The Washington State Ferries Risk Assessment

Final Report

JULY 1, 1999

Prepared for:

Blue Ribbon Panel on Washington State Ferry Safety

and

Washington State Transportation Commission
Olympia, Washington

By:

The George Washington University
Rensselaer Polytechnic Institute
Virginia Commonwealth University

PROJECT TEAM

The George Washington University
Institute for Crisis, Disaster, and Risk Management
John Harrald, Ph.D.,
Rene Van Dorp, D.Sc.
Thomas Mazzuchi, D.Sc.
Irmak Renda Tanali
Sunil Shrestha
Noraida Abdul Ghani

Rensselaer Polytechnic Institute /Le Moyne College
Department of Decision Sciences and Engineering Systems/Business Department
Martha Grabowski, Ph.D.

Rensselaer Polytechnic Institute
Department of Decision Sciences and Engineering Systems
Erman Coskun
Riza Hamzah
Cindy Kwong
Murat Mesiloglu
Rubin Mohan
Chan Park
Hongqing Yu

Virginia Commonwealth University
Jason Merrick, D.Sc.
Christopher Keaveney
Jamison Barnett

Consultants
Alan Brown, D.Sc.
RADM Gordon Piche, USCG (retired)
CAPT James Townley, USCG (retired)

BLUE RIBBON PANEL ON FERRY SAFETY

Tom Green
BRPFS Chair
Transportation Commission

Jennifer Joly
BRPFS Vice Chair
Governor's Transportation Policy Advisor

Representative Mike Cooper
House Transportation Committee
House of Representatives

Robert Distler
San Juan Islands Ferry Advisory Committee

Senator Georgia Gardner
Senate Transportation Committee
Senate

Paul Green, Director and CEO
Washington State Ferries

Rear Admiral Al Manning
U.S. Coast Guard (Retired)
Public Member

Senator Robert Oke
Senate Transportation Committee
Senate

Representative Karen Schmidt
House Transportation Committee
House of Representatives

Forrest Six
Bainbridge Island Ferry Advisory Committee

BLUE RIBBON PANEL ADMINISTRATOR

Chris Rose
Transportation Commission Administrator

WASHINGTON STATE FERRIES RISK ASSESSMENT EXECUTIVE SUMMARY

The Washington State Transportation Commission, at the request of the State Legislature, established an independent Blue Ribbon Panel to assess the adequacy of provisions for passenger and crew safety aboard the Washington State Ferries (WSF). On July 9, 1998, the Blue Ribbon Panel engaged a consultant team from The George Washington University Institute for Crisis, Disaster, and Risk Management and Rensselaer Polytechnic Institute/Le Moyne College. The team provides a unique combination of maritime operational experience and a record of successful maritime risk assessment projects. During the last five years, this team has completed formal risk assessments in Prince William Sound Alaska and the lower Mississippi River developing and testing the methodologies used in this study, and has provided risk management support to the U.S. Coast Guard, the Washington State Office of Marine Safety, the Port of Houston, and The Government of Argentina. The tasks assigned to the consultant team were:

- to assess the adequacy of passenger and crew safety on the Washington State Ferries,
- to evaluate the level of risk present in the Washington State Ferry system, and
- to develop recommendations for prioritized risk reduction measures, which, once implemented, can improve the level of safety in the Washington State Ferry system.

The report provides a description of the consultant team's approach, the results of the risk analysis, conclusions and recommendations. In addition, the report provides discussion of fundamental changes occurring in and around the Washington State Ferries (WSF), which are occasioning new organizational, technical, and management requirements, and the impact of these changes on the level of risk in the WSF. The report provides an evaluation of risk in the current system and the risk under potential future scenarios. Risk may be defined as the product of the probability (likelihood) of unwanted events and the consequences of these events. The approach to risk management developed in this report is to provide guidance for reducing accident likelihood (safety management) and minimizing accident consequences.

The report is structured to take the reader from the general to the specific, with full detail provided in technical appendices. Section I provides a summary of the survival craft issue that led to the commissioning of this study, an overview of the risk factors inherently present in the WSF and a brief description of the WSF operational environment. Section II contains the general conclusions and policy recommendations developed by the project team based on risk models, data analysis, and observations of the operations of the WSF system. Section III provides a framework for the characterization of maritime risk and an overview of the risk assessment methodology used. Section IV provides specific findings as well as important detailed results that support the conclusions and recommendations in Section II. These findings stem from the analysis using modeling tools developed under the framework in Section III, specifically the dynamic simulation risk model and the historical data analysis. Three technical appendices contain the detailed documentation required to support the more descriptive discussion presented in this report.

General Conclusions

Based on their expertise, analysis, and observations throughout the study, the consultant team arrived at the following general conclusions:

1. The Washington State Ferries has a historical safety record that compares favorably with other maritime and non-maritime surface transportation modes.
2. There is inherent risk in managing a complex, large scale system such as the Washington State Ferries.
3. The Washington State Ferries must operate in a changing environment and this suggests that systems, practices, and procedures, that have provided an adequate level of safety in the past, will not be adequate to meet the demands of the system in the future.
4. The regulatory environment affecting auto ferries has changed significantly with the implementation of 46CFR199 (Sub Chapter W) which requires that the WSF address the response to potential catastrophic accidents and ensure that passengers could survive such accidents
5. Accident prevention in the WSF can be improved by enhanced safety procedures, improved organizational and management systems, and the development of an enhanced safety culture within the Washington State Ferries. This safety culture must be consistently expressed both in the leadership and policies of shoreside operations and management and in the leadership of ferry deck and engineering officers.
6. Accident response and consequence management in the WSF can be improved by developing an effective, coordinated emergency and crisis response system, which is necessary to minimize the consequences of a potentially catastrophic accident.
7. Despite the need for effective accident response and consequence management, neither the Washington State Ferries nor public safety agencies, including the Coast Guard, have developed and exercised the plans and procedures required for an effective, immediate and coordinated response a catastrophic event.
8. Several initiatives within the Washington State Ferries have already begun to enhance safety and address prevention and response needs.
9. To some extent, questions about the need for additional survival craft in part occasioned the WSF Risk Assessment. However, analysis of potential collision scenarios demonstrates that in less than ten percent of these scenarios additional survival craft are one of the viable alternatives to provide additional time for response and prevent further injuries or casualties.
10. The results of the WSF Risk Assessment can be an effective risk mitigation tool in the years to come.

Specific Recommendations

Sixteen specific risk reduction recommendations are cited in the report. Recommendations derived from the analysis were divided into three categories: (1) general risk management recommendations for the Washington State Ferries to manage risk in the system, (2) recommendations for reducing the likelihood of accidents, and (3) recommendations for minimizing the potential consequences of accidents. In addition, four areas for additional study and analysis were identified by the consultant team.

In terms of general risk management, it was recommended that the Washington State Ferries should improve its capabilities to detect and manage risk and to prepare for potential emergencies. This requires a continuing set of systems, capabilities, and structures in order to be effective. Maintaining and enhancing safety in the Washington State Ferries requires management and resources devoted to risk prevention, accident response, and consequence management. Specific recommendation in the area of risk management state that the Washington State Ferries should:

1. enhance its ability to manage risk by making organizational changes and process improvements in four general areas:
   - the creation of a *system monitoring capability* that will provide a continuous ability to assess the level of risk and will detect hazardous situations and conditions,
   - the improvement of *consequence management systems* to ensure that the impacts of a crisis or disaster will be controlled and / or minimized,
   - the facilitation of the *information, planning, and leadership infrastructure* required to implement an effective risk management strategy, and
   - the creation of an *organizational culture* supported by management, operations, and shipboard personnel that will inherently mitigate risk by ensuring that small errors are not allowed to propagate into grave consequences,

2. continue to demonstrate leadership in effecting the changes to the safety and organizational culture necessary to insure safety in WSF system operations,

3. develop and maintain an information infrastructure that facilitates information sharing and communication of safety critical information,

4. actively participate in and support the Puget Sound Marine Committee (PSMC) to increase risk management communication and enhance emergency preparedness,

5. use the database and modeling capabilities developed during the Washington State Ferries Risk Assessment Project to support risk management and decision making and to assess the impact of future changes in the operating environment.

6. use this risk assessment as the system safety assessment required by Subchapter W.

It was further recommended that:

7. the Washington State Ferries and local public safety agencies and the U.S. Coast Guard should strive to meet the highest possible standards for disaster preparedness and planning for potential mass casualty events,

8. the Washington State Transportation Commission and the Washington State Legislature should provide the necessary policy and budgetary support to improve the Washington State Ferries safety infrastructure and level of emergency preparedness.

Reducing the likelihood of accidents: it was recommended that the Washington State Ferries should continue to implement safety management and training programs, provide adequate relief crews as necessary to accomplish training, and coordinate with the Coast Guard to minimize the likelihood of an accident. Specific recommendations in the area of reducing the likelihood of accidents state that the Washington State Ferries should:

9. implement the International Safety Management (ISM) system fleet wide, continue to integrate and expand its safety management, emergency preparedness, and training programs, expand the capability of its operations center,

10. investigate using simulators to support shipboard team training, and ensure that all personnel are properly trained for their fire fighting and other emergency management responsibilities,

11. develop personnel selection, certification, and re- qualification criteria, and investigate the use of proficiency and currency monitoring (e.g. check rides) for high speed ferry masters and mates.

It was further recommended that:

12. the Coast Guard should monitor increasing traffic congestion in Elliot Bay, Rich Passage, and Friday Harbor, particularly during periods of low visibility, and manage traffic as required.

Finally it was noted that since the consequences of an intentional act of destruction (sabotage or attack) aboard a ferry could be severe,

13. the Washington State Ferries should work with the Washington State Patrol and appropriate federal agencies to determine the need for additional appropriate security measures to combat the threat of intentional acts of destruction aboard ferries.

In terms of minimizing the potential consequences of accidents, it was recommended that the Washington State Ferries, the U.S. Coast Guard, and other response organizations should work collaboratively to ensure that consequences will be minimized for any accident that does occur. Specific recommendations in the area of minimizing the potential consequences state that

14. the shipboard crisis and emergency management capability of vessel crews should be improved by adopting the following measures:
    - scheduling, reporting, and evaluating meaningful shipboard emergency drills,
    - requiring periodic skill and physical qualification re-certification testing for all personnel assigned to crisis and emergency management duties,
    - improving methods for communicating with passengers during an emergency,
    - improving crew training in developing detailed emergency procedures,
    - improving the ability to account for and communicate with passengers during an emergency,
    - providing clear and visible emergency instructions and evacuation signage for passengers, and
    - providing adequate initial and re-qualification training in fire and rescue,

15. the external crisis and emergency response capability of the Washington State Ferries and the U.S. Coast Guard should be improved by:

- developing and conducting multi-organization response exercises based on defined accident scenarios,
- establishing formal agreements relative to response authority, responsibility, and organization,
- providing adequate response resources in high risk areas such as Central Puget Sound, where an immediate response may be required, and at Port Townsend/ Keystone, where current resources are not sufficient to evacuate passengers in an emergency,
- improving the communication and information management infrastructure,
- improving the effectiveness of interaction with external agencies such as fire, police, and emergency medical,
- developing comprehensive contingency, crisis management, and crisis communications plans,
- establishing agreements with commercial and military marine operators to ensure a planned for and coordinated rescue response,

16. the Washington State Ferries should devise, implement, exercise, and be able to demonstrate methods of evacuating passengers from ferries to a safe haven (other vessels or survival craft) where this analysis demonstrates that such evacuation may be required (e.g. Port Townsend– Keystone).

The four areas identified as requiring additional study and analysis are

- the impact of high speed ferry collisions,
- the implications of crew continuity, current manning and watch standing policies and procedures, and the impact of fatigue on the safety and emergency preparedness of Washington State Ferries 'operations,
- the implications of increasing traffic congestion (including small craft and float planes), new routes, and new technology on the safety of WSF operations,
- the need for survival craft on the Port Townsend-Keystone transit.

The report supports the currently planned and funded fleet wide implementation of the International Safety Management System. It strongly recommends that the Washington State Ferries and the U.S. Coast Guard and other public safety agencies address the problem of minimizing injury and loss of life from very low probability but potentially high consequence accidents through the planning, implementing, and exercising adequate response plans and procedures. It recognizes that the skills of the ferry crew will be crucial in any emergency situation and strongly recommends enhancing these emergency skills through training, certification, drills, and exercises. The report concludes that the most cost-effective way to minimize the risk of potential accidents, is to invest in WSF people and systems and to make improvements and changes to WSF policies, procedures, and management systems– rather than to merely invest in capital equipment. The creation of a safety culture that will enable these recommendations to be realized will require the support and leadership of Washington State Ferries management, shoreside operations, and fleet deck officers, engineers and other shipboard personnel.

