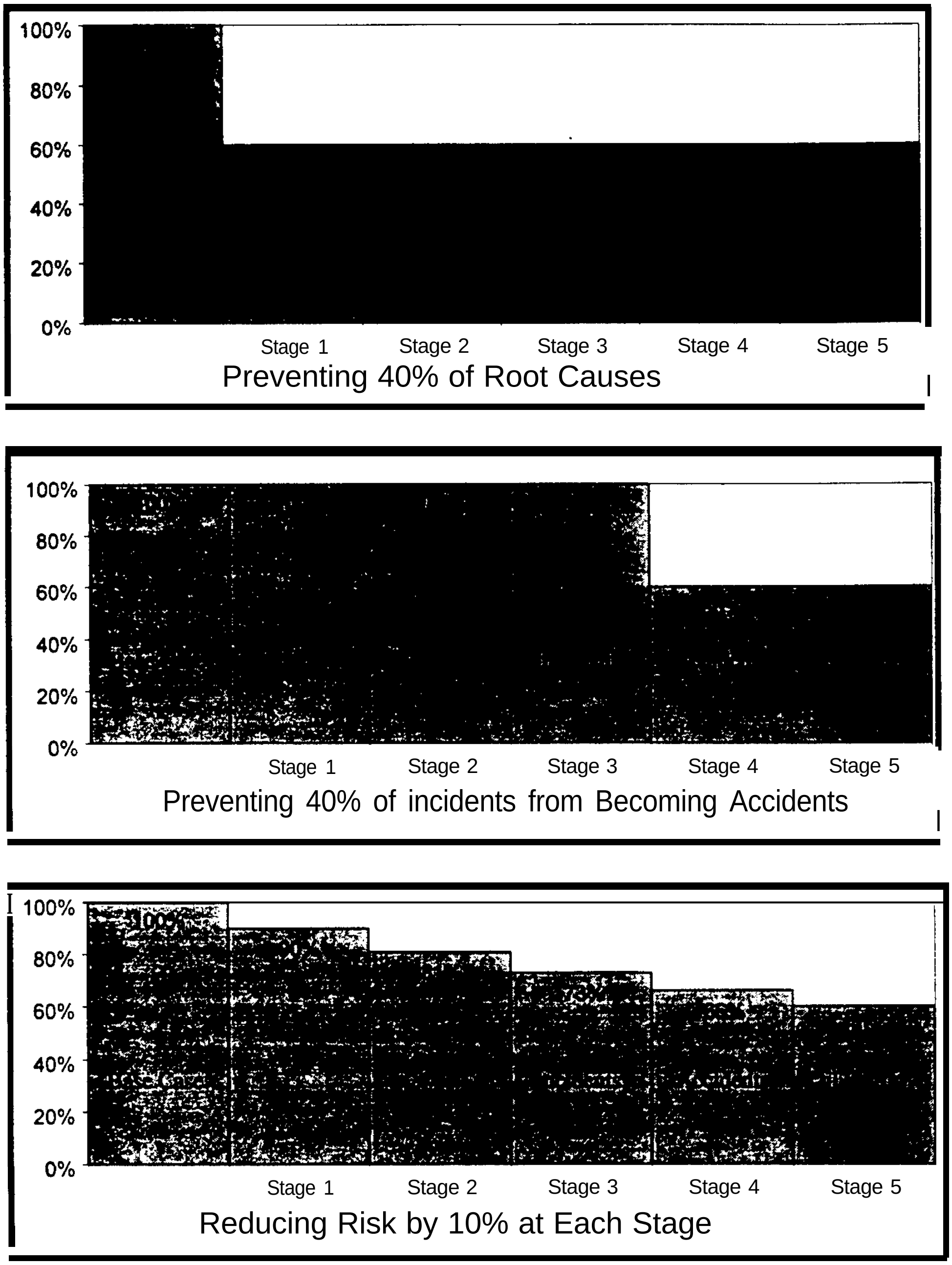
The modeling effort proceeded to finer levels of detail until it was stopped due to one of three reasons:

1) A sub category was shown to have an insignificant risk reduction effect or was shown to increase risk;

2) The modeling techniques used did not allow for a more detailed representation of the risk measures within a sub category; and

3) The analysis indicated that variations or combinations of risk measures that were not in the existing evaluation program should be tested. In these cases the analysis completed was adequate to present viable alternatives for future consideration to the steering committee.

Comparison Of Three Approaches To Reducing Oil Oufflows By 40 Percent



Preventing 40% of Root Causes

Preventing 40% of incidents from Becoming Accidents

Reducing Risk by 10% at Each Stage

Figure 7.2-l

As will be shown in Section 7.3, the area of human error reduction was the primary area where analysis had to stop before a desired level of detail was reached due to an inability to determine model parameter changes that could represent very specific interventions (i.e., inclusion of pilots in bridge team simulation training). The evaluation in Section 7.3 also indicates that, although some of the suggested changes to escort resources and procedures will not reduce risk, additional analysis could produce the criteria for an escort program that provides a risk reduction potential greater than that provided by the current program.

All risk reduction case comparisons made in Sections 7.2 and 7.3 are made on the basis of the percentage change from the base case risk described in Chapter 5. A negative change implies a risk reduction, a positive change implies a risk increase. The base case results and the risk reduction case results calculated by each individual model are used as the basis for the calculation of the change in base case risk for that model; MARCS/FT results are compared to MARCS/FT base case results. These measures of the relative effects of the interventions provide a more meaningful basis for comparison of model results than would the comparison of absolute reduction in accident frequency and oil outflows. Note that the discussion of all risk reduction measures is conditioned on the modeling assumptions that were used to represent the risk reduction measures in each specific model. The limitations discussed in Chapter 4 that restrict each modeling technique's ability to reflect reality also affect its ability to reflect changes to reality.

7.2.1.1 Case 1: Human and Organizational Performance

The objective of Case 1 was to capture the effect of as many of the Stage I human and organizational performance risk reduction measures as possible. The modeling changes to appropriately represent human and organizational error reducing interventions are best estimates determined by the judgment of the project team based on limited data, prior studies, and personal expertise. The percentage reductions in human error used as modeling inputs are estimates. These error reductions may not actually occur if the risk reduction measures represented are implemented. Conversely the risk reduction measures may have a greater affect on human error than predicted. In the system simulation, the measures listed in Table 6-6 were modeled by making the changes shown in Table 7.2-l (based on Rules 4, 6, 7, 8 in Section 6.3.2).

Table 7.2-l
Modeling Assumptions-Root Causes

Intervention	Modeling Assumptions
Reduce human and organizational error and provide better decision making information	1. Decrease the incidence of diminished ability by 10 percent 2. Decrease the incident of all human error by 20 percent 3. Improve bridge team continuity, team training and ship management by assuming that all tankers in the fleet had the stability, training, and management scores of the top rated vessels in the existing fleet
Reduce vessel reliability failures	1. Reduce all propulsion failures, steering failures, structural failures, and navigational/ communications failures by assuming that all the tankers in the fleet had the failure rates of the best vessels in the existing fleet.

The results calculated by the system simulation shown in Table 7.2-2 using the method described in Section 7.1 indicate that this reduction in the incidence of human error and reduction in failure rates produces significant reductions in outbound and inbound expected accident frequencies and expected oil outflows.

Table 7.2-2
Evaluation of Risk Reduction Case 1

Effect Of Measure	System Simulation Case 1
EXPECTED ACCIDENT FREQUENCY OUTBOUND	-17%
EXPECTED ACCIDENT FREQUENCY INBOUND	-21%
EXPECTED OIL OUTFLOW TOTAL	-22%

7.2.1.2 CASE 2: Immediate Causes/Internal Vigilance

As shown in Table 6-8, all the risk reduction measures modeled in the immediate cause stage dealt with increasing internal vigilance. Internal vigilance is modeled in Case 2 in the system simulation as shown in Table 7.2-3. The modeling assumptions are not intended to be prescriptive. They provide a testable intervention scenario, but equivalent risk reductions could be achieved by other interventions that capture the same effect (i.e., error detection and error capture on outbound tankers).

Table 7.2-3
Modeling Assumptions-Increased Internal Vigilance

Intervention	Modeling Assumption
Increase internal vigilance onboard outbound tanker	• A fourth qualified person is assumed to be on the bridge when laden tankers transit the Port, Narrows, or Arm; a third qualified person is assumed to be on the bridge for the remainder of the transit and disembarks at Hinchinbrook Entrance. • The incidence of human error is reduced by 40 percent due to the presence of the additional personnel.

The value of an extra person on the bridge is difficult to model. The benefit of an extra person is an increase in the ability to detect and correct errors made by others. In theory, if the redundancy in expertise provided identical expertise, the probability an error occurring with two officers on the bridge is $(p_o)^2$ where p_o is the probability that a human error will occur with one person on the bridge. The incremental gain of adding a third person would also be p_o. However, it is unlikely that this degree of error capture would occur due to inattention, reaction time, and other factors. The assumption made in the system simulation, based on the judgment of the project team, is that each additional officer provides an error capture potential of 40 percent. (The fault tree analysis assumes a reduction of 75 percent for a second officer on the bridge, and a reduction of 34 percent for each additional officer if two or more officers are on the bridge). Although these assumptions appear to be reasonable, the lack of empirical data supporting any assumption should be kept in mind when interpreting the results shown in Table 7.2-4, which show a significant reduction in both expected accident frequency and expected oil outflows.

Table 7.2-4
Evaluation Of Risk Reduction Case 2
Immediate Causes/Internal Vigilance

‘Effect Of Measure	System Simulation Case 2
EXPECTED ACCIDENT FREQUENCY OUTBOUND	-15%
EXPECTED ACCIDENT FREQUENCY INBOUND	-9%
EXPECTED OIL OUTFLOW TOTAL	-13%

7.2.1.3 MARCS/FT: Human and Organizational Performance

The approach taken in representing improved human and organizational performance in the MARCS/fault tree models was slightly different than that taken by the system simulation. An attempt was made to represent the measures that would be effected by implementation of the International Safety Management System (ISMS) in the collision, powered grounding, and structural failure fault trees. These measures modeled are shown in Table 6-7. The modeling changes made are listed in Rule 20, Section 6.3.2 were based on the expert opinion of DNV experts, and are summarized in Table 7.2-5.

Table 7.2-5
Modeling Assumptions--Cases 1 & 2 (International Safety Management System)

Intervention	Modeling Assumptions
Implement International Safety Management System	Reduce serious rudder and radar failure rates by 20 percent in powered grounding, collision fault trees. Change propulsion and steering failures in the MARCS/FT by making failure rate of all tankers equal to the best vessels in the existing fleet. Reduce the incidence of incapacitation in the powered grounding and collision fault trees by 20 percent. Reduce all human error probabilities in the powered grounding and collision fault trees by 20 percent. Reduce the incidence of failure of internal vigilance by 20 percent in the collision and powered grounding fault trees. Reduce the incidence of inspection failure in the structural failure fault tree by 20 percent. Reduce the incident of overloading and failure or good seamanship in the structural fault tree by 20 percent.

The MARCS/FT Human and Organizational Performance Case, since it includes increasing internal vigilance, closely approximates the combined system simulation Case 1 and Case 2. Table 7.2-6 compares the MARCS/FT and system simulation results computed for a combined Case 1 and Case 2. Since Case 1 interventions eliminate errors and Case 2 interventions capture errors after they occur, the cumulative risk value was calculated for the system simulation as the product of the residual risk value at each stage. Note, however, that this combined case is estimated, not calculated directly from a simulation run.

Table 7.2-6
Evaluation Of Risk Reduction
Cases 1 And 2

Effect Of Measure	System Simulation Case 1 & 2	MARCS/FT Case 1 And 2
EXPECTED ACCIDENT FREQUENCY OUTBOUND	-26%	-31%
EXPECTED ACCIDENT FREQUENCY INBOUND	-28%	N.M.
EXPECTED OIL OUTFLOW TOTAL	-32%	-40%

N.M. indicates not modeled

Table 7.2-1, 7.2-2, and 7.2-3 lead to two significant observations:

- The modeling changes made to represent the effect of reducing and capturing human and organizational error reduces expected accident frequencies for inbound and outbound tankers approximately 26-3 1 percent. Oil outflows are reduced by approximately 32-40 percent.

- The consistent and significant risk reduction results obtained by both models for this category indicate that a more detailed examination of individual interventions is warranted.

7.2.1.4 Case 3: Reduced Exposure

The objective of the reduced exposure case was to model as many of the Stage III interventions described in Table 6-9 as possible. These interventions reduce the exposure of a tanker to hazardous situations. This case combined three types of risk reduction interventions, all of which were directly modeled in the system simulation. Table 7.2-7 describes the interventions and the system changes used as the basis for modeling changes.

Table 7.2-7
Modeling Assumptions-Reduced Exposure Interventions

Interventions	Modeling Assumption
stricter closure conditions	Close Narrows to outbound tankers less than 150K DWT if wind exceeds 30 knots, 20 knots for outbound tankers >150K DWT. Close Hinchinbrook Entrance if wind exceeds 30 kts for all outbound laden tankers.
Coordination of fishing vessel and tanker interactions	Prevent tankers from transiting the Narrows if more than 20 fishing vessels are present. Require fishing vessels to clear channel if more than 4 tankers are in inbound or outbound queue. Ensure communication between tankers and fishing vessels.
Improve ice navigation	Restrict ice transits to daylight hours, speed restricted to 6 knots in ice, and no maneuvering outside of traffic lanes.

•

The results of the evaluation of Case 3 are shown in Table 7.2-8.

Table 7.2-8
Evaluation Of Risk Reduction Case 3
Reduced Exposure

[illegible]	[illegible]
EXPECTED ACCIDENT FREQUENCY OUTBOUND	-28%
EXPECTED ACCIDENT FREQUENCY INBOUND	+6%
EXPECTED OIL OUTFLOW TOTAL	+13%

Table 7.2-8 shows a mixed effect from this group of measures: the outbound accident frequencies are reduced, but the outbound expected oil outflow increases. This is due to the significant reduction in non oil outflow tanker - fishing vessel collisions, but an increase in oil outflow producing collisions and groundings produced by the increased traffic congestion and increased time in the system caused by the stringent closure conditions. These systemic interactions will be discussed in detail in Section 7.3, where the individual measures are evaluated. Additional Stage III waterways management interventions appear to be desirable for the prevention of accidents leading to loss of life, injury, and property damage. The interventions currently in place in the base case are, however, achieving their objective of preventing accidents leading to oil outflows.

7.2.1.5 Case 4: Intervention/Revised Escort

Stage IV interventions are intended to prevent accidents given that an incident has occurred. The existing escort system provides the base case intervention system. Both MARCS/FT and system simulation modeled a revised escort scheme consisting of the changes shown in Table 7.2-9.