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SECTION I: INTRODUCTION

1.1 PROJECT OVERVIEW

The Washington State Transportation Commission, at the request of the State Legislature, established an independent Blue Ribbon Panel to assess the adequacy of provisions for passenger and crew safety aboard the Washington State Ferries (WSF). On July 9, 1998, the Blue Ribbon Panel engaged a consultant team from The George Washington University Institute for Crisis, Disaster, and Risk Management and Rensselaer Polytechnic Institute/Le Moyne College. The team provides a unique combination of maritime operational experience and a record of successful maritime risk assessment projects. During the last five years, this team has completed formal risk assessments in Prince William Sound Alaska and the lower Mississippi River developing and testing the methodologies used in this study, and has provided risk management support to the U.S. Coast Guard, the Washington State Office of Marine Safety, the Port of Houston, and The Government of Argentina. The tasks assigned to the consultant team were:

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1.2 SURVIVAL CRAFT REQUIREMENTS – A CATALYST FOR THE RISK ASSESSMENT

Perhaps the most notable aspect of the WSF Risk Assessment is that it was not initiated as a result of a major accident. Although the study's objective is, as stated above, to assess the adequacy of safety in the WSF system, the debate over survival craft requirements for ferries was a primary reason for initiating the project. Media and public concern has been expressed over the adequacy of current survival craft requirements. WSF management has not had a basis for determining the benefits of changing or voluntarily exceeding these requirements, recognizing the significant equipment and personnel costs that would be required.

The Coast Guard certificates the Washington State Car Ferries under 46 CFR Subchapter H as vessels on lakes, bays, and sounds routes. Those ferries on an international voyage (Sidney, B.C.) must meet the additional requirements of SOLAS (IMO Safety of Life At Sea Conventions) requirements. Regulations issued by the U.S. Coast Guard in 46CFR require that all lifesaving appliances and arrangements on passenger vessels of at least 100 gross tons and carrying more than 12 passengers must comply with the new Subchapter W. The new 46 CFR 199 Subchapter W, issued in 1998, brings the U.S. in line with the international standards published by the International Maritime Organization that are recognized throughout the world maritime community.

These regulations apply to all Washington State ferries except for the passenger only ferries (the Tyee, Skagit, and Chinook), which are regulated by 46 CFR Subchapter T. The passenger only vessels currently exceed Coast Guard survival craft requirements. The Skagit and Kalama currently carry survival craft adequate for 100% of passenger capacity, and the Tyee and the Chinook carry approximately 65%. (Source: Washington State Ferries). The requirements for the number of survival craft on the WSF automobile ferries are of specific interest. Subchapter W provision 46 CFR 190.201(b) will require survival craft for 125% of the number of passengers permitted by the certificate of inspection issued by the U.S. Coast Guard, allowing a five year period to attain compliance. This is a particularly difficult issue for the WSF automobile ferries that often sail at capacity for vehicles, but rarely carry the full load of passengers authorized by their Coast Guard certificate. The WSF auto ferries currently carry survival craft adequate for 10%-30% of the number of passengers authorized by their certificates. These allowances are, therefore assessed to be adequate for an estimated 70-100% of the typical peak passenger loads experienced on all auto ferry routes.

The regulations provide an alternative to 125% survival craft for WSF auto ferries under the provisions of 46 CFR 199.630(f) if two documents are approved by the local Officer in Charge of Marine Inspection (OCMI). The first is a safety assessment that addresses navigation and vessel safety conditions within a vessel's planned operating area considering risks, hazards, traffic, trends, port configuration and environmental factors. The second is a comprehensive shipboard safety management and contingency plan that is tailored to the particular vessel, is easy to use, is understood by vessel management personnel both on board and ashore, and is updated regularly.

This risk analysis can satisfy the first requirement for a rigorous safety assessment. The second part, a comprehensive shipboard safety and management contingency plan, is essential for the Washington State Ferries, as compliance with 199.630(f) will significantly elevate the level of safety system wide. USCG Navigation and Vessel Inspection Circular Number 1-97, *Shipboard Safety Management and Contingency Plan for Passenger Vessels*, provides guidance on preparing the required plan. Many of the elements of this NAVIC and the requirements of Subchapter W will be met by the fleet wide implementation of the International Safety Management (ISM) System and other recommendations as discussed later in this report.

1.3 RISK FACTORS IN THE WASHINGTON STATE FERRY SYSTEM

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

The Washington State Ferries is a complex large-scale system, with inherent risk. Tasks in the WSF — navigation, vessel loading, arrivals and departures — are distributed across a large geographical area, are time-critical, and contain elements of embedded risk (e.g., vessel navigation in congested waters, in reduced visibility, carrying passengers on time-critical schedules). The technology used in the system — vessels, equipment, software, mooring lines, etc.— is also inherently risky. Human and organizational error is present in the system, and organizational structures which result in limited physical oversight and contact can make risk mitigation difficult. Finally, as in many large scale systems, the Washington State Ferries' organizational culture can send confusing or contradictory messages (e.g., safety bulletins that celebrate the number of accident free days while vessel watch schedules, crew rotations, training practices, and work hours raise questions about risk tolerance in the system).

Managing risk in the WSF is challenging. First, because the WSF system is distributed, risk in the system can migrate: for example, when risk mitigation measures are introduced. One risk problem may be solved with the introduction of a risk mitigation measure (i.e., prohibiting vessel sailings in fog) while at the same time new risk problems can emerge (i.e., traffic congestion problems at terminals clogged with vessels waiting for visibility to lift). Risk migration is thus an important concept for risk managers to be aware of when introducing risk mitigation measures into a system. A dynamic risk assessment, using a system simulation, can provide critical input to decision makers challenged to capture and analyze the dynamic nature of risk migration in a complex system.

A second problem in managing risk in the WSF system is that it is very large, with complex interactions between its constituent parts. As a result, precipitating factors in the system may have long incubation periods. That is, pathological risk factors may lie dormant for long periods of time, until catalyzed by the right combination of triggering events (e.g., an obstruction in the channel, a tired crew, a night time passage, a captain with impaired decision making abilities, and a host of crew failures such as mistakes in helm orders, locked-on autopilots, and missed warnings provided by navigational aids). Long incubation periods make the identification of leading error chains difficult, and provide particular challenges for risk managers observing short-term changes in a dynamic system. Historical safety assessments over reasonably long periods of time provide one antidote to pathogens in a large-scale system with long incubation periods.

A third challenge in managing risk in the distributed WSF system is that it is comprised of members with individual goals, policies, and cultures — ashore, aboard ship, and in the shipyard. The distributed nature of the WSF system makes the development of a shared culture of reliability difficult.

Summarizing, risk management in the Washington State Ferries requires attention to:

- *risk migration* (which suggests that using simulation within a dynamic risk assessment tool is an appropriate analytic method)
- *long incubation periods for pathogens in the system* (which suggests the importance of historical analysis of safety performance for benchmarking), and
- *the difficulties associated with developing a shared culture of reliability in a distributed system* (which highlights the importance of strong leadership that emphasizes shared commitments to safety goals).

1.4 SYSTEM DESCRIPTION

Created when the State purchased the Puget Sound Navigation Company in 1951, the Washington State Ferries currently operate 27 vessels, including 4 passenger only ferries, to twenty terminals on ten routes. It is the largest ferry system in the United States, with total ridership for the ferries serving the central Puget Sound region at approximately 26.2 million persons in 1998, more passengers than Amtrak handles in a year. The Puget Sound component of the ferry system consists of six main routes and two passenger-only routes, and is used mainly by people living on Kitsap Peninsula, Vashon Island and Whidbey Island who commute to work in King or Snohomish counties; people traveling to and from the Olympic Peninsula; and cross-Sound commercial traffic (Puget Sound Regional Council, 1998). Ferry runs also provide mainland access to Whidby Island from Port Townsend and provide service from Anacortes to the San Juan Islands and to Sidney, British Columbia.

Figure 1 shows the ferry routes for the central Puget Sound, Admiralty Inlet, and San Juan Islands regions. This map illustrates the ferry system's role in linking together the Washington State highway system in the Puget Sound region. In 1998, the Bainbridge Island-Seattle route carried the most riders by far, with almost 7.1 million riders (27% of the system total). The Edmonds-Kingston route was next with 4.43 million (17%), followed by Mukliteo-Clinton with 4.41 million (17%), Fauntleroy-Vashon-Southworth with 3.4 million (13%), and Bremerton-Seattle with 2.9 million (11%) and Pt. Defiance-Tahlequah with

830,000 (4%). These five central sound routes carry approximately 85% of the riders served by the Washington State Ferries. (Source: Washington State Ferries Operations Center).

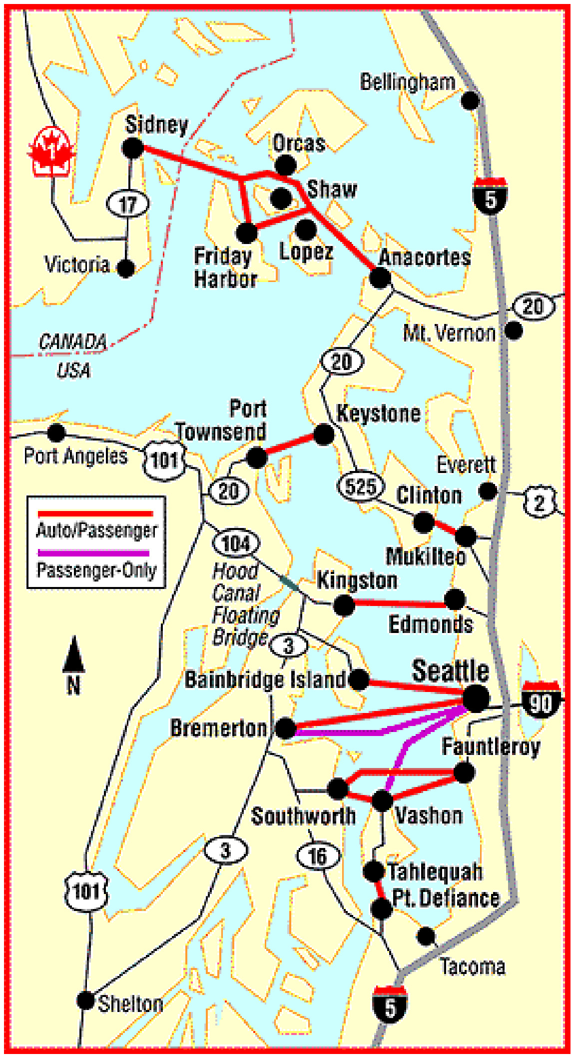


Figure 1. Washington State Ferry System Map

The overall growth in the system ridership from 1997 to 1998 was 2.4%, but this growth was uneven. The Seattle-Bremerton passenger-only boats, in place since 1986, carried 662,101 riders in 1998 and are the fastest growing part of the system. The introduction of the high-speed ferry Chinook on this route in 1998 resulted in a 132% growth in ridership on this route. The Seattle-Vashon passenger-only boats, running since 1990, carried 306,067 passengers, an 8.8% increase over 1997. Routes that experienced a decrease in ridership in 1997-1998 include: Anacortes-San Juans-Sidney (-19.8%), Seattle-Bremerton auto ferry (-10.1%), Southworth-Vashon auto ferry (-3.1%). The latter two route decreases are a result of the increase in passenger only ferry traffic.

SECTION II: CONCLUSIONS AND RECOMMENDATIONS FOR POLICY CONSIDERATIONS

2.1 GENERAL CONCLUSIONS

The conclusions and recommendations presented in this section are supported by the more detailed sections to follow and by the results fully documented in Appendix I and II.

1. The Washington State Ferries has a historical safety record that compares favorably with other maritime and non maritime surface transportation modes.

Over the past ten years, the Washington State Ferries has enjoyed a notable safety record. Despite the fact that the Ferries represented over 75% of the total traffic in Puget Sound and the San Juan Islands over the past ten years, the WSF safety record is substantially better than non ferry traffic in Puget Sound over the same period, when accident and incident rates are compared on a per transit basis. Moreover, most of the events that have occurred on Washington State Ferries have been incidents not resulting in property loss or personal injury (propulsion failures, steering failures, other equipment failures), rather than accidents (collisions, allisions, groundings, fires and explosions, structural failures, floodings, and founderings).

The Washington State Ferries' safety record compares favorably with that of other transportation modes: the Washington State Ferries carry approximately 26 million passengers on over 145,000 transits per year, and have never experienced a fatality. Comparison with rail and aviation accident rates shows that the ferry system accident rate (for accidents with property damage or injury) of 1.7 accidents per million miles traveled is lower than the historical experience of rail (4 accidents per million miles), but well above that of commercial airlines (7 accidents per billion miles flown). However, the aviation accident rate is expected to be significantly lower than that of other transportation modes since the consequences of aviation accidents are often catastrophic. The predicted rate of accidents with serious injury or death for the WSF is consistent with standards of acceptable safety developed for the International Maritime Organization's High Speed Code.

2. There is inherent risk in managing a complex, large scale system such as the Washington State Ferries.

An accident involving a Washington State Ferry that could produce potentially catastrophic consequences is a low probability event. However, as shown in this analysis, low probability scenarios that could produce a potential mass casualty accident, such as collisions and explosions, are feasible given the operating environment of the Washington State Ferries**.** If a low probability, high consequence event should occur, the Washington State Ferries would be evaluated on how it responds to the accident as much as (or more than) on its prevention efforts. Thus, although the Washington State Ferries' historical safety record is very good, there is inherent risk in managing and operating ferries in the WSF system, which necessitates thoughtful risk management practices.

3. The Washington State Ferries must operate in a changing environment and this suggests that systems, practices, and procedures, that have provided an adequate level of safety in the past will not be adequate to meet the demands of the system in the future.

Three trends are observable in the WSF that are responsible for significant changes in the Washington State Ferries' future. These trends include (1) a changing regulatory environment, (2) demographic and inter-modal transportation system changes, and (3) new technology changes.