Table 7.2-9
Modeling Assumptions-Intervention/Escorts

Intervention	Modeling Assumptions
Improve Escort system by enhancing save capability at Hincbinbrook Entrance and providing coverage for inbound tankers, without degrading benefits of existing system	Pre-positioned escort vessel at Hinchinbrook. Procedures ensure that the pre-positioned tug is capable of saving all vessels transiting under allowed conditions. Tankers escorted through Narrows and Arm as per current VERP. Escort stands by until tanker is more than one half way to Hinchinbrook. Escort vessel at Hinchinbrook stands by for tanker for outer one half of PWS, escorts tanker through Hinchinbrook Entrance, stands by until 20 miles off shore. Tankers transit central PWS at sea speed.

Table 7.2-10 shows that the revised escort plan with an enhanced capability tug at Hinchinbrook reduces the expected outbound and inbound accident frequency and oil outflows. The modeling assumptions shown in Table 7.2-10 were based on the alternative escort system proposed by Alyeska/SERVS. Other. more effective, configurations may be possible.

Table 7.2-10
Evaluation Of Risk Reduction Case 4
Revised Escort/Enhanced capability Tug at Hinchinbrook

[illegible]	[illegible]	[illegible]
EXPECTED ACCIDENT FREQUENCY OUTBOUND	**-3%**	**-23%**
EXPECTED OIL OUTFLOW OUTBOUND	-10%	-25%
EXPECTED ACCIDENT FREQUENCY INBOUND	-18%	N.M.

As will be shown in the detailed discussion of individual measures in Section 7.3, the risk reduction achieved by this change is almost entirely due to the improved ability to assist a disabled tanker at Hinchinbrook Entrance ensured by the provision that the standby vessel at Hinchinbrook was always capable of saving any tanker making an allowable transit. The system simulation shows less of a reduction in accident frequency for the pre-positioned escort case than does the MARCS due to the way the different models evaluate the presence of only one effective standby vessel in Central PWS. In the system simulation the probability of an accident given a situation is established by a regression analysis based the expert questionnaire responses. The PWS mariners attached a higher relative risk to situations where one escort tug was available than they assigned to situations where two or more tugs were available.

The MARCS calculates the save potential of the most capable tug on scene and does not consider additional tugs as resources that can effectively influence the save of the disabled vessel. The system simulation shows, however, that the presence of the pre-positioned escort at Hinchinbrook Entrance has a significant effect on the frequency of accidents involving inbound tankers. A revised escort system that provides an increase in save capability at Hinchinbrook Entrance and its approaches and provides coverage for inbound tankers while preserving the aspects of the current system in the Narrows and the Arm could produce a significant benefit.

7.2.1.6 Case 5: Consequences-Double Hull

The consequence intervention modeled by both models was the OPA 90 mandated replacement of the fleet with double hulled vessels. The modeling assumption made was the replacement fleet would be the same number of ships with the same oil carrying capacity as the current fleet. This fleet would, therefore, result in the same number of transits of laden tankers as the base case. As shown in Table 7.2-l 1, this intervention does not reduce accidents, but it does reduce the number of accidents with the potential for spilling oil, resulting in significant reduction in oil outflows. As discussed in Section 7.3, an alternative to double hulls (hydrostatic loading of single hull ships) produces an increase in both the expected number of accidents and in the potential oil outflow within PWS, even though a hydrostatically loaded tanker that grounds will release less oil than will either a single hull or double hulled vessel in an accident that pierces the outer hull. Since hydrostatic loading requires a reduction in oil carrying capacity of the current single skin tankers, it would result in an increase in tanker transits of approximately 15 percent, assuming additional vessels equal in size to the current fleet average could be brought into the trade. The increase in transits would result in an increase in accident frequency.

Table 7.2-l 1
Evaluation Of Risk Reduction Case 5
Double Hull

Effect Of Measure	**System Simulation Case 5**	**MARCS/Fault Tree Case 5**
EXPECTED ACCIDENT FREQUENCY OUTBOUND	0%	0%
EXPECTED OIL OUTFLOW OUTBOUND	-11%	-7%
EXPECTED ACCIDENT FREQUENCY INBOUND	0%	N.M.

7.2.1.7 Comparison of Cases l-5

Figure 7.2-2, 7.2-3 and 7.2-4 compare the effects of risk reduction Cases 1 and 2, 3, 4, 5. These figures are graphical plots known as “tornado diagrams”. In a tornado diagram, the quantities represented are ordered in descending order from top to bottom. In Figures 7.2-2, 7.2-3, and 7.2-4 a reduction in expected accident frequency or oil outflow is represented by a bar to the left of the center line, an increase is represented by a bar to the right of the centerline. The minimum value of the X (horizontal) axis is -100 percent, corresponding to zero risk since a bar reaching -100 percent would represent the removal of all risk in the base case. The maximum value is set at +100 percent for presentation purposes only. It is possible to increase the base case risk by more than 100 percent.

The values calculated by the system simulation are shown by a solid bar, those calculated by the MARCS/fault tree by a hollow bar. In the cases where the value was calculated by only one model, a single bar appears. Where values have been calculated by two models, the smallest risk reduction percentage is taken for ordering purposes. Where one modeling method calculates the result as a risk reduction and the other method calculates the affect as a risk increase, the measure is ranked using the value of the risk increase. Thus the alternatives are sorted in order of risk reduction from top to bottom of the diagram, using the most conservative estimate of risk reduction.

Figure 7.2-2 and Figure 7.2-3 show that the most significant reductions in accident frequencies could be attained through interventions that effectively prevent human errors or vessel reliability failures from occurring (Case 1) or from “capturing” human error when it occurs (Case 2). Figure 7.2-4 shows that these broad human and organizational interventions are also the most effective in preventing oil outflows. Preventing exposure to hazardous situations (Case 3) is the second ranked alternative when evaluated by frequency (Figures 7.2-2 and 7.2-3), but is the least desirable alternative when evaluated by oil outflow (7.2-4). The reason for this counter intuitive result, as will be shown in Section 7.3, is that two components of this intervention produce opposite effects. The improved traffic management prevents large numbers of non oil outflow producing tanker/fishing vessel interactions, reducing the expected frequency of collisions. The stricter closure conditions, however, increase powered groundings and tanker collisions that increase oil outflow. The revised escort/enhanced capability tug at Hinchinbrook Entrance option provides a significant reduction in both accident frequency and oil outflow. The double hull case (Case 5) is the bottom alternative in accident reduction, but does result in a significant reduction in oil outflows.

The discussion of base case results in Chapter 5 observed that risk reduction strategies targeted at specific risk scenarios would be more effective in reducing accident frequencies than in reducing oil outflows. The analysis showed that seven of the thirty six accident scenarios contributed 80 percent of the total expected accident frequency but that these same scenarios contributed less than 50 percent of the expected oil outflows. The analysis of risk reduction measures is consistent with this observation. Stage III (exposure/ closure) and Stage IV (intervention/enhanced capability tug at Hinchinbrook Entrance) interventions are intended to prevent specific accident scenarios. As stated above, some Stage III interventions may actually increase oil outflows. Stage I, II and V interventions are broad systemic interventions that affect the entire calling fleet. All three reduce oil outflows more than they reduce accident frequencies.

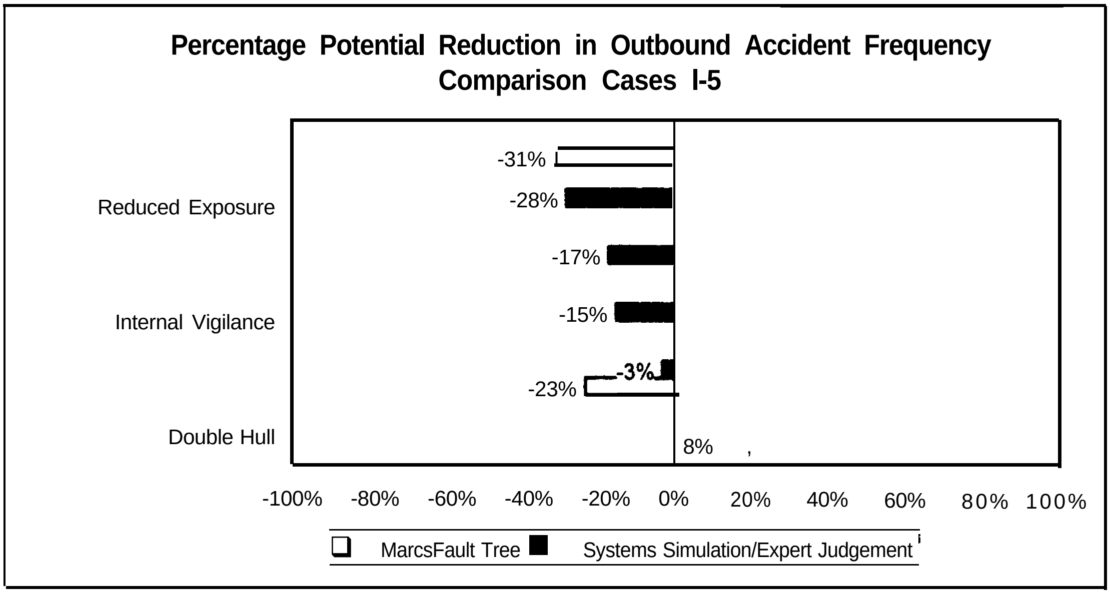

Percentage Potential Reduction in Outbound Accident Frequency
Comparison Cases I-5

Figure 7.2-2

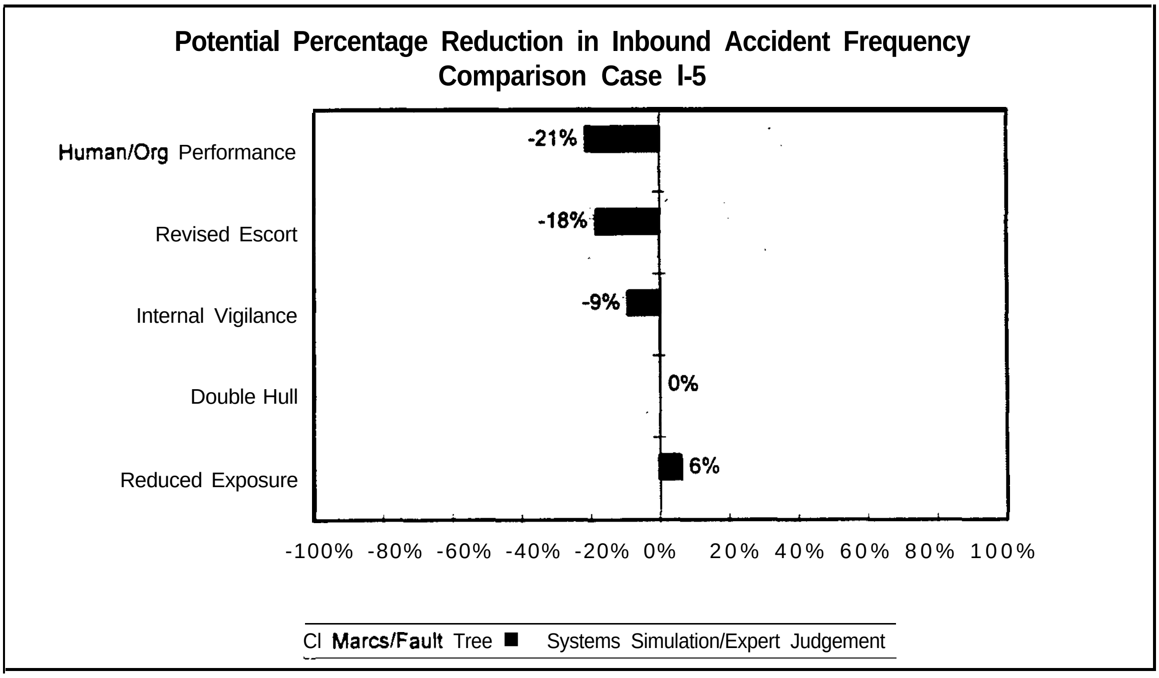


Figure 7.2-3

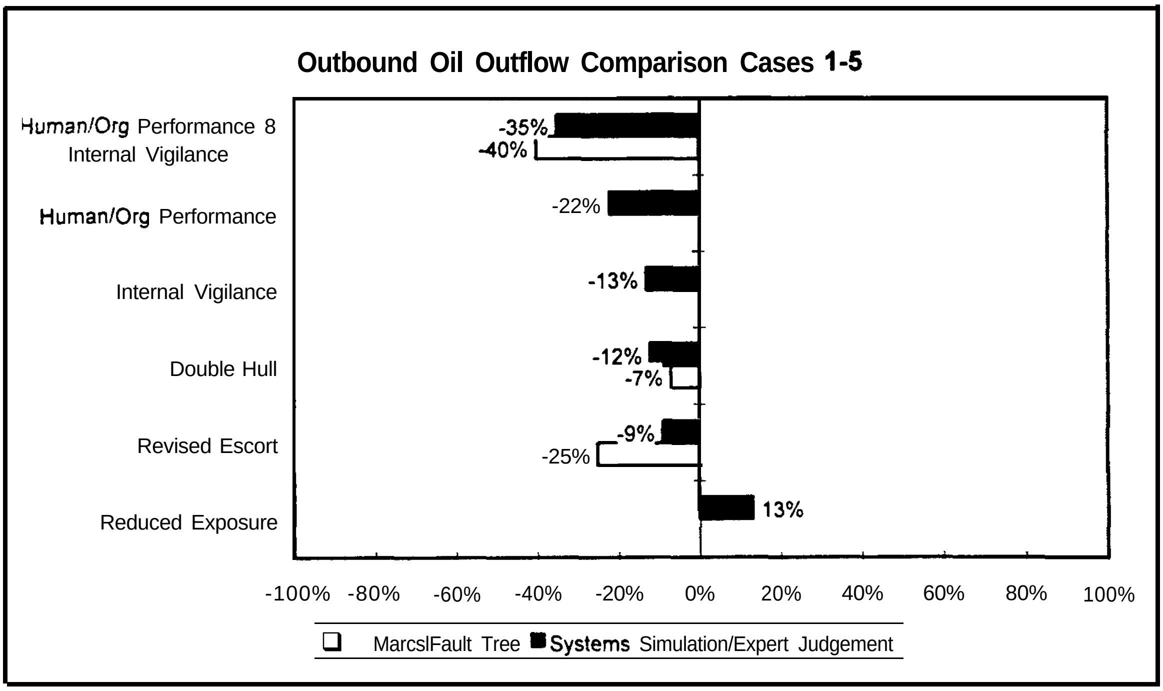


Figure 7.2-4

7.3 Ranking of Risk Reduction Interventions

7.3.1 Description of Risk Reduction Interventions

The objective of this section is to describe and to rank all risk reduction cases modeled. Additional cases are the component elements of the five cases listed above. The cases are defined below; complete descriptions of each case and the modeling changes made for each case are contained in Technical Documentation Part I.

Case 1: ***Improved Human and Organizational Performance was*** subdivided into five sub cases:

Case 1.1: ***Reduced Human*** Error - All elements of 1.1.1, 1.1.2, and 1.1.3

Case 1.1.1: ***Improved Management and Bridge Team Continuity*** by assuming that all tankers in the fleet had the bridge continuity and management scores of the top rated vessels in the existing fleet.

Case 1.1.2: ***Reduced Diminished Ability*** by decreasing the incidence of diminished ability by 10 percent.

Case 1.1.3: ***Improved Training and Navigation Information*** by reducing all human error due to lack of training, faulty perceptions, or poor management practices by 20 percent.

Case 1.2: ***Reduced Vessel Reliability Failures*** (VRF) by assuming that all the tankers in the fleet had the failure rates of the best vessels in the existing fleet.

Case 2: ***Immediate Causes/Internal Vigilance*** was not subdivided.

Case 3: ***Reduced Exposure*** was subdivided into the following four cases.

Case 3.1:	***Stricter closure conditions:*** Close Narrows if wind exceeds 30 knots for tanker <150K DWT, 20 knots for tankers >150K DWT. Close Hinchinbrook Entrance if wind exceeds 30 kts for all outbound laden tankers.
Case 3.1.1:	***Stricter closure conditions at Hinchinbrook Entrance:*** Close Hinchinbrook Entrance if wind exceeds 30 kts for all outbound laden tankers over 150K DWT.
Case 3.2:	***Revised Ice procedures:*** Restrict ice transits to daylight hours (simulation only), speed restricted to 6 knots in ice, and no maneuvering outside of traffic lanes.
Case 3.3:	***Revised Fishing Vessel/ Tanker Rules:*** Coordinate fishing vessel and tanker interactions by limiting tankers from transiting the Narrows during openers or scheduling openers. Ensure communication between tankers and fishing vessels.

Two versions of Case 4, the alternative escort case, were evaluated:

Case 4 :	***The Revised Escort*** case, where the standby vessel at Hinchinbrook Entrance was one of the most capable tugs in the current escort fleet.
Case 4A:	***The Enhanced capability Standby Vessel*** case, where the standby vessel at Hinchinbrook Entrance was assumed to be capable of saving all vessels in the current fleet under all allowed transit conditions.

Two unique cases that are classified as Stage IV interventions were evaluated independently but were not included as elements of Case 4:

Case 4.1:	***The Indirect Mode*** case is a fault tree model of a tractor tug in the indirect mode in the Narrows at an 8 knot transit speed. This case is described in detail in Technical Documentation Part IV and in Section 7.3.3.
Case 4.2:	***Reduce steering and propulsion failure*** by 50 percent through error capture and control. This case was modeled independently and not modeled as an sub element in Case

IV since it described a performance goal, not an intervention that could be described in operational terms.

Two mutually exclusive versions of Case 5, the consequences case were evaluated:

Case 5A: ***Double Hull only case*** assumed the replacement of the existing fleet with the identical number of double hulled vessels with identical cargo carrying capacity.

Case 5B: ***Hydrostatic Loading case*** assumed the hydrostatic loading of all single hull vessels in the existing fleet, and an increase in transits to account for the lost cargo carrying capacity.

One additional case was introduced by combining two existing cases.

The Revised Fishing Vessel/Tanker Rules/Escort case that combined Case 3.3 (fishing vessel management) and 4 (revised escort), was evaluated by the system simulation to explore potential interactions between cases.

7.3.2 Ranking of Risk Reduction Interventions

Table 7.3-l is a listing of these 19 cases and the base case indicating which models were used to evaluate each case. Tables 7.3-2 and 7.3-4 summarize the changes in outbound accident frequencies and total oil outflows calculated the MARCS/FT and regression/system simulation models for all nineteen risk reduction cases. Table 7.3-3 summarizes the changes in inbound accident frequencies calculated by the system simulation.

Figures 7.3-1, 7.3-2, and 7.3-3 are tornado diagrams representing the reduction in expected outbound accident frequencies, outbound oil outflows, and inbound accident frequencies for the nineteen risk reduction cases and the base case. These diagrams are sorted from top to bottom with the most effective risk reduction alternative at the top of the page. Where risk reduction values were calculated by two models, the most conservative value (the least reduction in risk or greatest increase in risk) was selected for ranking purposes. The tornado diagrams provide a visual sorting of risk reduction cases based on their effectiveness in reducing expected accident frequencies and oil outflows relative to the base case.

Table 7.3-l
Risk Reduction Cases

Case Numbers	GWU Regression/System [illegible] Simulation [illegible]	[illegible]
	Base	Base
1	Improved Human/Organization Performance	Improved Human/Organization Performance
1.1	Reduced Human Error	Not Modeled
1.11	Improved Management & Crew	Not Modeled
1.12	Reduced Diminished Ability	Not Modeled
1.13	Improved Training & Navigation Information	Not Modeled
1.2	Reduced VRF (All to best)	Reduced VRF (All to best)
2	Increased Internal Vigilance	Not Modeled
3	Reduced Exposure	Not Modeled
3.1	Stricter Closure	Stricter Closure
3.11	Stricter Closure at HE	Not Modeled
3.2	Revised Ice Procedures	Not Modeled
3.3	Revised Fishing Vessel/Tanker Rules	Not Modeled
4	Revised Escort	Revised Escort
4A	Escort with Enhanced capability Tug at HE	Escort with enhanced capability Tug at HE
4.1	Not Modeled	Tug in Indirect Mode in Narrows
4.2	Reduce Prop. & Steer. Failure by 50 %	Reduce Prop. & Steer. Failure by 50 %
5A	Double Hull Only	Double Hull only
5B	Not Modeled	Hydrostatic Loading
3.3+4	Revised Escort & Fishing Vessel /Tanker Rules	Not Modeled

Table 7.3-2
Percentage Change in Expected Accident Frequency for Outbound Tankers
Outbound Tankers : All Accidents

[redacted]	[redacted]	[redacted]
Revised Fishing Vessel/Tanker Rules	Not Modeled	-37%
Revised Escort & Fishing Vessel/Tanker Rules	Not Modeled	-32%
Reduced Exposure	Not Modeled	-28%
Improved Human/Organization Performance	-31%	-17%
Increased Internal Vigilance	Not Modeled	-15%
Reduced Human Error	Not Modeled	-13%
Reduce Prop. & Steer. Failure by 50 %	-8%	-12%
Improved Management & Crew	Not Modeled	-8%
Reduced VRF (All to best)	-10%	-7%
Improved Training & Navigation Information	Not Modeled	-4%
Revised Escort with Enhanced capability Tug at Hinchinbrook	-19%	3%
Revised Ice Procedures	-4%	3%
Tug in Indirect Mode in Narrows	-3%	Not Modeled
Reduced Diminished Ability	Not Modeled	-1%
Double Hull Only	0%	0%
Base	0%	0%
Stricter Closure at HE	Not Modeled	+2%
Revised Escort	-11%	+6%
Stricter Closure	-7%	+ 10%
Hydrostatic Loading	+17%	Not Modeled

Tables 7.3-3
Percentage Change in Expected Accident Frequency for Inbound Tankers
Inbound Tankers : All Accidents

[illegible]	[illegible]	[illegible]
Tug in Indirect Mode in Narrows	Not Modeled	Not Modeled
Hydrostatic Loading	Not Modeled	Not Modeled
Revised Escort & Fishing Vessel/Tanker Rules	Not Modeled	-42%
Revised Fishing Vessel/Tanker Rules	Not Modeled	-25%
Improved Human/Organization Performance	Not Modeled	-21%
Reduce Prop. & Steer. Failure by 50 %	Not Modeled	-21%
Escort with Enhanced capability Tug at HE	Not Modeled	-18%
Revised Escort	Not Modeled	-18%
Reduced Human Error	Not Modeled	-13%
Reduced VRF (All to best)	Not Modeled	-11%
Improved Management & Crew	Not Modeled	-11%
Increased Internal Vigilance	Not Modeled	-9%
Revised Ice Procedures	Not Modeled	-3%
Stricter Closure at HE	Not Modeled	-3%
Improved Training & Navigation Information	Not Modeled	-2%
Reduced Diminished Ability	Not Modeled	0%
Double Hull Only	Not Modeled	0%
Base	Not Modeled	0%
Reduced Exposure	Not Modeled	+6%
Stricter Closure	Not Modeled	+35%

Table 7.3-4
Percentage Change in Potential Average Oil Ouflow for Outbound & Inbound Tankers
Inbound & Outbound Tankers: All Accidents

Measures are Ranked by Min. % Reduction	**DNV : Average % Change in Oil Outflow**	**GWU : Average % Change in Oil Outflow**
Improved Human/Organization Performance	-40%	-22%
Reduced Human Error	Not Modeled	-14%
Reduce Prop. & Steer. Failure by 50 %	-13%	-19%
Increased Internal Vigilance	Not Modeled	-13%
Reduced VRF (All to best)	-16%	-11%
Revised Escort with Enhanced capability Tug	-25%	-10%
Improved Management & Crew	Not Modeled	-10%
Revised Fishing Vessel/Tanker Rules	Not Modeled	-10%
Double Hull Only	-7%	-12%
Improved Training & Navigation Information	Not Modeled	-3%
Revised Escort & Fishing Vessel/Tanker Rules	Not Modeled	-3%
Revised Ice Procedures	-3%	-2%
Tug in Indirect Mode in Narrows	-3%	Not Modeled
Reduced Diminished Ability	Not Modeled	-1%
Base	0%	0%
Stricter Closure at HE	Not Modeled	%
Revised Escort	-11%	+8%
Reduced Exposure	Not Modeled	%
Hydrostatic Loading	+15%	Not Modeled
Stricter Closure	-17%	+20%

Evaluation by Percentage Change in Accidents Frequency from Base Case for Outbound Tankers - All Accidents

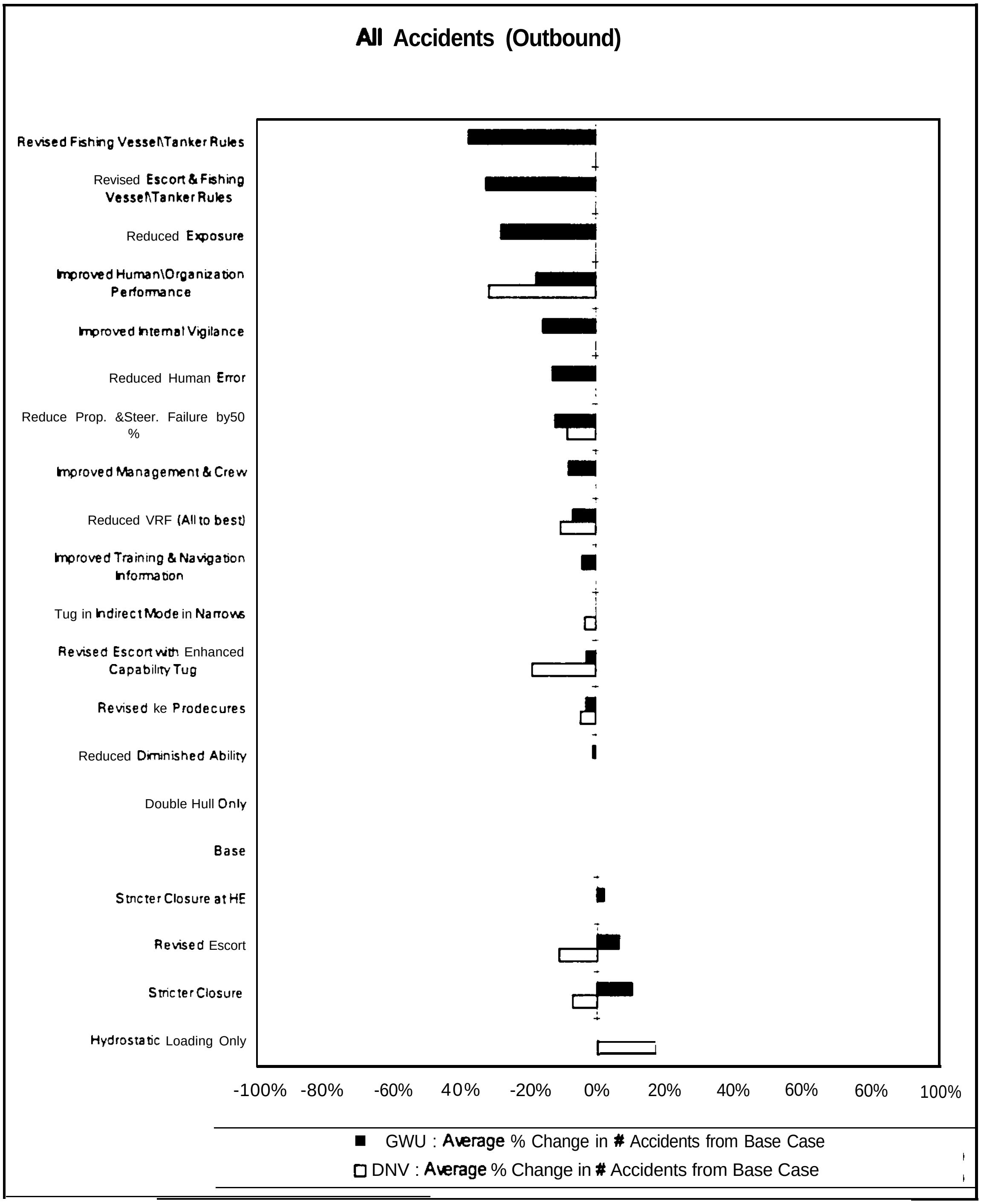


Figure 7.3-l

Evaluation by Percentage Change in Accident Frequency from Base Case for Inbound Tankers - All Accidents