(1) The regulatory environment affecting auto ferries has changed significantly with the implementation of 46CFR199 (Subchapter W), which requires that WSF addresses the response to catastrophic accidents and ensure that passengers could survive such accidents. Specifically, the regulations require the WSF system, within five years, either to equip all auto ferries with adequate survival craft or to provide a safety assessment, a comprehensive shipboard safety management system, and shipboard contingency plans approved by the U.S. Coast Guard.

(2) Demographic and inter-modal transportation system changes in Washington State have changed expectations of the WSF. For instance, the WSF is expected to perform as part of a seamless, inter modal transportation system in Washington State, and to meet the demand of increases in the volume and mix of riders on the ferries. With the introduction of high speed passenger only routes in the central Puget Sound area, WSF is evolving toward two distinct missions: 1) to meet significant growing demand for cross sound daily mass transit commuter traffic, and 2) to continue its role as an extension for the state and national highway network for vehicle born passenger and freight traffic. Satisfying these dual modes of transport will cause WSF's safety performance to be compared to safety trends for both mass transit systems and highway transport.

(3) Current technology changes are occasioning new operational and human factors requirements in the WSF. New high-speed ferries, with new navigation, engineering, and control system technology, are being introduced, and these vessels have significantly different maneuvering and response characteristics than traditional ferries. Additionally, the hull structure and transit speeds of this new class of ferries present a new set of problems with respect to traumatic passenger injuries and vessel survivability. Operators using these new technologies experience significantly increased vessel responsiveness coupled with significantly reduced operator response times, that suggests different standards for personnel selection, training, drills and procedures aboard these vessels.

Historically, human error has been a primary cause of WSF accidents, responsible for almost 70% of the WSF accidents over the past ten years. In a system where human error plays a primary role in causing accidents, attention to human factors challenges, particularly in a rapidly changing regulatory, demographic and technological environment, is prudent risk management. Moreover, because of these changes in the WSF, practices and procedures that in the past provided adequate levels of safety will be inadequate to meet the demands of the Washington State Ferries of the future.

4. ***Accident prevention* in the WSF can be improved by enhancing safety procedures, organizational and management systems, and developing an enhanced safety culture within the Washington State Ferries.**

Collision risk is a primary contributor to risk in the WSF system, since collisions can result in a significant number of injuries and fatalities. Scenarios that could have catastrophic consequences include collisions with passenger only ferries, collisions with high-speed ferries, and collisions between ferries and large, high speed vessels such as container ships. A primary cause of collision risk in the system is the relatively high level of traffic congestion in Central Puget Sound, particularly in Elliott Bay. Future increases in traffic in this area due to additional ferry runs, excursion boats, float planes, and commercial shipping will increase the collision risk in this area. Restricted visibility is also a significant contributor to collision risk. The addition of high speed (Chinook class) ferries to the system increases the risk of collision and substantially increases the probability of a collision requiring an emergency response.

In light of the risk potential, the Washington State Ferries have already started to mitigate the risk of potential accidents by improving WSF policies, procedures, and management systems rather than simply investing in capital equipment. Examples of effective risk prevention activities for the Washington State Ferries include the fleet-wide introduction of the International Safety Management system (ISM); the use of team-based training, drills, and procedures; improved maintenance and repair planning, scheduling, and facilities; improved information systems to facilitate effective communication of safety- and efficiency-critical information; and performance evaluation systems with appropriate evaluation metrics and measurements. These are all linked to safety and reliability goals that incorporate incentives which encourage the development of a high reliability organization. The creation of the safety culture necessary for this achievement is the will require the strong leadership and example by management, shoreside operations, and on board deck and engineering officers and other shipboard personnel.

5. ***Accident response and consequence management* in the WSF system can be improved by developing an effective, coordinated emergency and crisis response system, which is necessary to minimize the consequences of a potentially catastrophic accident.**

In contrast to risk prevention activities, accident response and consequence management activities require a great deal of external coordination, communication, and leadership. Coordinating disaster response and management activities requires that many different organizations work together in real time, sharing information, responsibilities, and lessons learned, in order to provide the most effective response possible. Thus, Washington State Ferries 'accident response and consequence management requires coordination with external organizations, as well as effective leadership, so that policies, procedures, and response actions are well rehearsed, familiar, and effective.

Safety improvements can ensure that the Washington State Ferries and other organizations will provide the coordinated emergency and crisis response necessary to effectively minimize the consequences of a potentially catastrophic accident. These improvements include upgrading personnel physical and skill qualification/certification requirements; increasing the quality and frequency of shipboard drills; enhancing the ability to coordinate an emergency response with fire, rescue, and medical responders by frequent inter organizational response exercises; and improving the capability of mustering and evacuating passengers from a ferry under emergency conditions.

6. Despite the need for effective accident response and consequence management, the Washington State Ferries, the Coast Guard, and other public safety agencies have not fully developed and exercised the plans and procedures required for an effective, immediate, and coordinated response to a catastrophic event.

Although the planning, preparation, exercises, and drills required to develop and maintain an immediate, coordinated emergency response have been initiated, much work to develop a coordinated emergency response capability is still needed. *The crew of a ferry is the first and most critical element of response in any emergency involving a Washington State ferry.* Thus, firstly, the crew on all ferries must be trained, qualified, and prepared to deal with emergency events. Moreover, crew training and certification activities must be continuous and on-going in order to ensure that the crew is adequately prepared to address emergencies. Secondly, Washington State Ferries' management and supervisors must have adequate knowledge and resources in order to effect these training, response, planning, and exercise requirements. Without such resources, the ability to respond to catastrophic emergencies is severely constrained. Finally, the WSF and Coast Guard plans, preparations, and procedures for response need to be drilled on a continuing basis, using both simulated and actual personnel, resources, and equipment. The plans, drills, and exercises should be based on credible accident scenarios, as identified in this report. In particular, the need for a rapid emergency response in the Central Sound and the creation of a viable evacuation strategy for the Port Townsend--Keystone route must be addressed. Trained crews, plans, knowledgeable management, adequate resources, and thoughtful and frequent drills and exercises that involve all potential response participants (e.g. fire, police, emergency medical) are all essential elements to ensure that a coordinated, effective response to catastrophic events in the WSF operating area is feasible.

7. Several initiatives within the Washington State Ferries have already begun to enhance safety and address prevention and response needs.

The Washington State Ferries has already begun implementation of the International Safety Management system (ISM) fleet wide, following its initial introduction on the WSF international routes. In this risk assessment, the fleet wide introduction of ISM has been shown to be a particularly effective risk mitigation measure as it addresses both accident prevention and accident response.

Another example of safety measures already underway in the Washington State Ferries is the recent development of a WSF emergency response plan, and the newly emergent disaster response exercises that test the system's ability to coordinate with the USCG and other organizations.

A third example of WSF safety measures that have been enacted is the set of crew training and qualification procedures developed by the Jumbo Mark II ferry project team. These qualification and training procedures provide a good example for future crews and training aboard other WSF vessels.

These initiatives should receive the continued support of the Washington State Ferries' management and other system stakeholders (e.g. the U.S. Coast Guard, the Washington State

Transportation Commission, the Washington State Department of Transportation, appropriate Washington State legislative committees, and the Washington State Ferries advisory committees).

8. To some extent, questions about the need for additional survival craft in part occasioned the WSF Risk Assessment. However, analysis of potential collision scenarios demonstrates that in less than ten percent of these scenarios additional survival craft are one of the viable alternatives to provide additional time for response and prevent further injuries or casualties.

Additional survival craft are an effective accident response tool only when adequate response platforms cannot reach a vessel prior to passengers having to abandon ship. Survival craft do not replace the need for a response; they provide additional time for the response to be successfully executed. There are two situations where it is currently unlikely that rescue craft could respond within the required response time: in Haro Strait and on the Pt. Townsend Keystone run. Vessels making the Haro Strait transit are subject to international conventions and currently carry survival craft adequate for all passengers. Analysis of simulated WSF collision scenarios showed that less than ten percent of potential collision scenarios have a 1 to 6 hour maximum required response time window to avoid additional (post collision) injuries and casualties. In this 1 to 6 hour maximum required response time category, additional survival craft are judged to be one of the viable response alternatives.

9. The results of the WSF Risk Assessment can be an effective risk mitigation tool in the years to come.

The results of the WSF Risk Assessment should satisfy the immediate Coast Guard requirement for a comprehensive safety assessment as a component of any sub chapter W waiver request. The models developed enable the analysis of risk changes caused by changes in operations, routes, equipment, or operating environment, and can help develop strategies to offset any potential increases in risk. Thus, the results of the WSF Risk Assessment can provide important input to many risk management activities in the coming years.

2.2 RECOMMENDATIONS

Recommendations derived from the analysis and conclusions can be divided into four categories: (1) general risk management recommendations for the Washington State Ferries to manage risk in the system, (2) recommendations for reducing the likelihood of accidents, (3) recommendations for minimizing the potential consequences of accidents, and (4) areas where future study and analysis should be conducted.

2.2.1 General Risk Management Recommendations

The Washington State Ferries should improve its capabilities to detect and manage risk and to prepare for potential emergencies. Risk management in the Washington State Ferries requires a continuing set of systems, capabilities, and structures in order to be effective. Maintaining and enhancing safety in the Washington State Ferries requires management and resources devoted to risk prevention, accident response, and consequence management.

1. The Washington State Ferries should enhance its ability to manage risk by making organizational changes and process improvements in four general areas:

    - the creation of a *system monitoring capability* that will provide a continuous ability to assess the level of risk and will detect hazardous situations and conditions,
    - the improvement of *consequence management systems* to ensure that the impacts of a crisis or disaster will be controlled and/or minimized,
    - the facilitation of the *information, planning, and leadership infrastructure* required to implement an effective risk management strategy, and
    - the creation of an *organizational culture* supported by management, operations, and shipboard personnel that will inherently mitigate risk by ensuring that small errors are not allowed to propagate into grave consequences.

2. The Washington State Transportation Commission and the Washington State Legislature should provide the necessary policy and budgetary support to improve the Washington State Ferries safety infrastructure and level of emergency preparedness.

3. The Washington State Ferries should continue to demonstrate leadership in effecting the changes to the safety and organizational culture necessary to insure safety in WSF system operations. Barriers to leadership development, trust, and increased accountability should be identified and removed. Ferry deck officers and engineers must demonstrate leadership by identifying, resolving where possible, and reporting safety issues and problems, including operational errors and unusual incidents. WSF operations and management personnel must support the tracking and resolution of safety issues and the sharing of safety related information.

4. The Washington State Ferries, the U.S. Coast Guard, and other public safety agencies should strive to meet the highest possible standards for disaster preparedness and planning for potential mass casualty events. The standards for response plans, exercises, drills, and family assistance required of airlines and airports should be used as an example.

5. The Washington State Ferries should develop and maintain an information infrastructure that facilitates information sharing and communication of safety critical information. This would include navigation, maintenance, weather, environmental, traffic, and scheduling information.

6. The Washington State Ferries should actively participate in the Puget Sound Marine Committee to increase risk management communication and enhance emergency preparedness.

7. The Washington State Ferries should use the database and modeling capabilities developed during the Washington State Ferries Risk Assessment Project. These capabilities should be managed, maintained, and used to support risk management and decision making.

8. The Washington State Ferries should adopt this risk assessment as their system safety assessment required by Subchapter W.

2.2.2 Reducing the Likelihood of Accidents

The Washington State Ferries should continue and expand safety management and training programs and coordinate with the Coast Guard and other maritime organizations to minimize the likelihood of an accident.

9. The Washington State Ferries should continue to integrate and expand its safety management, emergency preparedness, and training programs, provide adequate relief crews to accomplish training, and expand the capability of its operations center. ISM should be expanded fleet-wide and organization-wide as soon as practicable.

10. The Washington State Ferries should investigate using simulators to support shipboard team training, and ensure that all personnel are properly trained for their fire fighting and other emergency responsibilities.

11. The Washington State Ferries should develop personnel selection, certification, and re-qualification criteria, and investigate the use of proficiency and currency monitoring (e.g. check rides) for high speed ferry masters and mates.

12. The Coast Guard should monitor increasing traffic congestion in Elliot Bay, Rich Passage, and Friday Harbor, particularly during periods of low visibility, and manage traffic as required.

13. The consequences of an intentional act of destruction (sabotage or attack) aboard a ferry could be severe. The Washington State Ferries should work with the Washington State Patrol and appropriate federal agencies to determine the need for additional applicable security measures to combat the threat of intentional acts of destruction aboard ferries.

2.2.3 Minimizing the Potential Consequences of Accidents

The Washington State Ferries, the U.S. Coast Guard, and other response organizations should work collaboratively to ensure that consequences will be minimized for any accident that does occur.

14. The shipboard crisis and emergency management capability of vessel crews should be improved by adopting the following measures:
    - scheduling, reporting, and evaluating meaningful shipboard emergency drills,
    - requiring periodic skill and physical qualification re-certification testing for all personnel assigned to crisis and emergency management duties,
    - improving methods for communicating with passengers during an emergency,
    - improving crew training in developing detailed emergency procedures,
    - improving the ability to account for and communicate with passengers during an emergency,

- providing clear and visible emergency instructions and evacuation signage for passengers, and
- providing adequate initial and re-qualification training in fire and rescue.