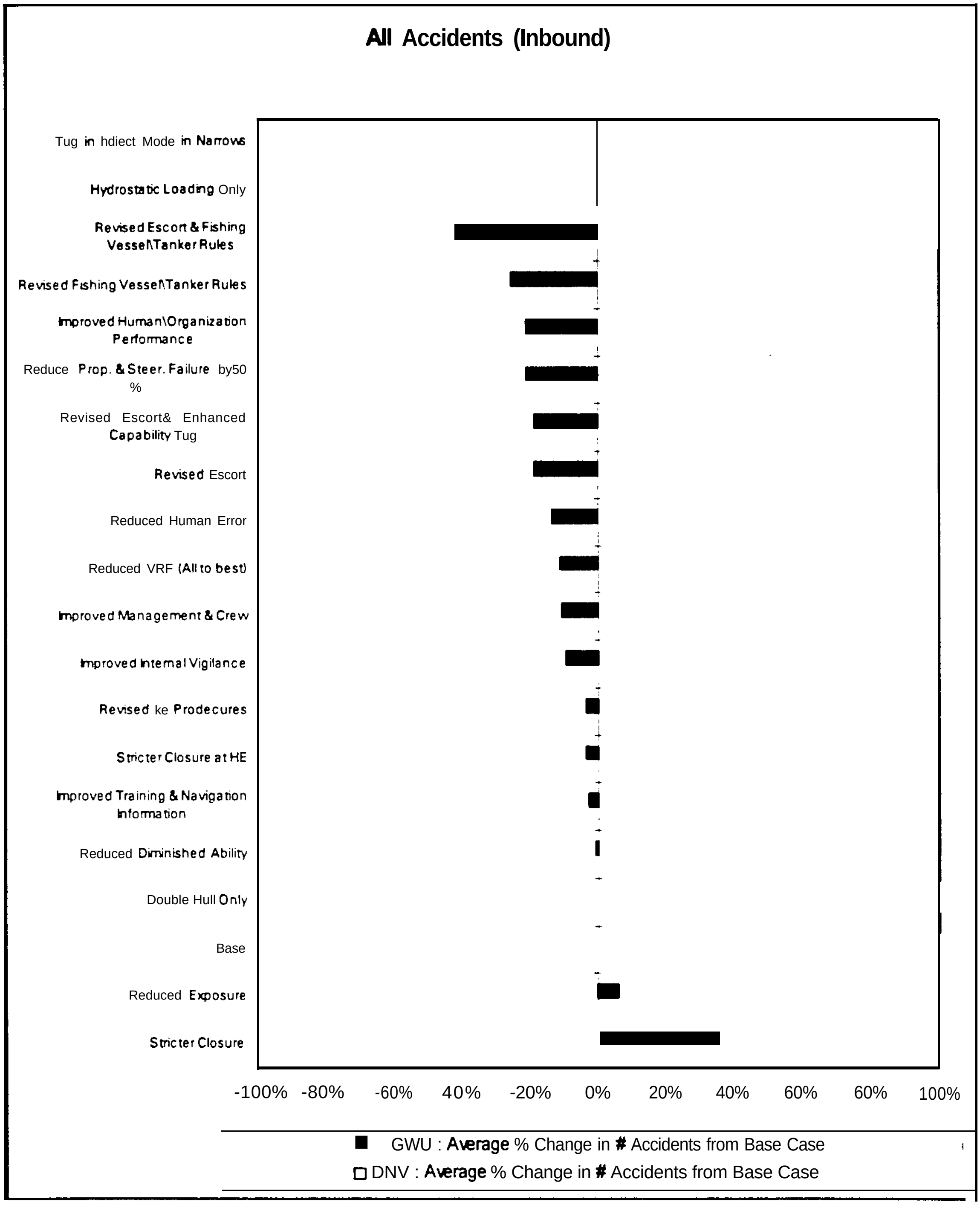


Figure 7.3-2

Evaluation by Percentage Change in Potential Oil Ouﬄow from Base Case for Outbound & Inbound Tankers - All Accidents

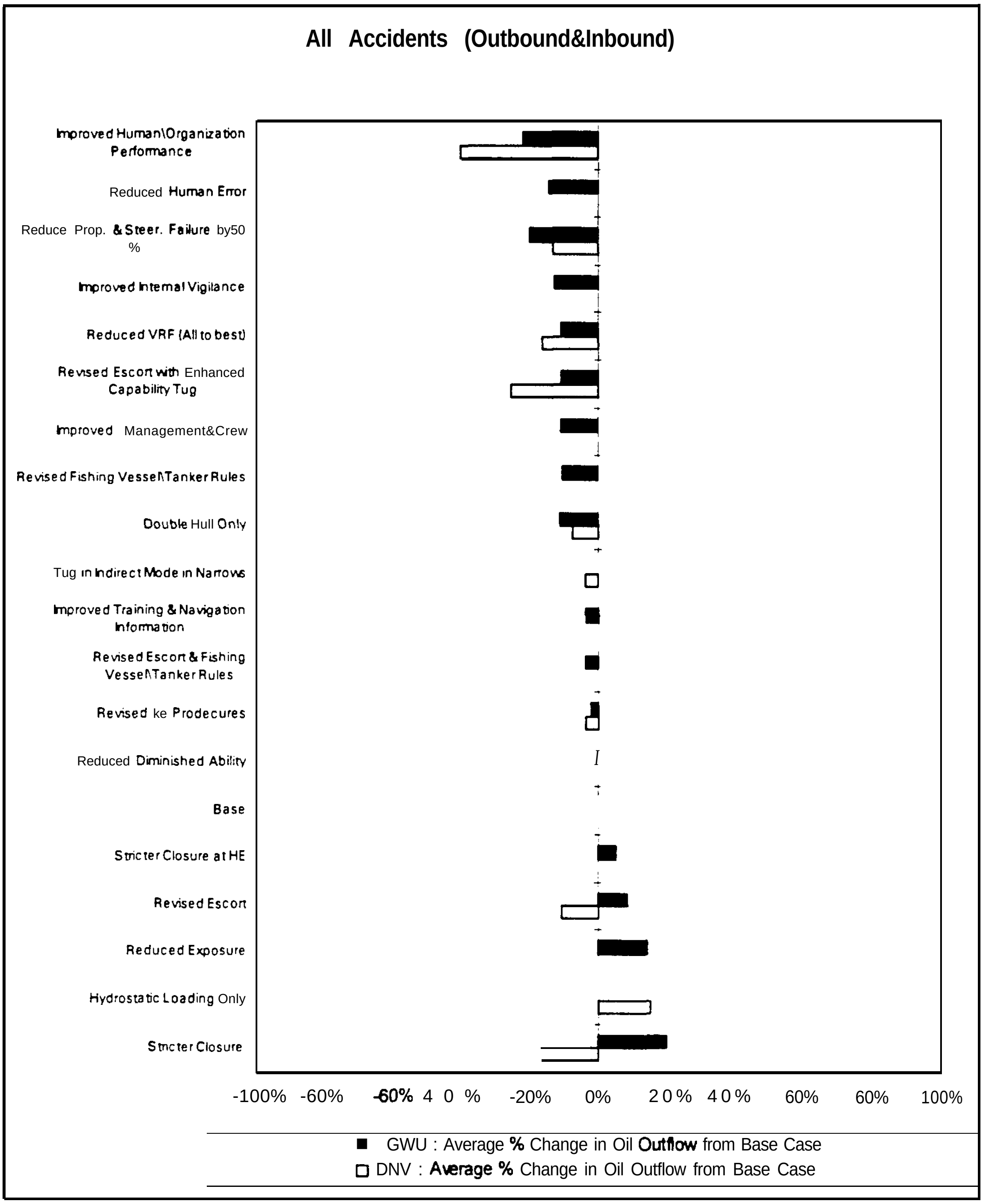


Figure 7.3.3

Fourteen of the nineteen individual measures or combinations of measures were shown to reduce oil outflows and reduce or not increase the frequency of outbound and inbound accidents. Table 7.3-5 lists these measures in order of their relative reduction in expected outbound accident frequency. Their ranking relative to total oil outflows is shown in column three of Table 7.3-5. As in Tables 7.3-2 through 7.2-4, measures are listed in the decreasing order of effectiveness; where two models were used to evaluate the measure the least effective result is used as the basis for the ranking. The inversion of relative rankings for oil outflows and accident frequencies is discussed in Section 7.5.

Table 7.3-5
Risk Reduction Measures Effective In Reducing Both Accident Frequencies And Oil Oufflows

Ranking **Relative To Expected Accident Frequency**	**Risk Reduction Measure**	Ranking **Relative To Expected Oil ouflows**
1	Revised Escort + Revised Fishing/tanker rules	11
2	Revised Fishing/Tanker Rules	8
3	Improved Human/Organizational Performance	1
4	Increased Internal Vigilance	4
5	Reduced human error	2
6	Reduce propulsion and steering failure by 50%	3
7	Improved Management and Crew	7
8	Reduced Vessel Reliability Failures	5
9	Improved Navigation and Training Information	10
10	Revised Escort with Enhanced capability Tug	6
11	Revised ice navigation procedures	12
12	Tug in the Narrows, indirect mode (no change for inbound accident frequency)	13
13	Reduced diminished ability	14
14	Double Hull (no change for inbound or outbound accident frequency)	9

The cases listed in Table 7.3-5 cannot be independently implemented since some measures are combinations of others or have redundant effects on the system as discussed in Section 7.2.1. Table 7.3-6 provides a summary of effective, independent measures and their potential impact on outbound and inbound expected accident frequencies and potential oil outflows. The values are taken from Tables 7.3-2, 3 and 4; where two values are shown, the measure was evaluated by two models. Note that independent and effective measures are possible in each of the five intervention stages described in Section 7.2.1. All of these measures except 4.2, capture 50 percent of all steering and propulsion failures, appear to be reasonably well defined and feasible. Measures 1 .1 (reduce human error), 1.2 (reduce vessel reliability failures), and 2 are addressed in organizational safety programs and regulatory standards. Measures 3.2 (ice navigation), 3.3 (revised fishing vessel/tanker interactions), 4A (revised escort), and 4.1 (tug procedures in the Narrows) are subjects for the USCG VTS rules, state regulations, and the Industry VERP. Measure 5A, double hulls, is mandated by OPA 90.

Table 7.3-6
Summary of Effective Independent Risk Reduction Measures

Intervention	% Reduction In Outbound Accident Freq.	% Reduction In Inbound Accident Freq.	% Reduction In Potential Oil Outflow
1.1 Reduce Human error	-13%	-13%	-14%
1.2 Reduce vessel reliability failure[1]	- 10% to -7%	-11%	-11%
2. Increase internal vigilance	-15%	-9%	-13%
3.2 Revise ice navigation procedures	-4 to -3%	-3%	-3 to -2%
3.3 Revise fishing vessel tanker interactions	-32%	-42%	-3%
4A Revise escort with enhanced capability tug	-19 to -3%	-18%	-25 to -10%
4.1 Tug in indirect mode in Narrows	-3%	0%	-3%
4.2 Capture 50% of all steering/propulsion failure	-8 to -12%	-21%	-13 to -19%
5A Double hulls	0%	0%	-7 to -12%

[1] When risk reduction interventions were evaluated by both MARCS/FT and the system simulation, two percentages are shown.

7.3.3 Discussion of Specific Cases

The revised *ice navigation procedures* case was evaluated by both the fault tree and the system simulation as slightly reducing expected accident frequencies and potential oil outflows. Both the system simulation and the fault tree predict a significant increase in risk of grounding and collision when ice is present. Presence of significant ice in the traffic lanes was, however, a relatively rare occurrence in the base case year. During this year ice of bergy bit size was encountered during 12.5 percent of the transits in the months of July through October and 5.6 percent of the transits in the remainder of the year.

The ice case was defined slightly differently in the two models. The ice case in the system simulation assumed daylight, good visibility, transits only. The system simulation did not distinguish between night time and reduced visibility. The day time restriction increases traffic congestion, increases the diversion of inbound tankers to anchorage, and increases the risk of ship to ship collisions and powered groundings. However, the reduction of the conditional probability of ice collision, ship to ship collision, and grounding during ice was large enough to offset these factors and to produce an overall 3 percent reduction in expected accident frequency.

The fault tree provides a detailed analysis of how to reduce the risk of navigating in ice (see Technical Documentation Part V, Close *Up on Ice Navigation).* Three specific maneuvering schemes were tested by the fault tree to evaluate their impact on the frequency of powered groundings in the Arm.

Option I consists of three procedures:

1. Tankers should always stay in the traffic lane but reduce speed to 6 knots;

2. Significant ice can be detected by the vessel and is to be avoided by tactical navigation; and

3. Sharp course changes are prohibited.

Option 2 consists of the following conditions and procedures:

1. A reliable ice reporting system provides tankers with enough advance warning to alter course to avoid the area with ice; and

2. Outbound tankers change course toward Bligh Reef and maneuver around ice area at 10 knots.

Option 3 is the same as Option 2 except that the alternative route is fixed and made permanent (established as a procedure and marked on charts).

The fault tree analysis assumed that ice larger than bergy bits would not be encountered and, therefore, ice collisions would not produce oil outflows if ice was encountered on the bow of the tanker. The change in the expected frequency of potential ice collisions was not calculated. Option 1 was identified by the fault tree analysis as the optimal case tested. This case does not assume daylight transits only, but does assume that significant ice can be reliably detected. This case was used in the comparison presented in Figures 7.3-1, 7.3-2, and 7.3-3 and reduced the expected frequency of powered grounding in Valdez Arm when ice is present by 53 percent and the overall system expected accident frequency by 4 percent; the other two alternatives increased the risk.

The system simulation and fault tree analysis both indicate that improved ice management could reduce system risk. However, neither analysis calculated the potential oil outflow due to ice--ship collisions (the simulation calculated the expected frequency of ice-ship collisions), nor were potential ice conditions (size and density) other than those experienced during the base case year analyzed. Both of these factors should be considered when developing improved ice navigation procedures.

The *indirect mode for tethered tug in the Narrows* case was analyzed through the use of the fault trees as part of a close up examination of the operation of tugs in the Narrows. The complete results of this analysis are described in the Technical Documentation Part V, Section 5.3. The analysis compared operations of conventional rudder tugs operating at 5 and 6 knots (assuming that procedures are in place that decouple the tanker from the effects of human error on the tug as described in Section 5.3), with a tractor tug operating in the indirect mode at 5, 6 and 8 knots. The base case transit speed of 5 knots is based on the detailed simulation of tug reaction to a hard-over rudder failure and other accident scenarios in the

Disabled Tanker Towing Study (DTTS) and actual tug and tanker trials. The fault tree, although capable of more detailed causal analysis than MARCS or the system simulation, was limited in its ability to differentiate the effectiveness of tug capability between these transit speeds. The fault tree analysis indicated, however, that the conventional rudder tug at 6 knots slightly decreased the risk of powered grounding in the Narrows and the tractor tug in the indirect mode at 8 knots slightly increased this risk when compared to the base case.

However, as shown in the analysis in Section 7.3.2, the tractor tug in the indirect mode option produces a slight decrease in system risk (a 3 percent reduction in expected accident frequencies and in potential oil outflows) when compared to the base case. This system risk reduction is attributed to the decreased exposure in the system due to the increased speed of transit in the Narrows and the Arm.

Hydrostatic loading of single hulled vessels reduces oil outflows for individual accidents. In a closed system such as PWS, however, the same volume of oil must be transported and therefore additional vessels must enter the trade or existing vessels must increase transits. Assuming that any additional vessels, if available, would be equal in size to the average sized vessel in the current calling fleet, approximately 15 percent more transits would be required to carry the same amount of oil. The hydrostatic loading case increases both expected accident frequency and potential oil outflows due to this increased vessel traffic.

The *control of fishing vessel/tanker interactions* case was tested using the modeling assumptions specified in Table 7.2-5. The base case modeled the 1995 fishing season. The problems caused by lack of communication and coordination during this season were recognized by the USCG, the State of Alaska, and the Cordova District Fishermen's Union (CDFU). As a result of discussions between the Alaska Department of Fish and Game, the CDFU, the RCAC, and the USCG a coordination policy for the 1996 salmon season was agreed upon. In 1996 all salmon opener announcements included procedural reminders for VHF-FM communications and VTS rules. The USCG broadcast Notice to Mariners advising of each tanker movement and established a moving 300 yard safety zone around each tanker. Fishing vessels were instructed by the State to stay clear of all tankers during openers. The 1996 fishing season was free of incidents. The analysis shows the critical importance of continuing and improving the communication and management protocols developed in 1996.