15. The external crisis and emergency response capability of the Washington State Ferries and the U.S. Coast Guard should be improved by:
    - developing and conducting multi-organization response exercises based on defined accident scenarios,
    - establishing formal agreements relative to response authority, responsibility, and organization,
    - providing adequate response resources in high risk areas such as Central Puget Sound, where an immediate response may be required, and at Port Townsend/ Keystone, where current resources are not sufficient to evacuate passengers in an emergency,
    - improving the communication and information management infrastructure,
    - improving the effectiveness of interaction with external agencies such as fire, police, and emergency medical,
    - developing comprehensive contingency, crisis management, and crisis communications plans.
    - Establishing agreements with commercial and military marine operators to ensure a planned for and coordinated rescue response.

16. The Washington State Ferries should devise, implement and exercise methods of evacuating passengers from ferries where this analysis demonstrates that such evacuation may be required (e.g. Port Townsend– Keystone). The Washington State Ferries should demonstrate this capability to the U.S. Coast Guard as part of its Subchapter W waiver request; failure to demonstrate this capability for certain routes may result in the USCG requiring additional survival craft on ferries transiting these routes.

2.2.4 Areas for Future Study and Analysis

Four areas have been identified as requiring additional study and analysis.

17. In the collision analysis, all collisions involving the Chinook class high speed ferry were judged to have a maximum required response time of less than 1 hour, due to the potential of severe injury in any collision involving a high speed ferry. Due to the sensitivity of the results to this assumption, a more detailed collision analysis of the high speed ferries should be considered.

18. The Washington State Ferries should evaluate the implications of crew continuity, current manning and watch standing policies and procedures, and the impact of fatigue on the safety and emergency preparedness of Washington State Ferries 'operations.

19. The Washington State Ferries, the U.S. Coast Guard, and the Puget Sound Marine Committee should further evaluate the implications of increasing traffic congestion

(including small craft and float planes), new routes, and new technology on the safety of Washington State Ferries 'operations.

20. It is currently unlikely that rescue craft could respond within the required response time on the Pt. Townsend Keystone run. Ferries on the Pt. Townsend - Keystone run are not required by current Coast Guard regulations to carry 100% survival craft. Additional survival craft are an effective accident response tool only when adequate response platforms cannot reach a vessel prior to having passengers abandon ship. This issue requires further consideration.

SECTION III: WSF RISK ASSESSMENT AND RISK MANAGEMENT - GUIDELINES, FRAMEWORK AND METHODOLOGY

3.1 NATIONAL RESEARCH COUNCIL (NRC) GENERAL GUIDELINES ON RISK ASSESSMENT

Risk may be defined as a measure of the probability of an unwanted event and the impact of that event. Risk assessment is a synthesis and summary of information about a potentially hazardous situation that addresses the needs and interests of decision-makers and of interested and affected parties. Risk assessment is a prelude to decision making and depends on an iterative, analytic-deliberative process.

The products and processes of a risk assessment should provide all decision participants with the information needed to make informed choices, in the form in which they need it. The appropriate level of effort for a risk assessment is situation specific, although two things are important: careful diagnosis of the decision situation to arrive at preliminary judgments and openness to reconsidering those judgments as the process moves along. The procedures that govern risk assessment should leave enough flexibility to be expanded or simplified to suit the needs of the decision-makers.

A risk assessment must address what the interested parties and affected parties believe to be at risk in the particular situation, and it must incorporate their perspectives and specialized knowledge at the earliest phases of the effort in order to understand the risks. The challenges of asking the right questions, making the appropriate assumptions, and finding the right ways to summarize information can be met by designing processes that pay appropriate attention to each of these judgments, inform them with the best available knowledge and the perspectives of the spectrum of decision participants, and make the choices through a process that those parties trust.

Structuring an effective analytic-deliberative process for informing a risk decision involves judgment, and the right choices are situation dependent. In 1996, the National Research Council's Committee on Risk Analysis articulated five general objectives for effective analytic-deliberative processes for risk assessment, which also serve as criteria for judging success in a risk assessment project.

- **Get the science right.** Getting the science right implies that the underlying analysis meets high scientific standards in terms of measurement, analytic methods, data bases used, plausibility of assumptions, and respectfulness of the both the magnitude and character of uncertainty, taking into consideration limitations that may have been placed on the analysis because of the level of effort judged appropriate for informing the decision. Attention to careful scientific analysis is particularly important in domains such as marine transportation, where the data quality is uneven, and where data sources are often incomplete, inconsistent, and contain inaccurate data.

- **Get the right science**. Getting the right science means that the risk analysis has addressed the significant risk-related concerns of public officials and the spectrum of interested parties and affected parties, with analytic priorities having been set so as to emphasize the issues most relevant to the decision.

- **Get the participation right.** Getting the right participation means that the risk assessment process had sufficiently broad participation to ensure that important, decision-relevant information entered into the process, that all important perspectives were considered, and that the parties' legitimate concerns about inclusiveness and openness were met.

- **Get the right participation.** Getting the participation rights means that the risk assessment processes satisfied the decision makers and the interested and affected parties that it was responsive to their needs: that their information, view points, and concerns had been adequately represented and taken into account; that they had been adequately consulted; and that their participation was able to affect the way risk problems are defined and characterized.

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

The five guidelines are related. To be decision-driven, a risk assessment must be accurate, balanced, and informative. This requires getting the science right and getting the right science. Participation helps ask the right questions of the science, checks the plausibility of assumptions, and ensures that any synthesis is both balanced and informative. Thus, each of the steps provides important input to an effective analytic-deliberative process. These five objectives provided critical benchmarks to the Blue Ribbon Panel and to the consultant team during the Washington State Ferry Risk Assessment. How these guidelines were met is discussed in Section 3.3 of this report

3.2 THE WSF RISK ASSESSMENT AND RISK MANAGEMENT FRAMEWORK

In this study, the unwanted outcome is an accident involving a Washington State ferry. Accident types that are a potential threat to the Washington State ferries include *collisions* (or striking of another vessel), *fires and/or explosions*, *allisions* (or striking of a fixed object), and *groundings* (or strandings). The potential impacts of such accidents include deaths, injuries, and economic or environmental losses that occur as an immediate or delayed consequence of an accident. The focus of this study was on passenger safety, including consideration of both the probability of occurrence and the severity of consequence of accidents. The consequence evaluation focused on defining the appropriate accident response alternatives as required by Subchapter W.

Therefore, a measure termed *maximum required response time* (MRRT) was developed as a surrogate measure for the potential accident impact. The MRRT was defined as the maximum allowable time for response to avoid additional (post accident) injuries or fatalities due to a failure to respond in time. Three categories of MRRT were deemed appropriate: less than one hour, between one and six hours, and greater than 6 hours. Accidents in the first category will require an effective external emergency response to prevent additional injuries or fatalities since the time would probably not permit the launching of survival craft. For accidents in the second category, time is available for evacuation to a safe haven. In order to meet subchapter W requirements, the WSF will have to demonstrate that they either have the ability to mobilize evacuation vessels or plan to provide survival craft adequate for all passengers. For accidents in the third category, adequate response in all cases can be provided without evacuating the passengers from the ferry.

The basic technique used in the study was Probabilistic Risk Assessment (PRA), extended by the GW/RPI/VCU project team to emphasize the effect of the dynamic nature of a transportation system on risk. The process of performing a risk assessment includes the identification of the series of events leading to an accident, estimation of the probabilities of these events and the evaluation of the consequences of different degrees of system failure. An accident is not a single event, but the culmination of a series of events. Figure 2 shows the maritime risk taxonomy used by the study team and illustrates the importance of dynamic organizational and situational factors in both the occurrence and severity of an accident. The assessment framework differentiates between these triggering events (i.e. incident) and causal events (either basic or root causes).

The final task assigned to the project team falls into the category of risk management. The objective of risk management is to take actions and implement policies and procedures that reduce the threat (to life, property, and/or the environment) posed by hazards. Figure 3 shows the framework for risk management used to classify and evaluate risk reduction measures. There are six general opportunities for interrupting this event chain, preventing accidents and/or minimizing their consequences. As shown in figure 3, four classes of interventions are intended to reduce the likelihood of occurrence of accidents, and two classes of interventions reduce the consequences of accidents that do occur. The objective of risk management is to choose cost effective risk interventions that impact all areas of the accident event chain.

3.3 THE WSF RISK ASSESSMENT METHODOLOGY

The methodology used in the Washington State Ferries Risk Assessment was attentive to the particular risk mitigation challenges of complex large-scale systems such as the Washington State Ferries. To ensure that the dynamic nature of risk in the system was captured, and risk migration assessed, simulation was used as part of a dynamic risk assessment tool. To ensure that historical safety performance and any latent pathogens in the system were used for benchmarking, an analysis of safety performance in the Washington State Ferries over the past ten years was undertaken. Finally, because of the difficulties associated with developing a shared culture of reliability in distributed, large scale systems, attention was paid to the management, leadership, and cultural challenges of risk mitigation in the WSF.

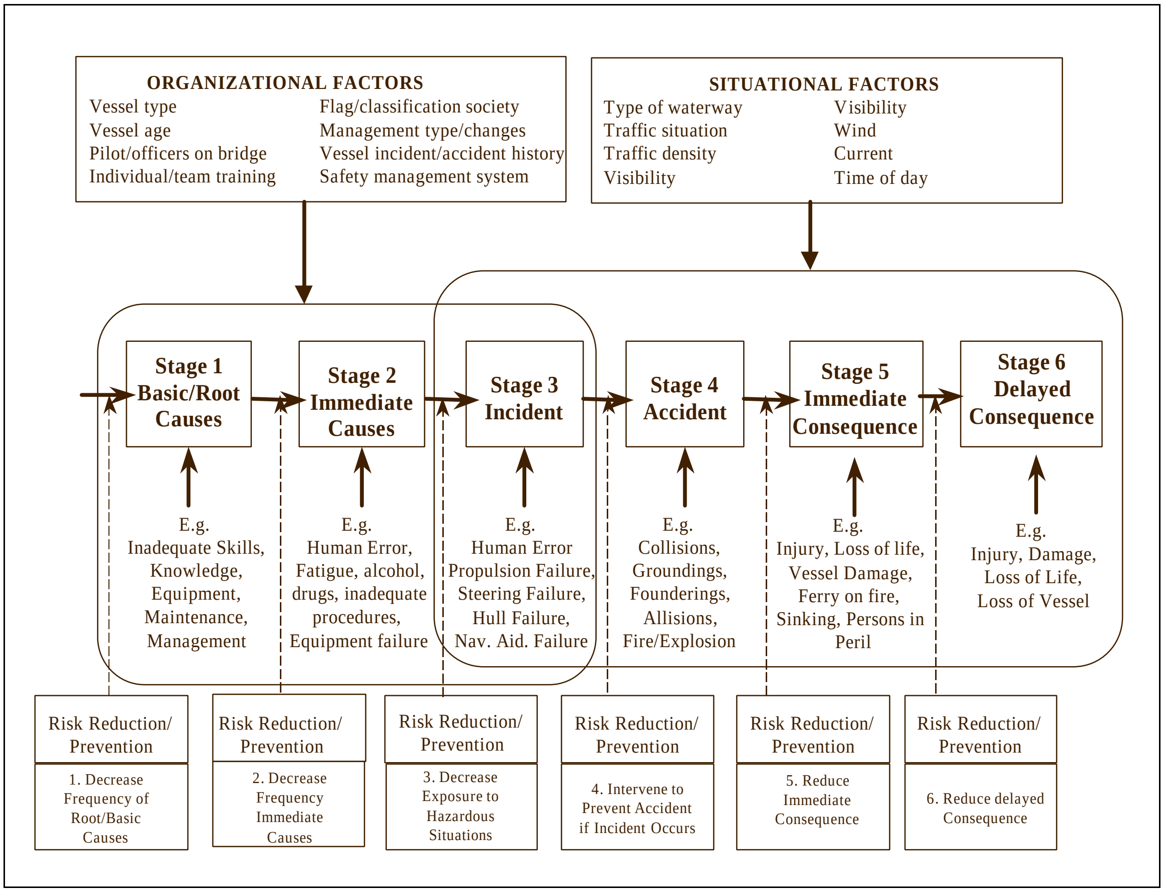


Figure 2. The Maritime Accident Event Chain and Intervening Risk Reduction Measures