The system simulation and the MARCS/FT produced mixed results in two *cases: the stricter closure case,* and the *revised escort case. The* stricter closure case, according to the system simulation, increases inbound accidents, outbound accidents, and oil outflows due to the increase in the potential for collision and powered grounding caused by increased traffic congestion and time spent in the system This effect is also seen in the reduced exposure case, where the simulation calculates an overall reduction in accidents (primarily due to the improved management of fishing vessel/tanker interactions) but predicts an increase in oil outflows due to the stricter closure conditions. The MARCS/FT does not predict this increase in collisions and calculates a risk reduction for the stricter closure case. A stricter closure condition at Hinchinbrook Entrance for tankers greater than 150,000 DWT was proposed as an alternative to an enhanced capability standby tug at Hinchinbrook. This alternative, when evaluated by the system simulation, was found to produce a slight increase in both expected oil outflows and accident frequency.

The *revised escort case* was evaluated by MARCS as an effective means of reducing both the expected accident frequency and expected oil outflow. The system simulation calculated that the revised escort case would result in an increase in both outbound accidents and oil outflows. The simulation did, however, find that the revised escort case would reduce the frequency of inbound accidents by 18 percent. As stated above, the difference between the two models was the evaluation of the effectiveness of replacing the two escort vessels with effectively one standby vessel in the Central Sound. Revised escort alternatives that provide the same level of standby coverage in the Central Sound will be evaluated as a risk reducing alternative by the system simulation.

Additional insight into the effect of risk reduction measures on the system, particularly on those measures which were evaluated differently by the system simulation and the MARCS/fault tree, may be gained by examining the interaction between collisions and groundings. Figures 7.3-4, 7.3-5, and 7.3-6 show the expected outbound drift grounding, powered grounding, and collision accident frequencies for the same nineteen risk reduction cases. Figure 7.3-7, 7.3-8, and 7.7-9 show the expected inbound drift grounding, powered grounding, and collision accident frequencies. Figures 7.3-4 and 7.3-7 show that interventions that reduce failure rates or improve the save capability of escorts have a significant effect on drift groundings.

The MARCS model predicts that significant risk reduction (76 percent of all drift groundings, 84 percent of all oil outflows due to drift groundings) could be achieved through stricter closure conditions. The system simulation predicts no significant change in drift groundings due to stricter closures. The simulation does predict a decrease in drift groundings at Hinchinbrook Entrance, but that this decrease is offset by the increased risk due to the increased exposure in the system (tankers "race tracking" in the Central PWS until Hinchinbrook is opened). The conditional probability of grounding given a specific situation is based on mariner's judgment in the system simulation, so it may be reasonable to assume that mariners routinely overestimate the "save" potential of their escorts in more extreme conditions. The simulation does, however, show that stricter closures could have a significant effect on both the outbound and inbound collision risk. Since the collision interactions potentially involve vessels with large numbers of persons onboard (cruise ships, ferries, tour boats), a risk intervention that trades a decreased frequency from grounding for an increased frequency of collisions based on a single metric of reduced oil outflows may not be a sound policy.

Figures 7.3-5 and 7.3-8 show that the interventions that reduce or capture human error, or reduce the necessity to maneuver in traffic are the most successful in reducing the frequency of powered groundings. Figures 7.3-6 and 7.3-9 show that the traffic management interventions are of primary importance in reducing collisions and human error reductions are secondary. Reducing mechanical failure rates has little impact on the frequency of collisions.

Evaluation by Percentage Change in Expected Accident Frequency from Base Case for Outbound Tankers - Drift Grounding

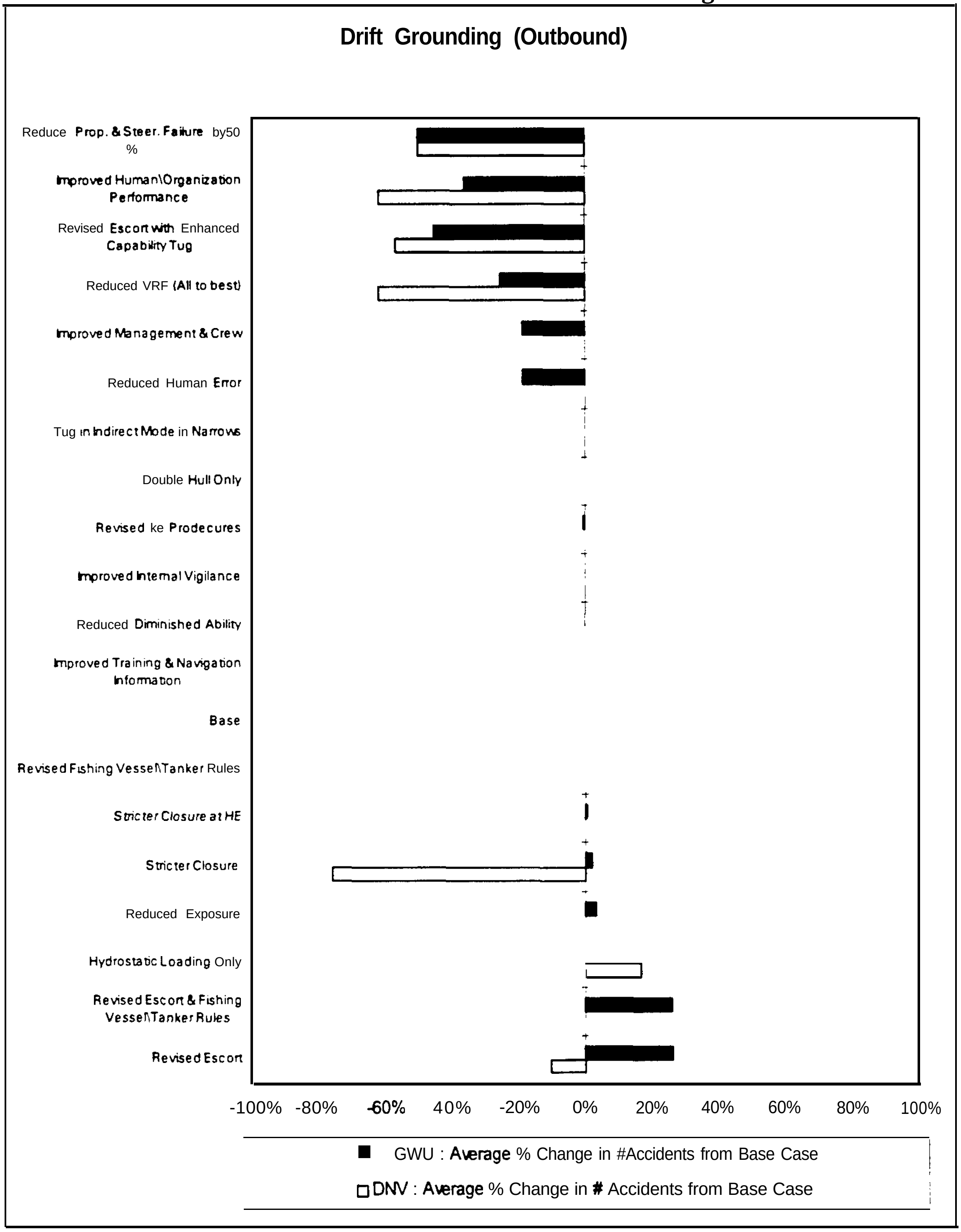


Figure 7.3-4

Evaluation of Percentage Change in Expected Accident Frequency from Base Case for Outbound Tankers-Powered Groundine

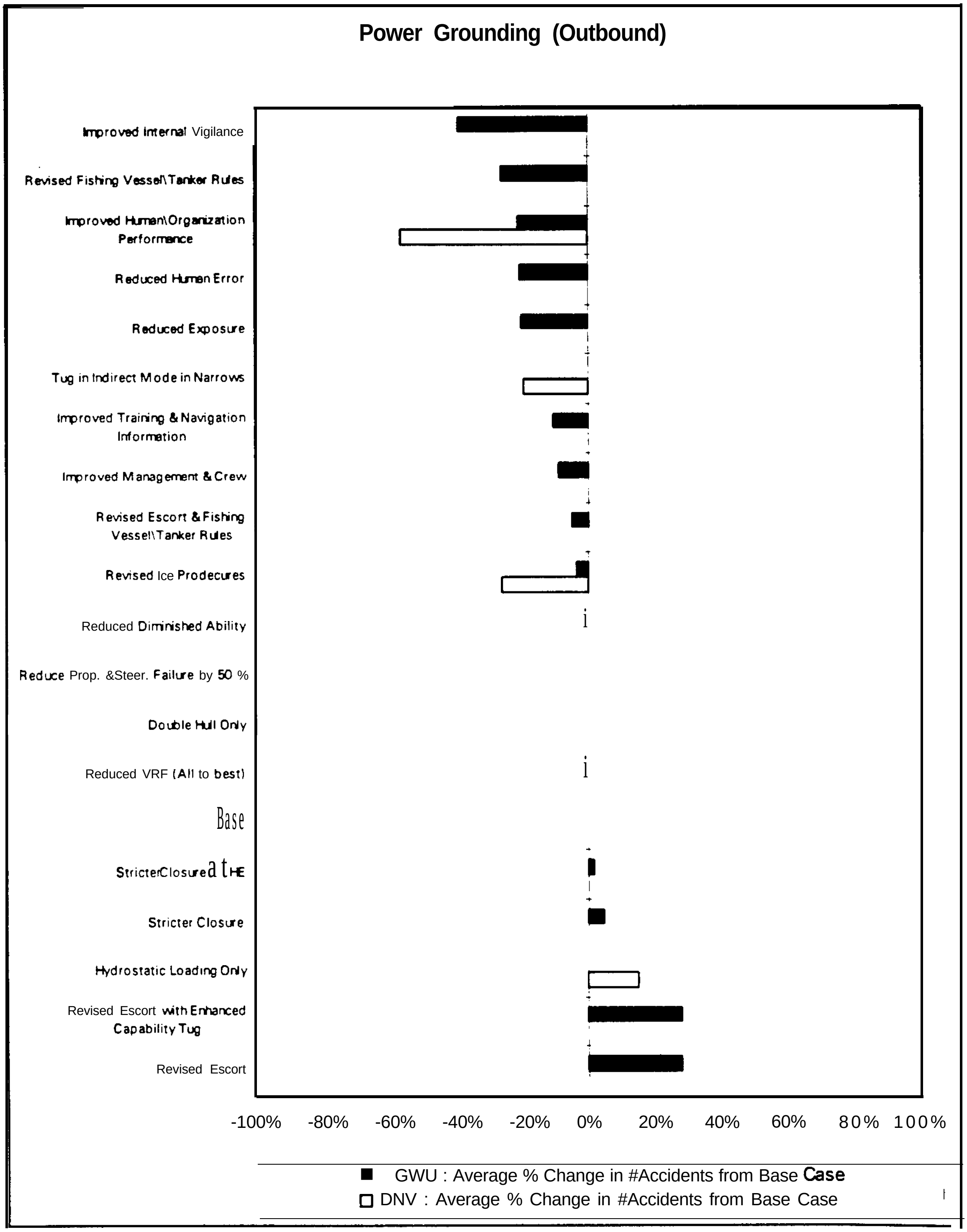


Figure 7.3-5

Evaluation by Percentage Change in Expected Accident Frequency from Base Case for Outbound Tankers - Collision

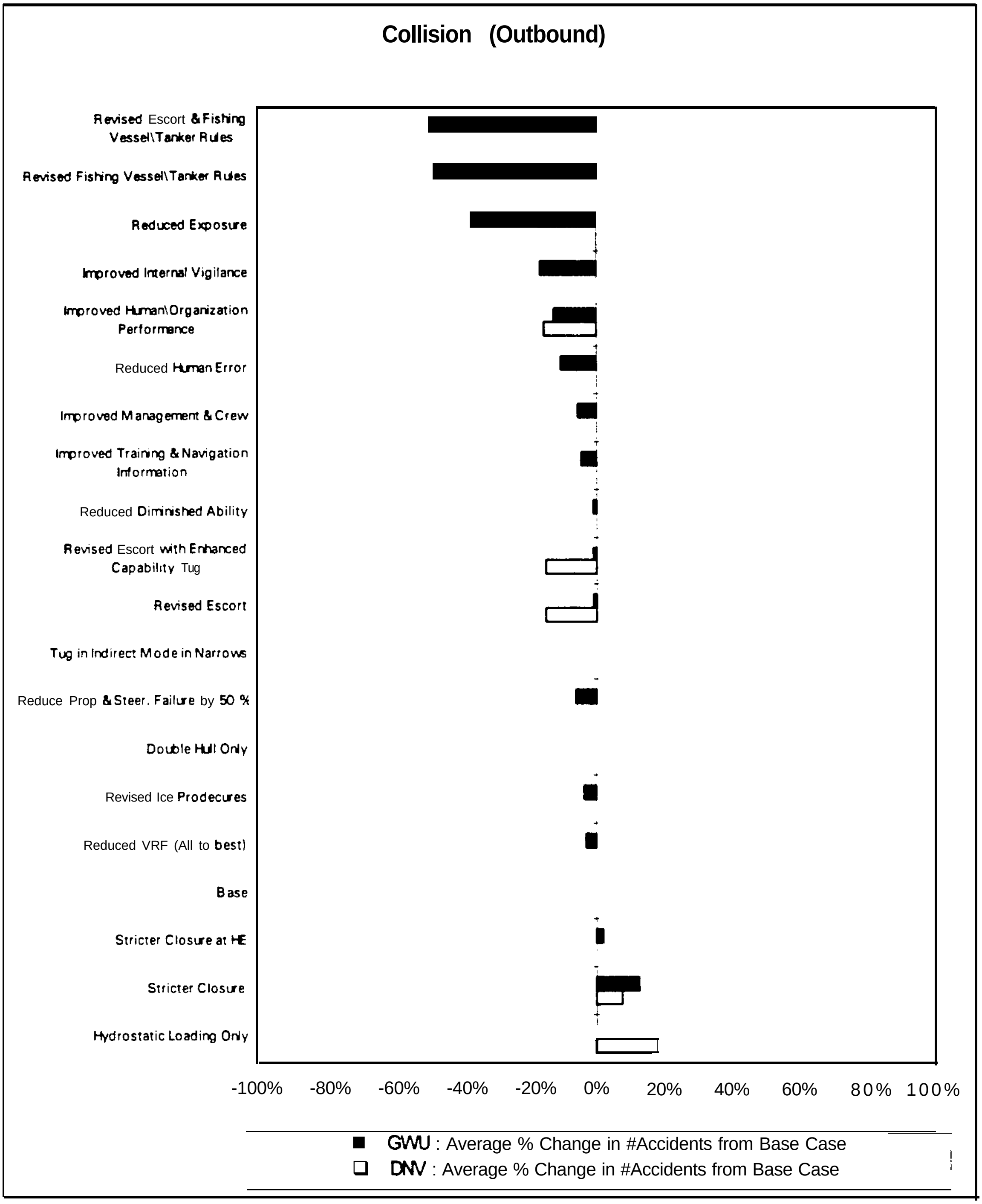


Figure 7.3-6

Evaluation by Percentage Change in Expected Accident Frequency from Base Case for Inbound Tankers - Drift Grounding