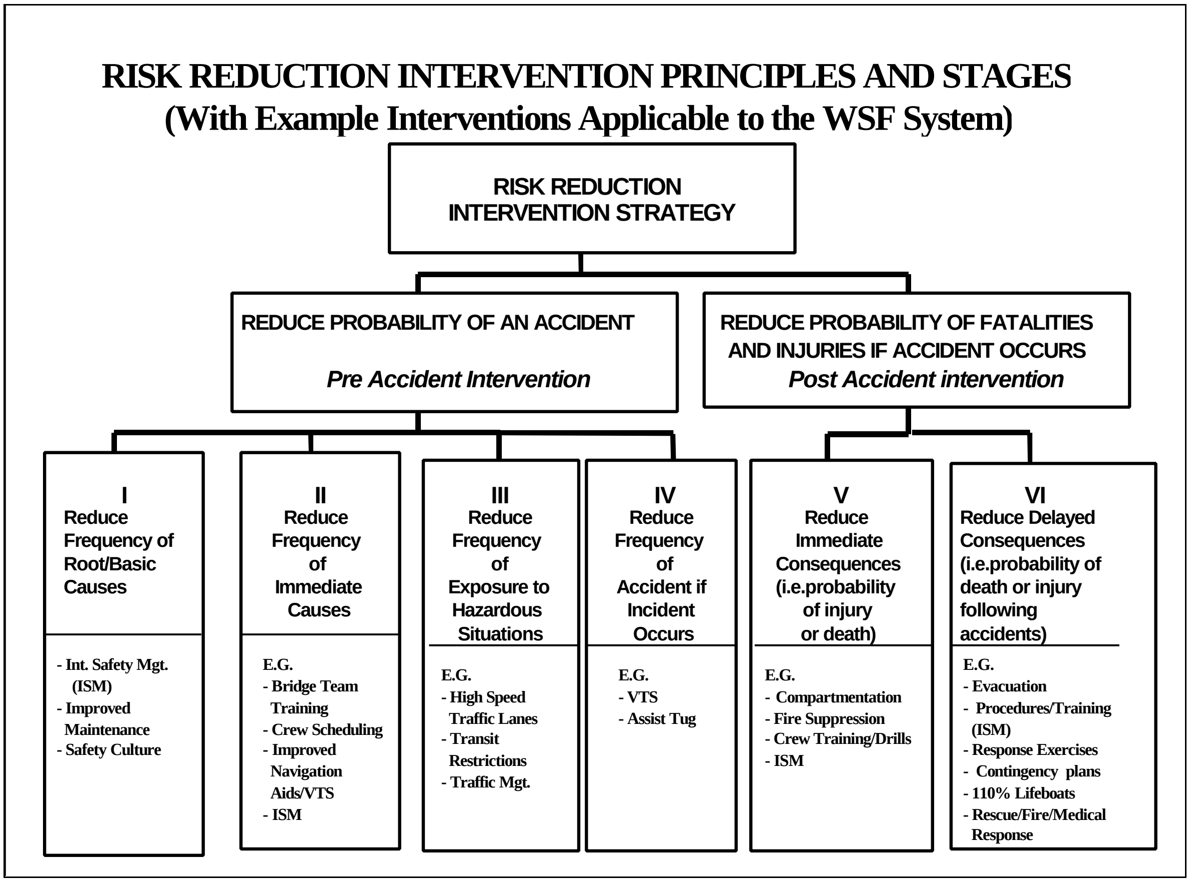


Figure 3. Classifying Potential Risk Reduction Interventions.

A detailed description of the methodology, models, and modeling assumptions used in this risk assessment is contained in Appendix III. Section IV describes the results and finding of this analysis and provides the basis for the conclusions and recommendations described in Section II. Arriving at these results, findings, conclusions, and recommendations required the following steps:

- The creation of an event data base from multiple sources containing data on incidents, accident, and unintended incidents in the WSF operating area of Puget Sound and the San Juan Islands.
- The analysis of this database to develop a basis for comparing the safety record of the Washington State Ferries with other waterway users for determining accident and incident trends and for providing the data required for risk modeling.
- The development of a computer system simulation that represents the operation of the Washington State Ferries, other vessels in the area, and the environmental conditions.
- The use of this simulation to determine the exposure to risk of all ferries on all routes. Exposure to collision risk was based on the number and type of interactions with other vessels. Exposure to grounding risk was based on the time actually spent in areas where grounding is possible. The number of dockings made determined allision risk exposure. Fire and explosion risk exposure was determined to be a function of the time underway.
- The calculation of the probabilities of occurrence of triggering incidents and the conditional probabilities of an accident given the occurrence of an incident was based on data where available and carefully elicited expert judgment where data was not available. Washington State Ferries relief masters and mates, Puget Sound Pilots, and Coast Guard VTS watchstanders formed the pool of experts used as the basis for the expert judgment elicitations. The methodology used for expert elicitations is described in appendix III, and is designed to minimize and account for potential bias.
- The dynamic risk assessment tool combined the system simulation with the accident and triggering incident probability models. The dynamic risk assessment tool was then used to calculate the system risk under four different scenarios:
  - Scenario I: a scenario based on the year 1997, before the introduction of the Chinook and the Jumbo Mark II ferries. Using 1997 as a historical base year was necessary since the majority of the event data on which the model is based was collected prior to 1998 and 1997 was a more typical year for commercial traffic than was 1998.
  - Scenario II: a baseline scenario based on the year 1998, with the Chinook and Jumbo Mark II ferries and the 1998 operating schedule (which involved a significant shifting of ferries between routes)
  - Scenario III: a future scenario based on adding a second high speed ferry
  - Scenario IV: Scenario 3 plus fleet wide implementation of the International Safety Management system.
- Estimates of the collision damage penetration for selected collision scenarios were made using an engineering model based on the methodology developed by Minorsky (1959). From the calculated damage penetration, the likelihood of flooding of multiple compartments was calculated. Given the flooding of a specific number of compartments, the likelihoods of the 3 MRRT categories were assessed.

- Potential risk reduction interventions were collected, classified and grouped. Their impact on events in the causal chain were estimated based on available data, other risk studies, interviews with experts, and the project teams best judgment.
- Finally, the impacts of risk reduction interventions on the system were estimated by changing parameters or variables in the dynamic risk assessment tool.

The five general objectives of Section 3.1 were adhered to in the analysis, specifically,

- *Get the science right*– meant using scientifically accepted risk assessment methodologies, using both qualitative and quantitative analysis. This methodology was developed by the consultant team, has been employed in a variety of maritime risk assessments over the past decade, and was peer reviewed in 1998 by the National Research Council as an example of a state-of-the-art risk assessment methodology.
- *Get the right science*– meant insuring that the Risk Assessment focused on the risk-related concerns of the Blue Ribbon Panel, the Washington State Transportation Commission, the Washington State Ferries, the U.S. Coast Guard, other public officials, members of the Puget Sound maritime community, scientists and other specialists, and a variety of interested and affected parties. These priorities were determined through analytic deliberation between the Blue Ribbon Panel, the interested and affected parties, and the project team. These priorities were articulated early in the risk assessment, and were refined as required throughout the risk assessment.
- *Get the participation right*– meant that participation was sought and garnered from a variety of sources: from the Washington State Ferries; the U.S. Coast Guard; the Washington State Department of Ecology; the Puget Sound Marine Exchange; the Puget Sound Pilots Association, from members of the American Waterways Operators (AWO) representing the tug and towing industry in Puget Sound; from commercial Puget Sound high speed ferry operators, from other passenger vessel and cruise lines; from the U.S. Navy; and from other members of the Puget Sound maritime community. Members of the project team used different venues and methods to seek participation from different interested and affected parties in the risk assessment project: members of the project team conducted formal and informal interviews, rode vessels, sought and requested data, reviewed databases and information systems for applicability to the risk assessment, reviewed literature and documents, and participated in planning and execution of exercises in the system.
- *Get the right participation*– meant that Washington State Ferries masters, mates and engineers were observed and interviewed on board the ferries where problems and issues could be demonstrated, and that Washington State Ferries management, operations, engineering, maintenance, and safety personnel were interviewed and consulted during the project. Experts external to the Washington State Ferry were also interviewed and consulted (e.g. Puget Sound Pilots, tow boat operators, U.S. Navy personnel). System stakeholders were also identified by Blue Ribbon Panel members and contacted by the project team.
- *Develop an accurate, balanced, and informative synthesis*– meant recognizing that risk analysis is as much of an art as it is a science and that limits to knowledge, ambiguity, and uncertainty must be acknowledged and assumptions must be understood. The project team and the Blue Ribbon Panel devoted extensive time to defining and discussing the assumptions and models that lead to the results and conclusions presented in this report.

Moreover, the consultant team was attentive to presentations of the state of knowledge and sensitivity of results to modeling assumptions in the risk assessment, and was attentive to the importance of careful analysis and presentation of the synthesized information.

SECTION IV: SPECIFIC FINDINGS AND RESULTS OF THE WSF RISK ASSESSMENT

4.1 Specific Findings

The risk analysis findings are based on the analysis of the data base created for this project from eleven years of incident and accident data, and the predictive risk models developed specifically for the analysis of the likelihood and consequences of accidents effecting the Washington State Ferries. The quantitative analysis was framed and guided by observations of the system and interviews with key personnel within the Washington State Ferries, the U.S. Coast Guard, Puget Sound Pilots, and other organizations. The findings are grouped in four categories: (1) assessments of the acceptability of system risk, (2) assessments of historical safety performance based on analysis of the data base, (3) predicted accident frequencies and accident scenarios based on the dynamic simulation risk model categorized by potential consequences based on the collision damage models, and (4) assessment of the effectiveness of potential interventions.

The WSF system has a notable historical safety record.

1. Most (84%) of the 1,429 safety related events that have been recorded in Puget Sound over the past eleven years have been incidents (events not resulting in property loss or injury), not accidents with reportable consequences. Despite the fact that Washington State Ferry vessels comprise 75-80% of the traffic on Puget Sound and the San Juan Islands, Washington State Ferries have been involved in only 43% of the incidents and in 19% of all accidents over the eleven year period.

2. A total of 538 Washington State Ferry events were recorded between 1988 and 1998. Consistent with the trend in Puget Sound, most of the events occurring to Washington State Ferry vessels were incidents (propulsion failures, steering failures, equipment failures, and errors), rather than accidents. Of the 538 WSF events, 85.5% (460 events) were incidents, 8.6% of the events (a total of 46) were accidents; and 3.7% (or 20 events) were unusual incidents, and 2.2% (12 events) were unclassified.

3. Of the 46 accidents that occurred to WSF vessels between 1988 and 1998, 26 (or 56.5% of all accidents) were allisions (the striking of a fixed object such as a dock), 4 (8.7%) were collisions with another vessel, 9 (19.6%) were fires and/or explosions, 1 was a flooding, and 6 (13%) were groundings. Thus, the greatest number of accidents occurring to WSF vessels over the 10 year period was allisions, followed by fires and explosions, primarily crank case explosions. The four collisions with WSF vessels during the period were: one between two ferries, one between a ferry and a tug and her tow, and two between WSF vessels and pleasure craft.

4. Human error was the primary cause of WSF accidents; 68.6% of the causes were categorized as human error, and 31.4% of the causes were categorized as mechanical failures. This data provides an interesting contrast to the oft-quoted 80% human error figure used in many maritime studies.

The risk models demonstrate that potential accidents have serious consequences and identify the dominant potential accident scenarios.

5. Credible accident scenarios that should form the basis of response and consequence management were demonstrated. Collisions are the most likely accident type that could result in a significant number of injuries and fatalities, and the statistical frequency for collisions was calculated to be 0.223 collisions/year. Several collision scenarios were developed that could have catastrophic consequences (passenger only vessel collisions--particularly high speed ferry collisions, automobile ferry collisions with large, high speed vessels such as container ships)

6. A surrogate measure, termed *maximum required response time* (MRRT), was used as the potential accident impact. The MRRT was defined as the maximum allowable time for response to avoid additional (post accident) injuries or fatalities due to a failure to respond in time. Three classes of MRRT were deemed appropriate: less than one hour, between one and six hours, and greater than 6 hours. A MRRT of more than 6 hours occurred in 68% of all the statistical expected number of collisions (0.152 collisions/year). In 7% of the predicted collisions (0.015 collisions/year) a MRRT between 1 and 6 hours would be required, and the remaining 25% (0.055 collisions/year) would require a MRRT of less than 1 hour.

7. The average return time (the average time between two consecutive events) for collisions involving Washington State Ferries (regardless of its severity) is 4½ years. However, the average return time of collisions requiring a MRRT of 1 to 6 hours is 67 years and the average return time of collisions requiring a MRRT of less than 1 hour is 18 years.

8. The routes, listed in order of collision potential account for 94% of the total statistical frequency of collisions (1 collision every 4.5 years or 0.223 collisions/year):
   - Seattle-Bainbridge Island ferries (24.3%)
   - Seattle-Bremerton car ferries (22.1%)
   - Seattle-Bremerton passenger-only ferries (18.6%)
   - Edmonds-Kingston ferries (13.7%)
   - Fauntleroy-Vashon ferries (8%)
   - Seattle-Vashon passenger-only ferries (7.5%)

   The percentages indicated in the brackets are the percentage contribution of the route to the total statistical frequency of collisions.

9. Collisions that would require a response between 1 and 6 hours would also require the evacuation of passengers to a safe haven such as another ferry, a rescue vessel, or a survival craft launched from the ferry. The following routes account for 95% of the total statistical frequency of collisions of this type (1 collision every 67 years or 0.015 collisions/year):
   - Edmonds-Kingston ferries (30.5%)
   - Seattle-Bremerton passenger-only ferries (15.6%)
   - Seattle-Bremerton car ferries (15.6%)
   - Seattle-Bainbridge Island ferries (13.5%)
   - Seattle-Vashon passenger-only ferries (11.7%)

- Fauntleroy-Vashon ferries (8.2%)

The percentages indicated in the brackets are the percentage contribution of the route to the total statistical expected frequency of collisions per year with an MRRT of 1 to 6 hours.

10. Collisions that would require a response time of less than 1 hour would require a coordinated emergency response from the U.S. Coast Guard and the Washington State Ferries. The following routes account for 99% of the total statistical frequency of collisions of this type (1 collision every 18 years or 0.055 collisions/year):
    - Seattle-Bremerton passenger-only ferries (52.5%)
    - Seattle-Bremerton car ferries (17%)
    - Seattle-Vashon passenger-only ferries (10.7%)
    - Edmonds-Kingston ferries (8.2%)
    - Seattle-Bainbridge Island ferries (8.1%)
    - Fauntleroy-Vashon ferries (2.3%)

    The percentages indicated in the brackets are the percentage contribution of the route to the total statistical frequency of collisions per year with an MRRT of less than 1 hour.