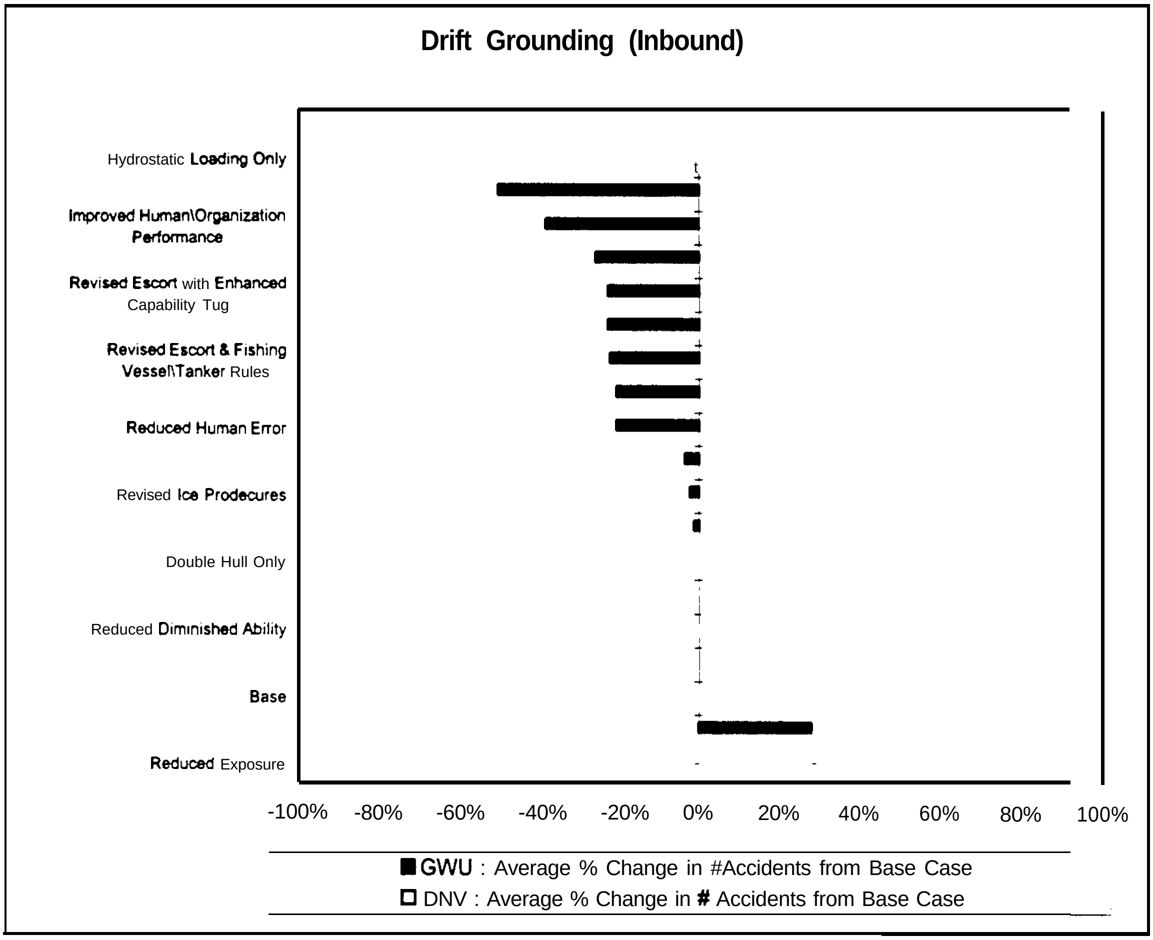


Figure 7.3-7

Evaluation by Percentage Change in Expected Accident Frequency from Base Case for Inbound Tankers - Powered Grounding

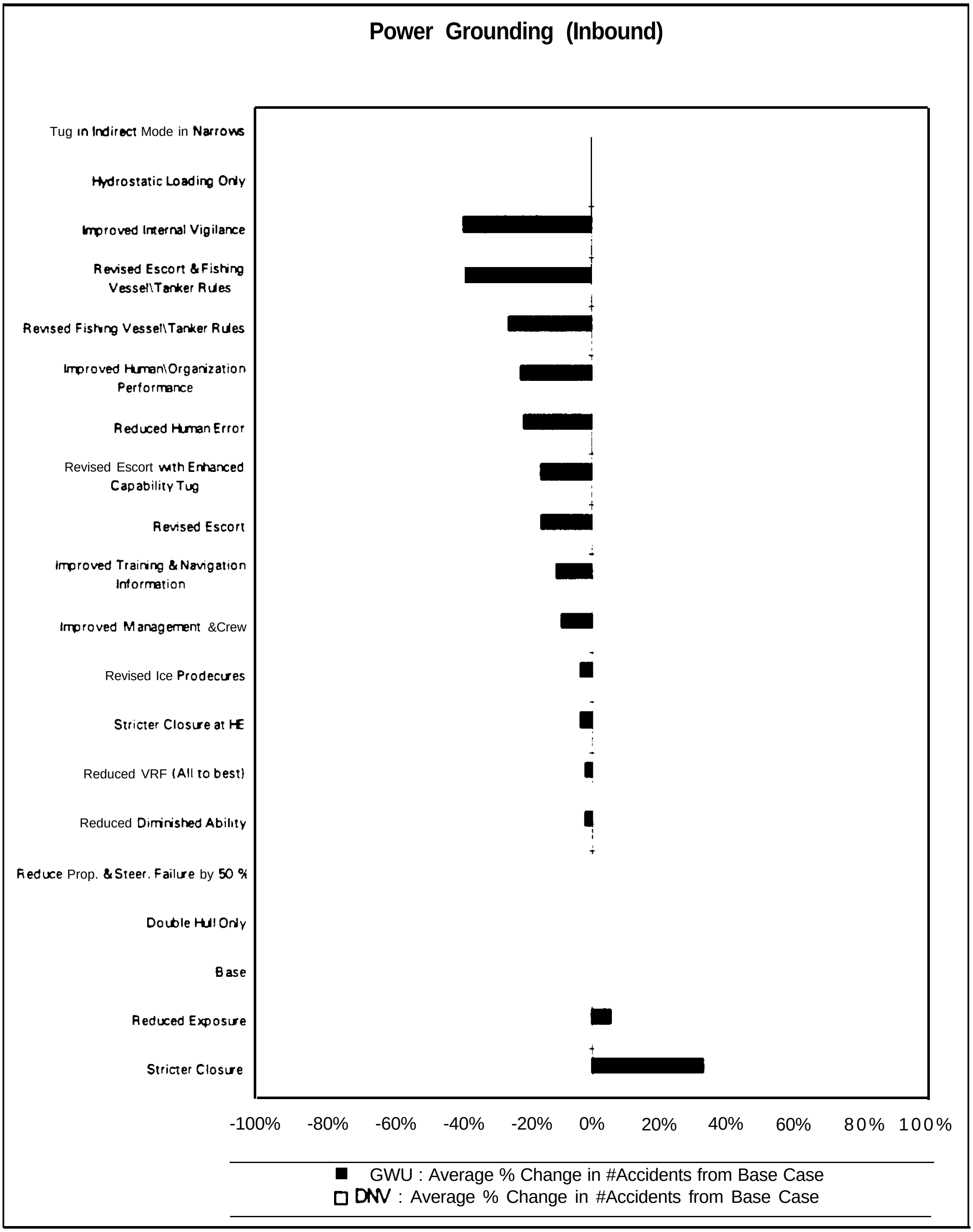


Figure 7.3-8

Evaluation by Percentage Change in Expected Accident Frequency from Base Case for Inbound Tankers - Collisions

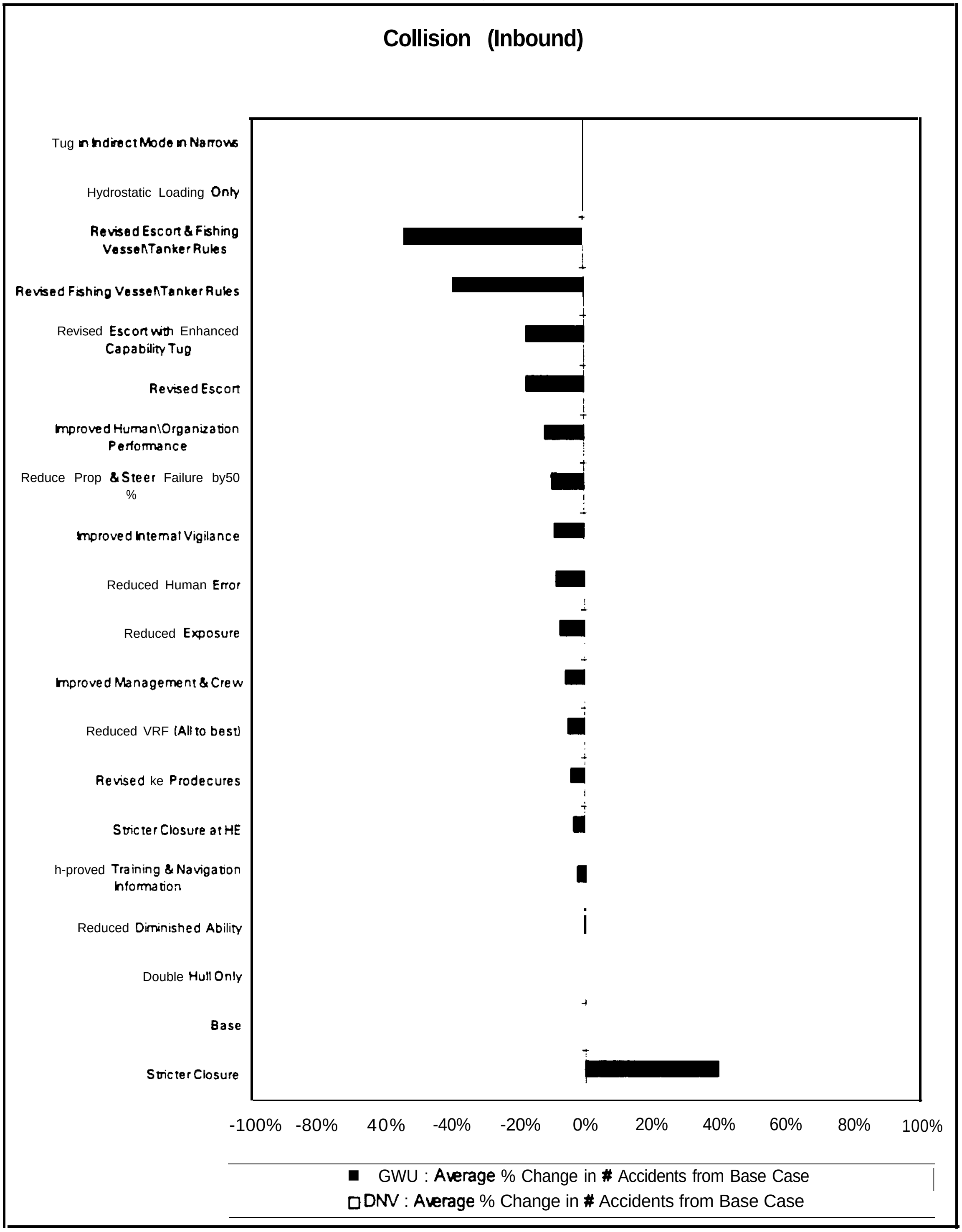


Figure 7.3-9

7.4 The Effect Of Multiple Risk Reduction Interventions

Case 1 (human and organizational performance), Case 3 (exposure), and the revised escort plus revised fishing/tanker rules are all cases that combine risk reduction measures. An attempt was made **to** create a maximum safeguard case by combining all proposed cases as defined in Chapter 6 in Table 6-l and Table 6-25. This case was evaluated by both the MARCS/FT and the system simulation and the results are shown in Table 7.4-l. An additional case, the maximum safeguard case with base case parameters was defined as the maximum Stage 3 (exposure) and 4 (intervention/escort) interventions. This case is really a "maximum external control/assistance" case. The results of this case are shown in Table 7.4-2. The intent of defining these two cases was to approximate the goal of the "best possible" system. The results show that the maximum safeguard case is not the "best case". The discussion in Section 7.3 showed that some "risk reduction" measures actually increase risk. Due to the conflicting results obtained for stricter closure conditions by the dynamic system simulation and the static MARCS, the inclusion of these conditions in the maximum safeguard case makes interpretation and comparison difficult. Table 7.4-l shows that both the system simulation and the MARCS/FT found that the maximum safeguard case would reduce the expected frequency of outbound accident by approximately 50 percent, and that the maximum external control/assistance case would reduce the risk of accidents by approximately 20 percent. The models disagreed significantly, however, on expected oil outflows. The MARCS predicts oil outflow reductions that exceed the reduction in accident frequency since closure restrictions and improved escorts reduce drift groundings, a high oil outflow event. The system simulation indicates that the maximum control case would eliminate many low outflow accidents (fishing vessel/tanker collisions), but the congestion in the system would result in a higher expected frequency of powered groundings and collisions with larger vessels. As a result, the system simulation predicts only a 16 percent reduction in oil outflows in the "maximum safeguard" case, and a increase in oil outflows in the maximum external control/assistance case.

Table 7.4-l
Evaluation Of Maximum Safeguard Case
Change from Base Case in Expected Outbound Accident Frequency

EFFECT OF MEASURES	**SYSTEM SIMULATION**	**MARCS /FAULT TREE**
EXPECTED OUTBOUND ACCIDENT FREQUENCY MAXIMUM SAFEGUARD CASE	-47%	-59%
EXPECTED OUTBOUND OIL OUTFLOW MAXIMUM SAFEGUARD CASE	-16%	-61%

Table 7.4-2
Evaluation Of Maximum Case With Base Case Parameters
Change from Base Case in Potential Oil Ouflow

EFFECT OF MEASURES	**SYSTEM SIMULATION**	**MARCS /FAULT TREE**
EXPECTED OUTBOUND ACCIDENT FREQUENCY MAXIMUM SAFEGUARD WITH BASE CASE PARAMETERS	-18%	-22%
EXPECTED OIL OUTFLOW MAXIMUM SAFEGUARD WITH BASE CASE PARAMETERS	+21%	-27%

A theoretical calculation of the maximum effective safeguard case can be made from the results shown in Table 7.3-6 and estimating the maximum change in expected accident frequency and oil outflow that could be achieved at each stage. The results are shown in Table 7.4-3.

Table 7.4-3
Theoretical Maximum Reduction in Expected Accident Frequencies and Oil Outflows

[redacted]	[redacted]	[redacted]	[redacted]
Stage I: reduce basic or root causes	-23 to -30%	-24%	-25 to -30%
Stage II: decrease frequency of triggering events	-15%	-9%	-13%
Stage III: decease exposure to hazardous situations	-35 to -36%	-45%	-5 to -6%
Stage IV: Prevent accidents if incidents occur	-14 to -34%	-39%	-26 to -42%
Stage V: Reduce oil outflows if accidents **occurs**	0%	0%	-7 to -12%
Theoretical Maximum Reduction	-64 to -75%	-77%	-58 to -71%

7.5 Removing Risk Reduction Measures

Two cases were designed to remove risk reduction cases in an attempt to establish a minimum case for comparison purposes. The two cases were a minimum case as defined in Chapter 6, Table 6-2 and 6-25, and a no escort case. The relative success of the international, national or local risk reduction measures affecting Prince William Sound that have been implemented may be seen by comparing the minimum case with the base case as shown in Table 7.5.1.

Table 7.5.1
Comparison of Base Case and No Escort Case with Minimum Case

	POTENTIAL CHANGE IN EXPECTED ACCIDENT FREQUENCY	PERCENT CHANGE IN POTENTIAL OIL OUTFLOWS
BASE CASE	-62% to -85%	-74% to -86%
No Escort Case	-59% to -62%	-62% to -67%

The purpose of the escort system has been to prevent the grounding of laden tankers. The two tornado diagrams showing the base case and no escort case for groundings only show that the escort program has been effective. Figure 7.5.1 (outbound expected grounding frequency) shows that escorts can be credited with avoiding 15 to 28 percent of the groundings in the minimum case. Figure 7.5.2 (potential oil outflow from groundings) shows that escorts can be credited with avoiding 13 to 29 percent of the oil outflows due to grounding. The remaining reduction in the risk of grounding from the minimum to the base case is due to the reduced occurrence of triggering incidents (human errors, propulsion failures, and steering failures) attributable to other system safeguards.

Comparison of Base Case, Minimum Case, and No Escort Case
Expected Frequency of Outbound Grounding Accidents

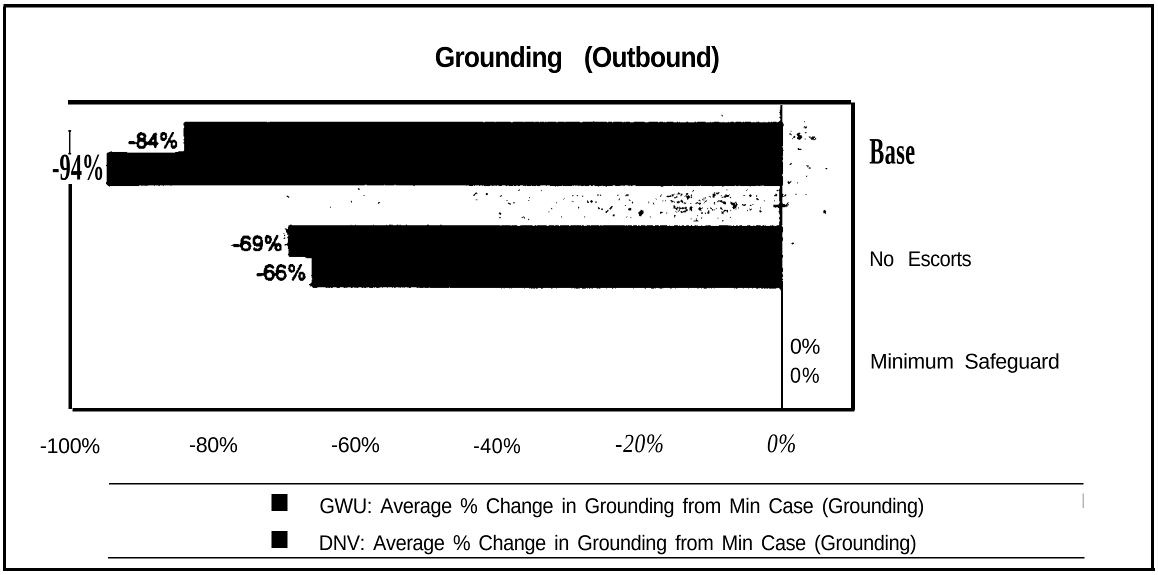


Figure 7.5.1

Comparison of Base Case, Minimum Case, and No Escort Case
Expected Potential Oil Ouflow from Grounding Accidents

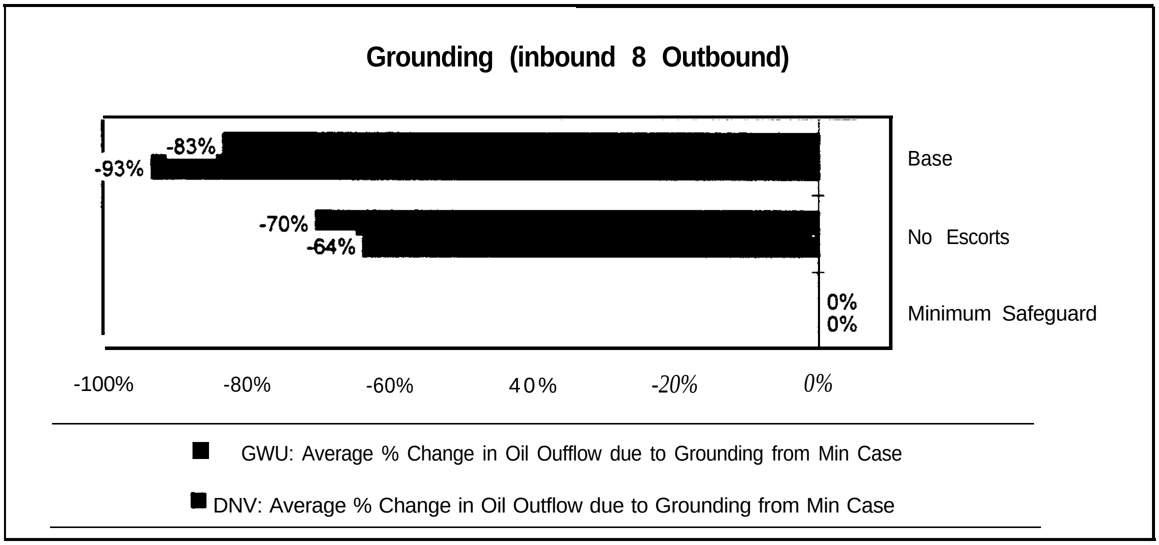


Figure 7.5.2

7.6 Summary

The analysis of risk reduction measures shows that, although effective risk reduction measures are in place, significant additional risk reduction is possible. One of the most effective risk reduction measures was discussed in Chapter 5: decoupling the operations of the tethered tug to ensure that human error on the tethered tug could not cause a grounding of the tanker in the Narrows. A formal procedure that accomplished this decoupling and ensured internal vigilance on the tug was shown to effectively remove this potential risk. The analysis in this chapter assumed that this procedure is already in place, and the modified base case described in Chapter 5 was used as the basis for all additional risk reduction comparisons. This summary highlights three general observations:

1) Systemic risk reduction interventions that affect the entire calling fleet effectively reduce both accident frequencies and oil outflows;

2) Targeted risk reduction interventions that are designed to mitigate a specific accident scenario are typically effective at reducing either oil outflows or accident frequencies, but not both. Risk reduction interventions targeted at specific system areas may also have unintended effects in other areas of the system; and

3) Risk reduction interventions may actually increase risk. It is difficult to anticipate the effects of any intervention on a complex system.

7.6.1 Systemwide Interventions

Four broad systemic interventions were examined: reducing human and organizational error, reducing failure rates, implementing double hulls, and revising the escort program. Reducing human and organizational error and reducing vessel failure rates provide the most consistent and largest risk reductions. There are, however, problems with relying on these interventions as a cure all. The experience and data to substantiate the modeling assumptions that produced these results is very sparse. The model results show the need for research and data collection in this critical area. The international maritime community has adopted an international safety management (ISM) code as an approach to safety management. Historical data suggests that this will result in significant risk reductions, but implementation across organizations will be inconsistent. The effectiveness of implementation of safety management systems is difficult for government regulators and citizen observers to ascertain, and a lag time exists between the implementation of these systems and the occurrence of any observable effects.

The analysis shows that double hulls are an effective systemic intervention that will reduce oil outflows, assuming that the existing vessels are replaced by ships with equal cargo capacity, and the conversion does not result in additional vessel transits. Hydrostatic loading of single hulled vessels is not an effective alternative to double hulls since the increase in transits required to carry the same volume of oil results in an increase in expected accidents and oil outflows.

The analysis shows that a revised escort program that preserves the risk reduction achieved under the current highly effective escort program, but that will decrease the risk of collisions, drift groundings at Hinchinbrook, and risk to inbound tankers is possible. The alternatives tested do not provide the optimal configuration, but other options may be easily tested and will provide the information required to re-design the system.

7.6.2 Targeted Scenario Interventions

Five scenario based intervention strategies were examined: an enhanced capability tug at Hinchinbrook capable of saving all vessels under all allowable transit conditions to prevent drift groundings; stricter closures to prevent drift groundings; management of fishing vessel/tanker interactions to prevent collisions; improved ice navigation, and improved escorts in the Narrows.

The location of an enhanced capability tug at Hinchinbrook Entrance and the imposition of stricter closure conditions at Hinchinbrook are options that affect the same scenario - the drift grounding at Hinchinbrook. Both the system simulation and the MARCS show that the provision of an enhanced capability vessel with the ability to save the largest tankers under all allowable transit conditions will reduce the expected frequency of drift groundings for vessels > 150K DWT. The simulation showed that stricter closure conditions at Hinchinbrook Entrance are not a viable option. Although they reduce the expected frequency of drift groundings, their net effect on the system would be an increase in risk. Additional closures of any type do not appear to be an effective option since the congestion and traffic disruption they cause leads to an increase in the risk of powered grounding and collision.

The more rational management of fishing vessel/tanker interactions will increase system safety by reducing interactions that could lead to collisions. Since most of the potential F/V - tanker collisions do not have the potential to spill oil, this intervention has a minor impact on expected oil outflow (but could have a significant impact on the potential loss of life and injury). The measures tested do not require prohibiting fishing in any area or closing the port to tanker traffic during fishing openers. Better communication, better State and USCG coordination, and better USCG traffic management during fishing openers as achieved in the summer of 1996 will realize the benefits modeled.

Better ice navigation procedures can significantly lower the risk of navigating in ice. The revised procedures modeled in the fault tree and system simulation produce a significant decrease in the risk of navigating through ice and a slight decrease in system risk. The alternative modeled in the system simulation, daylight transits only, is optimal for individual vessels, but requiring that all vessels transit during the daytime increases congestion and increases the risk of collisions and powered groundings. Due to the relatively low incidence of heavy ice in the lanes in the base case year, this intervention does not provide a large risk reduction compared to other interventions. It is, however, an effective solution to a well defined risk spike that will become more important if ice increases.

7.6.3 Maximum Risk Reduction Possible

As shown in Table 7.4-3, the risk reductions that are theoretically possible could potentially reduce the expected base case accident frequency by another 64 to 75 percent, and the potential oil outflows by 58 to 71 percent. These reductions, although large relative to the base case, are smaller in absolute terms than the reductions already made. As shown in Figure 7.5-l and 7.5-2, approximately three quarters of the potential risk in the minimum case (62 to 85 percent of the expected accident frequency and 74 to 86 percent of the potential oil outflow) has been negated by international, national, and local regulatory and industry interventions. Approximately three quarters of the remaining one quarter is, therefore, the feasible target for future risk reduction. The risk reduction interventions specified in Table 7.3-6 and discussed in Sections 7.6.1 and 7.6.2 will enable a continuing improvement of the safety systems in Prince William Sound.

8.0 Conclusions and Recommendations

8.0 Conclusions and Recommendations

8.1 Summary of Process and Discussion of Uncertainty

The Prince William Sound Risk Assessment described in this report provides an in depth analysis of a complex maritime system. The utility and validity of the results are, in a large part, due to four elements of the project design:

1. The project was created and managed by a Steering Committee comprised of stakeholders in Prince William Sound (PWS). The project team was linked to this Steering Committee by a Project Coordinator who worked for the Steering Committee, not the project team. Frequent briefings of the Steering Committee by the project team and the involvement of the Project Coordinator ensured that the project team was informed of salient items in the system and had access to available information.

2. The project team combined technical expertise from two major research universities and one international maritime consulting company. Each team partner had both maritime expertise and experience in maritime risk assessment. The geographically dispersed, multi-cultural team brought unique breadth, depth, and critical insight to the project.

3. Four models, as described in Chapter 3, were used to assess risk in the PWS system. As shown in Chapters 5 and 7, the multiple views of the system provided by these models were used to develop an integrated picture of risk and to provide the basis for the Risk Management Plan. The multiple model approach enabled the team to capture aspects of the system and interactions within the system that any individual approach might have missed. The conclusions and recommendations that follow are, therefore, the beneficiaries of these multiple views of the system, which provided a valuable internal check of the consistency and validity of the analysis.

4. Most risk assessments provide an analysis of the existing risk in a system or sub system. Assessing the base case risk (Chapter 5) was only the starting point for the PWS Risk Assessment. The project's charter focuses on the goal of making the system safer. The structuring of the proposed risk reduction interventions described in Chapter 6 and the analysis of the risk reduction potential of many of these interventions discussed in Chapter 7 are critical elements of the PWS Risk Assessment. This structured investigation of risk interventions provides the basis for a rational risk management plan.

Any modeling process involves dealing with uncertainty (the true value of a number may be different from the assumed or calculated value) and ambiguity (the meaning of a statement, definition, or number may be unclear). In the Prince William Sound Risk Assessment, there are at least five areas of ambiguity that affect the computation and interpretation of results.

1. *Ambiguity concerning* goals. The objectives of the Prince William Sound Risk Assessment were to (1) identify and evaluate the risk of oil transportation in PWS, (2) to identify, evaluate and rank proposed risk reduction measures, and (3) to develop a risk management plan and risk management tools that can be used to support a risk management program. Although these goals seem unambiguous, their clarification or interpretation by the Steering Committee was essential.

2. *Ambiguity concerning values.* Oil outflow was selected as the measure of consequence for a tanker accident. This is obviously a surrogate measure for the true environmental and social impacts of an oil spill. Different stakeholders attached different values to equal outcomes depending upon other situational considerations such as location and time of year leading to different priorities for analysis.

3. *Ambiguity concerning models.* Models are selective abstractions of reality. The critical element in model construction is the selection of those portions of reality that should be and can be modeled. An incomplete understanding of the system or an inadequate abstraction or representation of the system in the model can produce ambiguous results. The models are not representing what the modelers intended. The unlimited access to stakeholders and to available information, and the internal check between models provided some safeguard against this area of ambiguity, but even good models are just representations of reality.