11. The highest average collision probability per interaction is on the Edmonds-Kingston route. This is because a large proportion of the interactions is with non-WSF vessels. These interactions have a higher probability of leading to a collision and thus the average collision probability is higher. Other routes with higher average collision probabilities per interaction are the Seattle-Bremerton passenger-only ferries, the Seattle-Bainbridge ferries, the Port Townsend-Keystone ferries and the Seattle-Vashon passenger-only ferries.

12. A primary cause of collision risk in the system is the relatively high level of traffic congestion in the Central Puget Sound, particularly in Elliott Bay. Future increases in traffic in this area due to additional Ferry runs, excursion boats, and commercial shipping will increase the potential risk in this area.

13. A secondary cause of collision risk in the system is operations in conditions of high traffic and restricted visibility. The visibility model developed for the risk analysis determined that ferries operate in restricted visibility 12% of the time; 54% of the total statistical frequency of collisions were found to occur during periods of restricted visibility.

14. Over 90% of the statistical frequency of collisions requiring an immediate response would occur in the Central Puget Sound on the routes that carry 85% of the Washington State Ferry ridership.

15. The addition of the high speed (Chinook) class ferry to the schedule and the subsequent additional interactions in a high ferry to ferry interaction area has resulted in an increased statistical expected number of collisions. However, the average collision probability per interaction for the Chinook is less than that for the older passenger-only ferries. Since all collisions involving high-speed class vessels were assumed to require an immediate

response, the introduction of the high-speed class ferries increases the statistical frequency of collisions requiring a MRRT of less than 1 hour by over 50%.

16. The Port Townsend-Keystone route was a course of concern prior to the study due to its isolation and the single ferry assigned to the route during the winter months. The statistical expected number of collisions for this route is low relative to the central Puget Sound routes, but the average collision probability is the fourth highest. This is because a large proportion of the interactions is with non-WSF, commercial traffic. It should also be noted that collisions with such vessels could have an MRRT of less than 6 hours and thus require evacuation of the passengers to a safe haven. Emergency response planning should, therefore, be carefully considered for this route.

17. The international ferry to Sidney is also isolated from other WSF ferries and US Coast Guard response capabilities. Crossing Haro Strait, this ferry can interact with non-WSF, commercial traffic with which collisions can have an MRRT of less than 6 hours. However, this vessel is required to have life rafts for 110% of its passenger capacity by US Coast Guard SOLAS regulations.

18. Fires on board ferries have historically been limited to engine spaces, the car deck, and galley and all of these spaces have adequate fire control systems. However, a fire on the car deck could lead to an explosion that could produce catastrophic results– particularly if there was an illegal hazardous cargo in a truck or vehicle near the source of the fire, or if the explosion is the result of a deliberate act. The Edmonds-Kingston route is the route with the highest historical rate of minor fires.

19. There is no evidence of a serious threat of sabotage or attack against the Washington State Ferries. However, the relatively open boarding procedures, lack of security systems, and minimal capability for checking vehicle contents make it highly unlikely that an attempt, were it to occur, would be detected and thwarted.

20. Allisions are serious property damage and service interruption issues, but not significant threats to passengers. Allisions are the most common accident in the WSF system and must be avoided to minimize property and service losses due to accidents. The highest historical allision rates observed were in the San Juan Islands: Issaquah class ferries at the Orcas Island terminal, Steel Electric class ferries at the Lopez Island terminal, and Super class ferries at the Anacortes terminal.

21. There were six groundings of Washington State Ferries during the period 1988-1998. There are only certain geographical areas where groundings are possible. The area of greatest risk for grounding is Keystone Harbor. Groundings are not an immediate threat to passengers and the MRRT for groundings is assumed to be 6 hours or greater in all cases.

22. Flooding and foundering are insignificant threats to passenger safety. No serious structural incidents have been reported in the last eleven years.

- **Risk reduction interventions are required to maintain the current low likelihood of accidents and to reduce the potential consequences of accidents that could occur by increasing the effectiveness of emergency response.**

23. The single most effective risk management intervention is the fleet wide implementation of the International Safety Management System (ISM). It is estimated that fleet wide implementation of ISM will reduce the potential rate of accidents by approximately 15%, offsetting the potential increase in risk due to the introduction of new ferries and routes. Funds for fleet wide implementation have been approved by the Washington State Legislature. ISM will reduce both the probability of accidents and the consequences if accidents do occur.

24. Reducing the occurrence of mechanical failures through appropriate improvements to the Washington State Ferries' maintenance policies, rules and procedures can lead to a proportional reduction in the number of accidents triggered by these incidents.

25. Due to the potential risk of an accident with an MRRT of less than 1 hour, the Washington State Ferries the Coast Guard, and other public safety agencies must be prepared to respond to a potentially catastrophic event requiring an immediate, coordinated response. Example scenarios are a collision of a high-speed ferry, a collision of an automobile ferry with a large, high-speed container vessel or an explosion. The planning, preparation, exercises and drills required to develop and maintain such a capability have been initiated and these efforts should be fully supported and expanded. ISM provides for enhanced crew training and qualifications for emergency procedures.

26. Policies and procedures that reduce nearby vessel interactions during periods of low visibility and high speed ferry operating procedures that reduce the number of nearby interactions with other vessels would be effective risk reduction interventions. The operational feasibility and cost of such procedures is difficult to evaluate since their impact is on service, not capital or operational budgets.

27. Although the statistical expected number of collision with an MRRT of less than 1 hour on the Port Townsend-Keystone and Haro Strait transits are low relative to other routes, the isolation of these routes from other Washington State ferries and US Coast Guard response equipment is a cause of concern. Vessels making the Haro Strait transit are subject to international conventions and currently carry survival craft adequate for all passengers. Ferries on the Pt. Townsend– Keystone run are not required by current Coast Guard regulations to carry 100% survival craft.

4.2 Results from the Data Analysis

The Puget Sound marine transportation system is a moderately active port: a total of 1429 events (accidents, incidents, and unusual events occurring to vessels other than recreational vessels) were recorded during the period 1988 - 1998. This activity level compares to 604 events for the period 1975-1997 in Prince William Sound, Alaska (a port where activity levels are relatively small), and 1920 events for the port of Houston/Galveston, for the period 1991-1996 (an active port).

Traffic in the Puget Sound marine transportation system has been relatively stable over the past 10 years, as shown in figure 4.

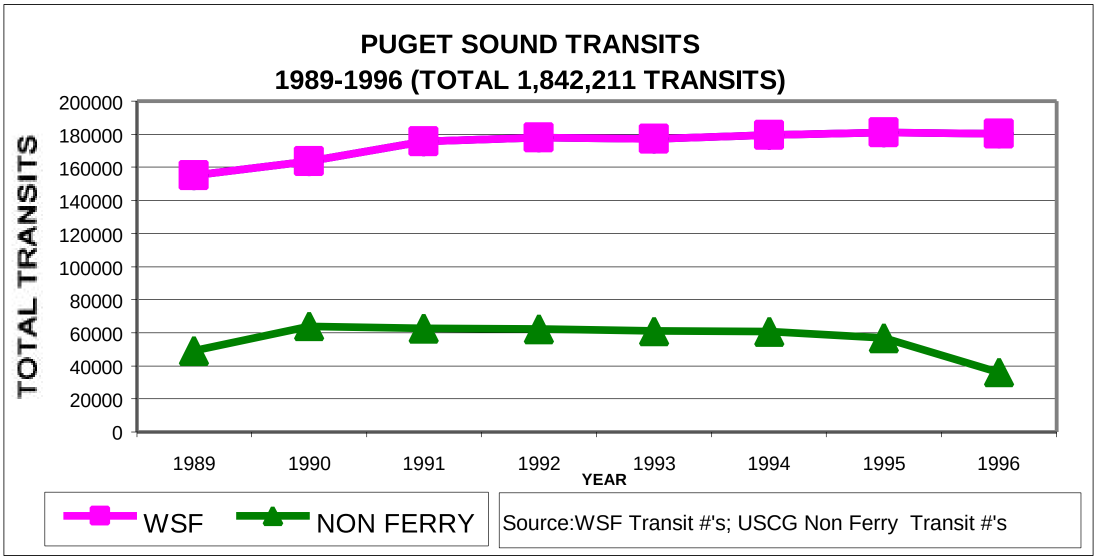


Figure 4. Transits in Puget Sound, 1989 – 1996

Between 1989 and 1996 (dates for which transit statistics were available), there were 1,842,211 transits in Puget Sound: 78% of those transits (1,390,723) were Washington State Ferry transits; 22% (451,488) were non-ferry transits. Review of Figure 4 shows that over the period, Washington State Ferry traffic comprised 75-80% of the traffic in Puget Sound.

Transits per year increased gradually for Washington State Ferries for the period 1989 - 1996, as seen in Figure 4. In contrast, non-ferry transits per year declined gradually, particularly after 1994. This trend for non ferry traffic has been the result of trends to build larger and sail fewer commercial vessels, the advent of container alliances which consolidated shipping operations into fewer ship's bottoms, the decline of Pacific Rim markets, and the decline of logging traffic in Puget Sound.

Despite the fact that Washington State Ferries comprise 75-80% of the traffic in Puget Sound, there have been significantly fewer ferry events, compared to non-ferry events, over the past ten years. An analysis of events in Puget Sound shows that the number of events occurring has risen steadily over the past ten years, particularly after 1991. However, patterns for the Washington State Ferries and non ferry vessels differ: events involving non-ferry vessels have substantially risen since 1993, at the same time that events involving Washington State Ferries 'events have declined.

Caution is required, however, in reviewing the data illustrated in Figure 5, as there are external factors that complicate the data analysis. First, a Washington State agency with maritime reporting oversight and responsibilities, the Office of Marine Safety, was formed in 1991. This agency increased the attention focused on accidents, incidents, and unusual incidents in marine transportation, and introduced a reporting system and reporting requirements, which considerably increased the reporting effect in the data collected. Thus, the increased number of events shown in Figure 5 can be attributed to events that occurred as well as increased interest and resources focused on event reporting.

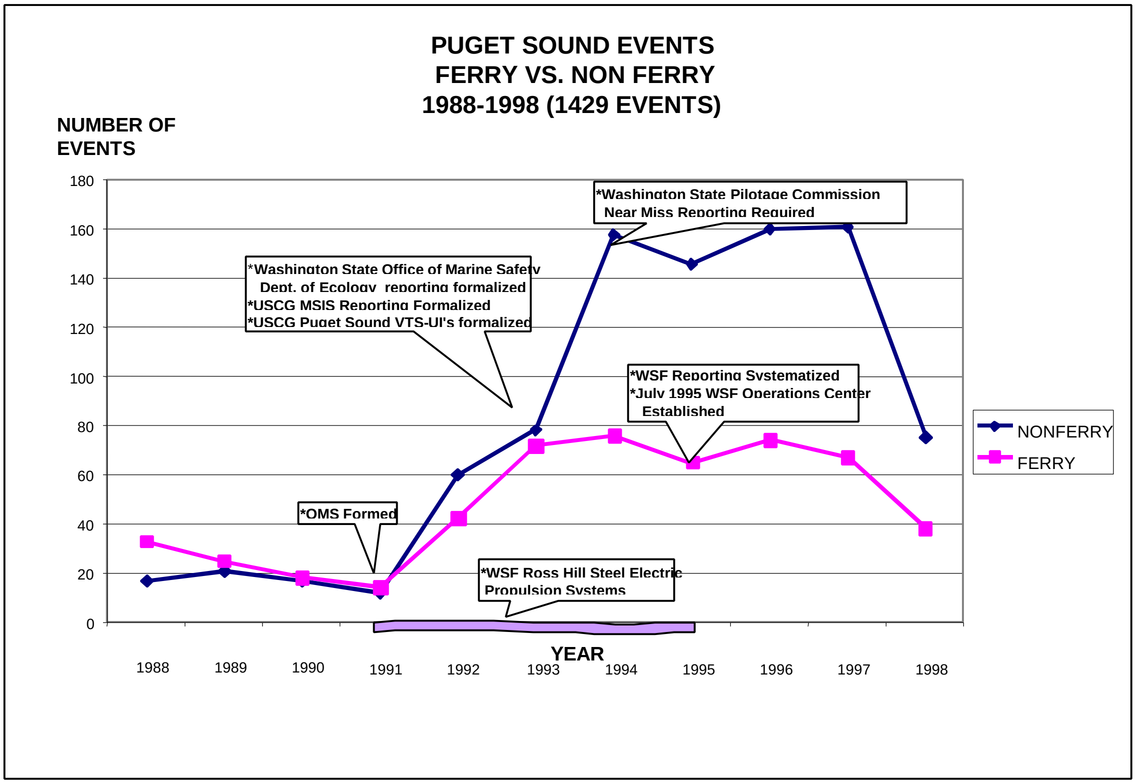


Figure 5. Puget Sound Ferry vs. Non Ferry Events, 1988-1998

At the same time, the U.S. Coast Guard Marine Safety Information System (MSIS) was formalized, as was the U.S. Coast Guard Puget Sound Vessel Traffic System Unusual Incident reporting system. Similarly, the Washington State Pilotage Commission finalized their near miss reporting system, and the Washington State Ferries formalized their Operations Center and their reporting procedures. Thus, although the event occurrence rates illustrated in figure 5 appear to rise dramatically from 1991 onward, external factors – the reporting effect introduced by the maturation and proliferation of responsible agencies – are difficult to separate from the event trend, and caution is advised with the use of the Figure 5 trend data.

When event occurrences are normalized for traffic and events/transit are compared, differences between ferry and non-ferry event occurrence rates are exacerbated, and the safety record of the Washington State Ferries is highlighted. Normalized event occurrence rates account for the fact that the Washington State Ferries represent 75-80% of the traffic in Puget Sound, using events/transit statistics as a basis for comparison. As can be seen in Figure 6, events per transit rates for Washington State Ferries, compared to non-ferry vessels, are significantly different. Normalized event rates for non-ferry vessels have been increasing since 1991, as seen in Figure 6. At the same time, events/transit rates for the Washington State Ferries have remained relatively the same, and at a significantly lower level than that of non-ferry vessels. Caution should be exercised with the use of the trend illustrated in Figure 6, however, because of the organizational and reporting complexities described earlier.

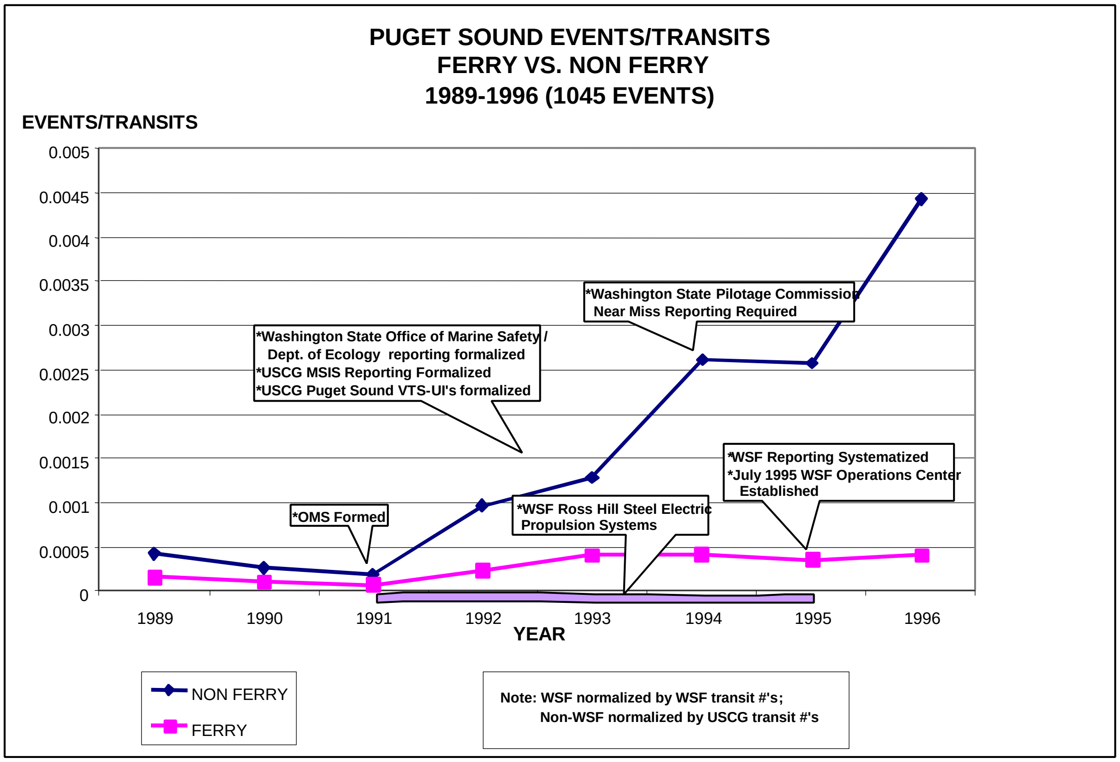


Figure 6. Puget Sound Events/Transit Ferry vs. Non Ferry Events, 1988-1998

Thus, ferry events per year have decreased significantly since 1994, and ferry events/transit have also decreased since 1994. This trend is primarily due to the significant decrease in Washington State Ferry propulsion failures since 1994. At the same time, non ferry events per year in Puget Sound have increased significantly, and non-ferry events/transit have also increased steadily since 1994. Thus, ferry and non-ferry event patterns are significantly different over the past ten years, and both patterns highlight the safety record of the Washington State Ferries during the period.

Table 1 gives a tally of all events in the Puget Sound area over the period 1988-98. In this table, the events are classified by WSF vs. non-WSF events and into incident, unusual incident and accident categories. The following observations were made from the data in Table 1.

76% of the events that were recorded in Puget Sound over the past ten years have been precipitating incidents (propulsion failures, steering failures, and other equipment failures), rather than accidents (collisions, allisions, groundings, fires and explosions, or founderings). Of the 1,429 events that occurred between 1988 and 1998, 76% of those events were incidents, 17% accidents, and 8% unusual incidents. This finding contrasts with other ports in the United States, with different event profiles. For instance, of the 1,920 events that occurred between 1991 and 1996 in the port of Houston/Galveston, 75% were accidents--pollution events, allisions and groundings--rather than incidents. These patterns of event occurrences in a port or waterway provide important clues as to the utility of candidate risk reduction measures.

In total, there have been 237 accidents in Puget Sound over the past ten years, 46 involving Washington State Ferries and 191 involving non-WSF vessels. As the Washington State Ferries comprise 75% of the traffic in the Puget Sound, the safety record for the WSF is substantially better than for non-WSF vessels. Most of the accidents that have occurred have been allisions and groundings; primarily occurring to non-ferry vessels.

Table 1. Washington State Ferry Events, 1988-1998

	WSF		Non-WSF		TOTAL	
Event Type	**Number of Events**	**% of WSF Total Events**	**Number of Events**	**% of Non-WSF Total**	**Number of Events**	**% of Total**
Accidents	46	8.8%	191	21.1%	237	16.6%
Incidents	460	87.8%	624	69.0%	1084	75.9%
Unusual Incidents	18	3.4%	90	9.9%	108	7.6%
Total Events	524	100.0%	905	100.0%	1429	100.0%

	WSF		Non-WSF		TOTAL	
Accidents	**Number of Accidents**	**% of WSF Total Accidents**	**Number of Accidents**	**% of Non-WSF Total Accidents**	**Number of Events**	**% of Total**
Allisions	26	56.5%	65	34.0%	91	38.4%
Collisions	4	8.7%	34	17.8%	38	16.0%
Fires/Explosions	9	19.6%	38	19.9%	47	19.8%
Floodings	1	2.2%	6	3.1%	7	3.0%
Founderings	0	0.0%	12	6.3%	12	5.1%
Groundings	6	13.0%	36	18.8%	42	17.7%
Total Accidents	46	100.0%	191	100.0%	237	100.0%

	WSF		Non-WSF		TOTAL	
Incidents	**Number of Incidents**	**% of WSF Total Incidents**	**Number of Incidents**	**% of Non-WSF Total Incidents**	**Number of Events**	**% of Total**
Steering Failure	58	12.6%	45	7.2%	103	9.5%
Propulsion Failure	190	41.3%	93	14.9%	283	26.1%
Other Equipment Failure	212	46.1%	486	77.9%	698	64.4%
Total Incidents	460	100.0%	624	100.0%	1084	100.0%

Most of the Washington State Ferry accidents between 1988 and 1998 were allisions. Of the 46 accidents that occurred to WSF vessels between 1988 and 1998, 26 (or 56.5% of all WSF accidents, 1988-1998) were allisions, 4 (8.7%) were collisions, 9 events (19.6%) were fire and/or explosion, 1 was a flooding, and 6 (13%) were groundings, as shown in Table 1.

There were four collisions with WSF vessels during the period, as detailed in Table 2, below: one between two ferries, one between a ferry and a tug and her tow, and two between WSF vessels and pleasure craft.

Over the past ten years, almost 70% of the errors which resulted in WSF accidents were human error-related. In order to analyze the role of human and organizational error in the Washington State Ferries, an event analysis of the 46 WSF accidents that occurred between

1988 and 1998 was conducted. During this analysis, a total of 51 errors were identified and then categorized as human errors or mechanical failures. The analysis showed that 68.6% (35 errors) of the errors that occurred during the accidents were categorized as human error and 31.4% (16 errors) were categorized as mechanical failures. The availability and completeness of accident narrative reports from the U.S. Coast Guard and the Washington State Ferries limited this analysis.

Table 2. WSF Collisions, 1988-1998

MCCASE #	Date	Vessel	Accident Type	Narrative	Location
MC91004921	9/16/91	Sealth, Kitsap	Collision	2 ferries collide in fog; imprudent speed, improper use of radar info	Rich Passage
MC93002746	2/14/93	Spokane	Collision	Victor E pleasure craft collision; craft failed to give way	2 nmi E of Eagle Harbor
MC94024175	9/10/94	Issaquah	Collision	Hits unlighted tug boomsticks (missed tug, hit tow)	Enroute to Southworth
MC94010890	9/21/94	Kitsap	Collision	Hits unlighted, adrift 21' pleasure craft at midnight	Bremerton

Thus, in the Washington State Ferries Risk Assessment, approximately 70% of the errors committed during accidents were related to human and organizational error. This suggests that attention to human error-related risk mitigation measures is warranted in the Washington State Ferries.

4.3 Results from Risk Models

Multiple linked risk models were used to estimate the risk of collision, allision, grounding, and fire and explosion and the results are presented in that order. The modeling of collision risk through the use of the dynamic simulation was the most complex since the likelihood of collision depends upon the number and type of interactions with other vessels as well as situational factors. In addition, the damage sustained in a collision depends upon the size and speed of the colliding vessel and the angle and location of impact. These were determined through an event tree model and a damage model. This level of modeling detail was necessary since collisions are potentially the most serious accidents that could occur in the WSF system. The likelihood of ferry allisions depend upon the number of dockings and situational factors, groundings depend upon time spent in certain locations and situation factors. Allisions and groundings were modeled using the dynamic simulation model. Detailed description of the risk models and modeling assumptions are contained in Appendix III, methodology. Complete results from the collision and damage models are contained in the Appendix II.

4.3.1 Collision Analysis Results

Four system scenarios were simulated for the collision analysis as defined in Table 3. Sample results from the analysis of the 1998 scenario, scenario 2 in table 3, are discussed in this section. The year 1998 was chosen as a base case since it is the most recent year for which complete data was available. Complete results for all four scenarios are documented in Appendix II.

Table 3. Collision Model Scenario Definitions

Scenario	Definition
Scenario 1— 1997 historical case	Selected as representative of historical accident and traffic data. No high speed ferry, no Jumbo Mark II ferries
Scenario 2— 1998 base case	Last complete year for traffic data. One high speed ferry, two Jumbo Mark II ferries
Scenario 3— future case 1	Scenario 2 plus a second high speed ferry
Scenario 4— future case 2	Scenario 3 plus fleet wide implementation of the International Safety Management system

Figure 7 shows the statistical expected number of collisions per year for each ferry route and each type of vessel that interacts with the ferries on that route for 1998 routes and vessel assignments. The ferry route and interacting vessel combinations are ordered from left to right by the percentage contribution to the statistical frequency of collisions per year. Only the interacting vessel is noted in the table, the other vessel is the ferry sailing on that route.

The dark part of each bar in figure 7 indicates the percentage contribution to the statistical frequency of collisions for that combination. The total height of the bar indicates the cumulative percentage including all combinations to the left. In other words, figure 7 contains the combinations of collision interactions that accumulate to 60% of the statistical frequency number of collisions per year.

The majority of potential collisions are with other Washington State Ferries. This is to be expected, however, since 94% of all interactions of a ferry are with other Washington State Ferries. The primary collision risk from non-WSF vessels is with container vessels. The ferry route/interacting vessel combination that has the highest statistical frequency of collisions is the Jumbo Mark II ferry interacting with the Seattle-Bainbridge ferries (also a Jumbo Mark II). The second most prominent potential collision combination is the Seattle Bremerton passenger ferry (Chinook or POV) with an Issaquah class ferry (the Seattle Bremerton auto ferry). The first combination that involves an interacting vessel other than a Washington State ferry is container vessels interacting with the ferries on the Edmonds-Kingston route.

Two subsets of this collision frequency distribution are of particular interest. The first subset is potential accidents with a mean required response time (MRRT) of less than one hour. Recall that these accidents will require an effective external emergency response to prevent additional injuries or fatalities since the time would probably not permit the launching of survival craft. The second group is accidents with a MRRT of 1 to 6 hours. For this category, time is available for evacuation to a safe haven.

Figure 8 shows the percentage contribution to the expected number of collisions per year with a 0 to 1 hour MRRT for each ferry route and each type of vessel that interacts with the ferries on that route. The format of figure 8 is the same as described for figure 7.