4. *Ambiguity concerning data.* Data ambiguity is the assumption that data represents measure of a certain condition or object when in fact it represents something else. Data ambiguity differs from data uncertainty, which is due to inaccurate, incomplete, inconsistent, or not current data. Several cases of data ambiguity were discovered and clarified during the analysis (e.g., the differing definitions of "propulsion failure" or "structural failure" in different data bases; the interpretation of fishing opener data). Other ambiguities in data may not have been discovered.

5. *Ambiguity concerning rules.* This source of ambiguity was a major concern in the system simulation. Although the vessel traffic and escort rules contained in Chapter 3 appear to be clear and unambiguous, a continuous dialogue with the USCG and Alyeska/SERVS was necessary to determine how these rules were actually interpreted and followed. This ambiguity could not have been clarified without the access to and cooperation of the system stakeholders enjoyed by the project team.

Sources of uncertainty in the modeling assumptions and data analysis process are discussed in Chapters 3 and 4 and in the Technical Documentation. Several important sources of uncertainty are important to remember when reviewing the conclusions and recommendations that follow in Sections 8.2 and 8.3.

1. The system simulation/regression analysis modeling methodology relies upon expert judgment as the source of data for the regression analysis that calculates the relative probability of incidents and accidents. This methodology has two intrinsic sources of uncertainty: (1) the individuals selected may not be experts and (2) the perceptions of experts may not actually reflect reality, the experts may be wrong or biased. The methodology for selecting experts in this analysis was aided by the cooperation of the stakeholders. The systematic elimination of bias was part of the elicitation process described in Technical Documentation Part III, Section 3.4.

2. The fault tree analysis was the basis for significant results, conclusions, and recommendations. Uncertainty in the fault tree is produced by uncertainty in the data and judgments used to assess the frequencies and probabilities in each tree (see Technical Documentation Part III, Section 3.4). Historical data used from other domains has an uncertain applicability. The judgment of analysts and experts, used when data is unavailable, is subject to an uncertain bias.

3. The MARCS model uses either historical data or fault tree results to assess the probability of an accident given a situation. It therefore contains the same data uncertainty present in the fault tree along with uncertainties in the content or applicability of the historical data used.

4. The oil outflow model is based on worldwide historical oil outflow data. Effort was made, however, to select vessel and accident types that were similar to those in the PWS system. In addition to being based on worldwide data, the statistical expectation of oil outflows for each accident are determined primarily by the probability of total loss for that accident type. Whether or not this probability of total loss is representative of PWS is uncertain. PWS has

severe weather conditions, but it also has more resources available to assist after an accident has occurred.

5. The assumptions made in all models to represent changes in the system were, as described in Chapters 6 and 7, based on available data and the judgment of the project team. Each of these estimates has a high degree of uncertainty. The risk reduction results based on these estimates are also uncertain.

6. Data uncertainties are also present in the system. These uncertainties are associated with incomplete, inaccurate and inconsistent data as described in Chapter 4.

8.2 Conclusions

The conclusions of the study address the state of the PWS oil transportation system in 1995 and suggested mitigation measures. The conclusions are statements that can be directly inferred from the text, and can be traced directly to earlier text (see references in parentheses). The analysis and discussion in the preceding chapters leads to the following conclusions.

1. Current safeguards in the Prince William Sound oil transportation system have effectively and substantially reduced risk. Analysis revealed that current system safeguards have removed approximately 75 percent of the system risk that would exist if these safeguards were not in place (Section 7.5).

2. The single most effective risk reduction measure to date has been the current escort system which effectively reduces potential oil outflows due to groundings (Section 7.5).

3. In light of 1 above, and in order to continue process improvement in the system, accident scenarios with the greatest potential for additional risk reduction were identified for further consideration. These included:

   - Powered grounding of a laden outbound tanker in the Narrows caused by the present inability to prevent, detect, or correct human errors which may occur in the operation of the tethered tug (Section 5.3.2).

- Collision in the Port, Narrows, Arm and Central Sound caused by fishing vessel and tanker interactions, traffic congestion (often due to closure conditions and management of the exclusion zone) and human error (Section 5.3.3 and 5.35).

- Drift grounding at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance (denoted by the title Gulf of Alaska in this report) caused by propulsion or steering failures and the inability of current escort vessels to prevent larger disabled tankers from grounding in the upper range of weather conditions allowed by weather closure restrictions at Hinchinbrook Entrance (Section 5.3.3 and 5.3.5).

- Powered grounding in the Narrows caused by loss of ship control, predominantly due to human error on the tanker (Section 5.3.3 and 5.3.5).

- Powered grounding at Hinchinbrook Entrance and in Valdez Arm caused by human error (Section 5.3.3 and 5.3.5).

4. The probability of an accident for a vessel in transit through the Arm in heavy ice is 3 to 4 times greater than that for a vessel during a transit without ice. Collisions and powered groundings due to the presence of ice were not primary accident scenarios due to the low incidence of heavy ice in the traffic lanes during the base case year. However, improvements can be made in managing ice transits in the system to mitigate the increased risk when ice is present (Section 7.3.3).

5. The existing escort program with improved human error capture capability on the tug effectively reduces powered groundings in the Narrows. Existing escort vessels are capable of assisting tankers and preventing grounding accident scenarios due to mechanical errors in the Narrows. The current escort program does not always insure adequate save capability in the upper range of weather conditions allowed by weather closure restrictions for drift grounding by outbound laden tankers at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance. In addition, the escort program has one counterintuitive impact: the presence in the system of escort vessels returning to Port Valdez is a contributor to the statistical expectation of the frequency of collisions. This risk is reflective of the relative density of SERVS vessel traffic

in Prince William Sound, rather than reflective of inherent risk of SERVS vessels (Section 7.3.2, 7.3.3, and 7.6.1).

6. Existing system closure conditions and traffic management procedures effectively reduce the statistical expectation of the frequency of accidents (and associated oil outflows). However, the net effect of more strict closure conditions could increase systemwide risk. For example, closing Hinchinbrook Entrance to tankers greater than 150,000 DWT when wind is greater than 30 knots would reduce the risk of drift groundings at Hinchinbrook and the approaches to Hinchinbrook Entrance by reducing the instances of failed saves. However, it would increase the risk of collisions and powered groundings in the Arm and Central PWS due to increased vessel interactions and increase the risk of structural failures, fires, and explosions in Prince William Sound due to increased exposure (Section 7.3.2, 7.3.3, and 7.6.2).

7. Effective coordination between tankers and fishing vessels can significantly reduce risk of collision with fishing vessels, as was underscored with coordination efforts which were reinstituted in 1996. These coordination efforts should continue in the future (Section 7.3.2, 7.3.3, and 7.6.2).

8. Methods for achieving the potential risk reduction were defined in two ways: *targeted risk mitigation measures* (defined as those measures which address problems in specific scenarios) and *systemwide risk mitigation measures* (defined as those measures which address risk from a systemwide perspective).

Targeted risk mitigation measures that are designed to mitigate a specific accident may also have unintended impacts in other areas of the system. Thus a risk management plan that effectively reduces the risk in the system as a whole will contain both systemwide risk mitigation measures and complementary targeted risk mitigation measures. Effective targeted risk mitigation measures for PWS include:

- Improved ability to prevent, detect, or correct human error which may occur in the operation of the tethered tugs in the Narrows in order to prevent powered groundings (Section 7.6.2).

- Improved ability to save disabled outbound laden tankers at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance in the upper range of weather conditions allowed by weather closure restrictions (Section 7.6.2).

- Coordinating fishing vessel/tanker interactions and escort vessel interactions to minimize the risk of collision in the Port, Narrows, and Arm (Section 7.6.2).

- Improved ice transit management so as to minimize the risk of powered grounding and vessel damage due to maneuvering in ice (Section 7.6.2).

Effective *systemwide* risk mitigation measures included:

- The implementation of safety management systems that have the potential for reducing human error and vessel reliability failures, which reduce both accident frequencies and oil outflows (Section 7.6.1).

- The replacement of the single hulled vessels with double hulled vessels, with the same carrying capacity, which will reduce oil outflow (Section 7.6.1).

- A revised escort program that will maintain current system risk reductions, minimize the collision risk due to escort vessels, and provide coverage for inbound tankers (Section 7.6.1).

9. Two process conclusions were evident from the study:

   - The measured weather data poorly represents site-specific conditions being used to make closure conditions. System closure conditions are based on wind and sea state data that is obtained from a different site (e.g., Potato Point for the Narrows) or at a different time (a SERVS vessel at Hinchinbrook Entrance during the prior transit) than the place and/or time required. This may result in the system being closed when it should be open, and open when it should be closed (Section 4.8 and 8.1).

   - Historical data does not adequately support a detailed analysis of the contribution of human error to incidents and accidents or the estimation of the effect of specific interventions designed to mitigate human and organizational error. In addition, historical data for vessel repair times is inadequate to support detailed risk analyses (Section *4.8).*

8.3 Recommendations

Recommendations are based on the project team's analysis in Chapters 5 and 7, and the conclusions detailed in the previous section. As such, these recommendations were made on the basis of risk reduction potential only and are intended as input for consideration by the PWS Risk Management team. Issues such as cost, human safety, and feasibility of implementation are to be considered by this team in the development of the Risk Management Plan. Recommendations are made in three groups.

1. **The following changes should be considered for implementation as soon as is practical.**

- Formal procedures for preventing, detecting, or correcting human error which may occur in the operation of the tethered tug in the Narrows should be developed and implemented.

- The USCG, the Alaska Department of Fish and Game, shipping companies, and representatives of the commercial fishing industry should continue to coordinate fishing vessel/tanker interactions as was done in 1996. These procedures should specify communications procedures to be followed by the Vessel Traffic Center (VTC), tankers, and fishing vessels; ensure that queues of inbound or outbound tankers are efficiently managed; and prevent tankers from maneuvering through large concentrations of fishing vessels.

- A strategy, including the use of appropriate equipment and procedures, should be developed and implemented to provide adequate save capability for outbound laden tankers in the upper range of weather conditions allowed by weather closure restrictions at Hinchinbrook Entrance.

2. **The following changes should be considered for implementation with the understanding that they may take more time to implement or to receive the benefits from their implementation.**

- All Prince William Sound shipping companies should continue to improve formal management and safety systems designed to reduce human and organizational errors. A component of these systems should be improved procedures for collecting data relating to human error and for analyzing accidents and incidents where human or organizational error was a contributing factor.

- The OPA 90 requirements for replacement of single hulled tankers with double hulls should occur as scheduled.

- Real time weather, ice, and current information should be made available to the USCG, SERVS, and to tanker **masters,** pilots, and escort vessel masters. This data includes wind, current, and visibility data at the Narrows; wind and sea state information at Hinchinbrook Entrance; and ice, weather, and visibility information in the Arm.

3. The following changes should be considered for implementation should additional analysis, to be completed before the close of the current contract, indicate their net benefits.

- A revised escort program should be developed to address the risk of drift groundings of inbound and outbound tankers and minimize risk of collision with SERVS vessels. This program should provide in Central Prince William Sound, a save capability at least equivalent to that provided by the current escort system and should provide for improved save capability at Hinchinbrook Entrance and the approaches to Hinchinbrook Entrance.

- Improved ice navigation procedures, including ice detection and tracking, should be developed and implemented. Ice should be avoided; however, if ice collisions are unavoidable, low energy ice collisions on the bow are preferable to high energy ice collisions to the vessel's sideshells.

a.4 Future Analysis and Decision Support

The contractual structure of the Prince William Sound Risk Assessment provides for continuing analysis after the issuance of the Final Report in support of the Risk Management Plan developed by the Steering Committee. The following areas of analysis are potential areas for investigation in the short term:

1. Sensitivity analysis on input data (weather, current and traffic) could be continued.

2. The evaluation of risk reduction interventions in areas where significant potential reductions have been identified could be expanded. Specific areas include stage 1 interventions (reducing human and organizational error) and stage 2 interventions (capturing errors and failures/preventing triggering incidents). Specific areas of investigation could be those interventions identified as effective in Chapter 7 (e.g., extended pilotage zone, bridge team stability, team simulation training).

3. Likely alternative futures of the system could be modeled and investigated. The PWS system may undergo significant changes in the near future. For instance, fleet phase outs and hull replacements under OPA 90 may result in a fleet composed of newer, double hulled vessels. The provisions for oil export may change traffic patterns. Changes in international and domestic rules may affect the operation of the fleet. Future increases or decreases in North Slope oil production throughput could also be investigated.

4. Examinations of alternative ice transit management and closure condition management scenarios could also be investigated.

Prince William Sound Risk Assessment Project
Master Glossary Of Acronyms

ABS	Able Bodied Seamen
ABS	American Bureau of Shipping
ADEC	Alaska Department of Environmental Conservation
ADSS	Automated Dependent Surveillance System
APSC	Alyeska Pipeline Service Company
BAT	Best Available Technology
BPOSC	BP Oil Shipping Company, USA
BRM	Bridge Resource Management
CFEC	Commercial Fisheries Entry Commission (State of Alaska)
CM	Centimeter
COTP	Captain of the Port
DGPS	Differential Global Positioning System
DTTS	Disabled Tanker Towing Study
DNV	Det Norske Veritas
DWT	Deadweight Ton
ERV	Escort Response Vessel
FT	Fault Tree
F/V	Fishing Vessels
GWU	George Washington University
IMO	International Maritime Organization
IMSRS	International Marine Safety Rating System
ISM	International Safety Management Code
IS0	International Standards Organization
ISRS	International Safety Rating System
ISV	Ice Scout Vessels
KDWT	Thousands of Tons Deadweight
KTS	Knots
LTIR	Lost Time Injury Rates
MARCS	Marine Accident Risk Calculation System
MIAT	Mean Inter Arrival Times
MMS	Mineral Management Service
MPH	Miles Per Hour
MSIS	Marine Safety Information System
NOM	National Oceanic and Atmospheric Administration
NRC	National Research Council
NTSB	U.S. National Transportation Safety Board
OPA 90	Oil Pollution Act of 1990
PWS	Prince William Sound

PWSRA	Prince William Sound Risk Assessment
PWSTA	Prince William Sound Tanker Association
PWS VTS	Prince William Sound Vessel Traffic Service
QAT	Quality Action Team
RCAC	Prince William Sound Regional Citizens' Advisory Council
RPI	Rensselaer Polytechnic Institute
SEP	Safety and Environmental Protection
SERVS	Ship Escort Response Vessel System
SOLAS	Safety of Life at Sea
SWAPA	Southwest Alaska Pilots Association
TAPS	Trans Alaska Pipeline System
TSS	Traffic Separation Scheme
USA	United States of America
USCG	United States Coast Guard
USCGC	United States Coast Guard Cutter
USDOC	U.S. Department of Commerce
VERP	Vessel Escort Response Plan
VMRS	Vessel Movement Reporting System
VMT	Valdez Marine Terminal
VOE	Vessel Operational Errors
VRF	Vessel Reliability Failures
VTC	Vessel Traffic Center
VTS	Vessel Traffic Service
VTSA	Vessel Traffic Service Area
WAMS	Waterways Analysis and Management System