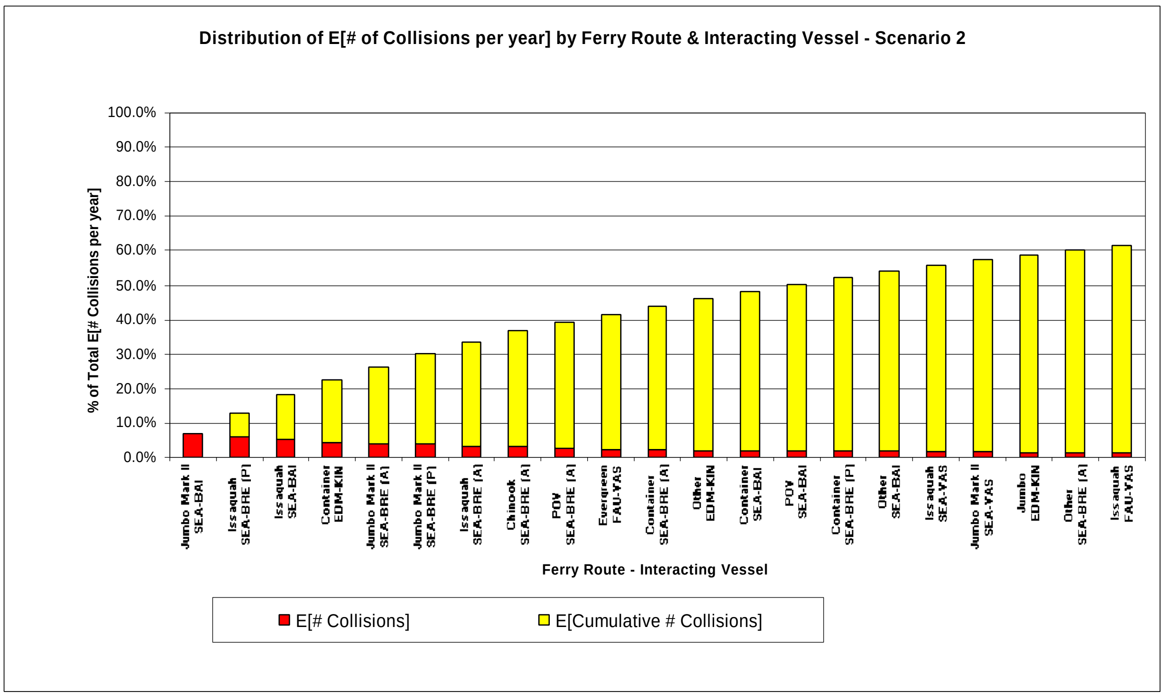


Figure 7. The distribution of the statistical expected number of collision per year by ferry route and interacting vessel type-- 1998 Scenario (Expected number of collisions per year for entire system is 0.223 collisions/year, average time between consecutive collisions is 4.5 years)

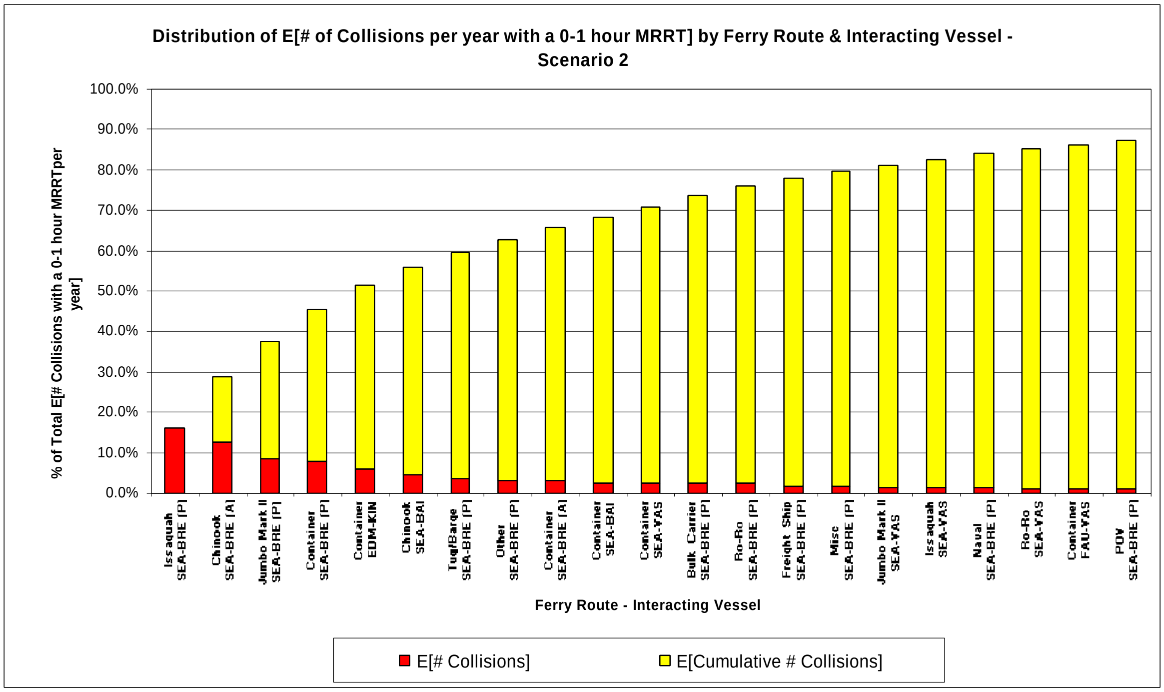


Figure 8. The distribution of the statistical expected number of collision per year with a MRRT of less than 1 hour by ferry route and interacting vessel type– 1998 Scenario (Expected number of collisions per year with a MRRT of less than 1 hour for entire system is 0.055 collisions/year, average time between consecutive collisions in this MRRT Category is 18.1 yrs)

Note that the statistical frequency of collisions with the potential for requiring an immediate response, are concentrated in a relatively few routes. The top four combinations all involve a Seattle Bremerton passenger ferry, either the Chinook or another passenger only ferry. The first 15 combinations in the ranking of MRRT 0-1 hr collisions involve either the Chinook, passenger-only ferries or container vessels. The most significant observation drawn from this graph is that over 50% of all potential collisions requiring an immediate response involve either the Chinook and/or other Passenger Only Ferry. A second important finding is that container vessels are the most non-ferry interacting vessel most likely to be involved in a collision requiring an immediate response. Figure 8 also shows that over 90% of the potential collisions requiring an immediate response would occur in the Central Puget Sound on the routes that carry 85% of the Washington State Ferry ridership.

The second important sub category contains those accidents where survival craft would be a viable lifesaving alternative for the Washington State Ferries. Figure 9 shows the expected number of collisions per year that require a response time of 1 to 6 hours for each ferry route and each type of vessel that interacts with the ferries on that route. The format of figure 7 is again used for the percentage contribution of the combinations to the statistical frequency of collisions with an MRRT between 1 and 6 hours. Three routes account for approximately 50% of these potential collisions. The interaction of container vessels with ferries on the Edmonds– Kingston rout account for more than 20% of the potential collisions with an MRRT between 1 and 6 hours. The Seattle Bremerton auto route accounts for approximately 15% (interacting with container and ro-ro vessels) and the Seattle Bremerton passenger only route accounts for another 15% (interacting with other ferries)

Appendix II contains a detailed collision analysis for each ferry route and ferry class. Two examples of this analysis, two of the routes with the highest predicted collision rates, are presented here. The first is the Seattle Bremerton car ferry route, in figure 10, and the second is the Seattle Bremerton passenger ferry route, in figure 11. These examples show how the collision damage model was used to categorize the collisions into the three MRRT classes.

Figure 10 combines the 3 graphs of the statistical frequency of collisions, the average collision probability and the number of interactions per year. On the Seattle to Bremerton car ferries, the majority of interactions are with the Jumbo Mark II class ferries on the Seattle to Bainbridge Island route and then the other Issaquah class ferry and the passenger only ferries on the Seattle to Bremerton route.

The Damage Scenario Model and the Response Time Model showed that collision with the Issaquah class and Jumbo Mark II class ferries would allow a MRRT of more than 6 hours. Whereas the collision scenarios that may require a response time of 0 to 1 hour or 1 to 6 hours are primarily with the Chinook and with container and ro-ro vessels (vessels of large size and relatively high transit speeds).

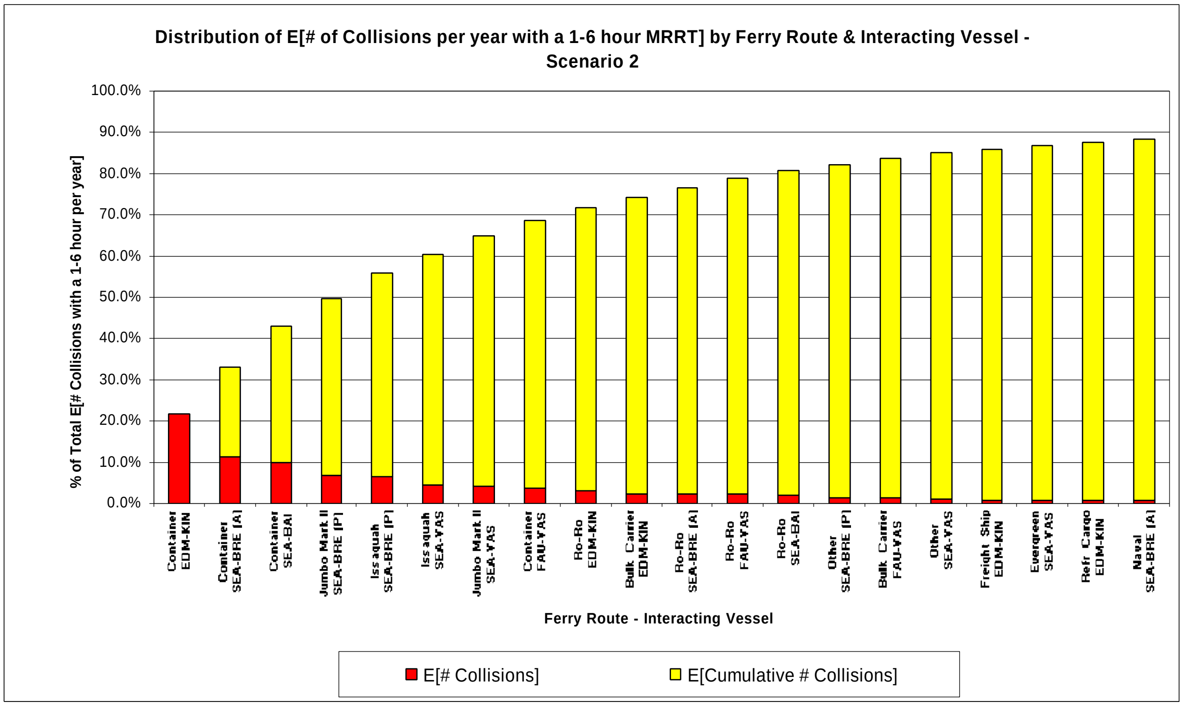


Figure 9. The statistical expected number of collision per year with a MRRT of 1 to 6 hours by ferry route and interacting vessel type– 1998 Scenario (Expected number of collisions per year with a MRRT of 1 to 6 hours for entire system is 0.015 collisions/year, average time between consecutive collisions in this MRRT category is 67.5 yrs)

Figure 11 shows that, for Seattle to Bremerton passenger-only ferries, the majority of interactions are with the Issaquah class ferries on the Seattle to Bremerton car ferry route, the Jumbo Mark II ferries on the Seattle to Bainbridge Island route and the other passenger-only ferry on the Seattle to Bremerton route. The average collision probabilities given an interaction are much higher for interactions with non-WSF vessels than for these WSF vessels. The relatively high proportion of the expected number of collisions that require less than 1 hour response times on this route raises concern.

4.3.2 A Comparison of the 4 Scenarios

The previous discussion shows that collisions involving the Chinook class high-speed, passenger-only ferries are of concern due to the likelihood of a very constrained response time. The significance of this addition to the Washington State Ferries is illustrated by the summary results of the four scenarios modeled. In the 1997 baseline scenario 1, the Chinook was not operating. In the 1998 scenario 2, the Chinook class is operational, while in scenario 3, there are two Chinook class ferries operating. The other major differences between scenarios is the Jumbo Mark II ferries introduced in scenarios 2 and 3 and absent from scenario 1 and several vessel/route changes made in 1998. Scenario 4 is based on scenario 3 but includes an estimate of the effect of implementing the Safety Management System fleet wide. The introduction of ISM is discussed in more detail below. Thus a comparison of the 4 scenarios is necessary to understand the potential change in the systemic risk caused by the introduction of the new ferry classes.

Scenario 2, the 1998 case, represents the operational characteristics of the Washington State Ferries during the study and is used as the case with which to compare the other scenarios. Table 4 shows the % changes in the statistical expected number of collisions per year for the 4 scenarios when compared to scenario 2. The changes between case 1 and 2 and between case 2 and 3, due primarily to the addition of a high-speed ferry, are of interest. The statistical expected number of collisions for the 1997 scenario (scenario 1) was 18% less than that for the 1998 scenario (scenario 2). This difference is primarily due to the addition of the Chinook class ferry to the schedule and its subsequent additional interactions in a high ferry to ferry interaction area.

In scenario 3, the second Chinook replaces the passenger-only vessel assigned in scenario 2 to the Seattle-Bremerton route. Table 4 shows that the total statistical expected number of collisions does not change significantly. However, the expected number of accidents with a 0 to 1 hour MRRT increases by 36%. Thus some proportion of the statistical frequency of collisions with an MRRT of more than 1 hour have been replaced by collisions with a MRRT of less than 1 hour. The replacement of the conventional POV with a high speed ferry will not increase the probability of a collision, but will effect the potential severity of consequences and thus resulted in an increase in risk.

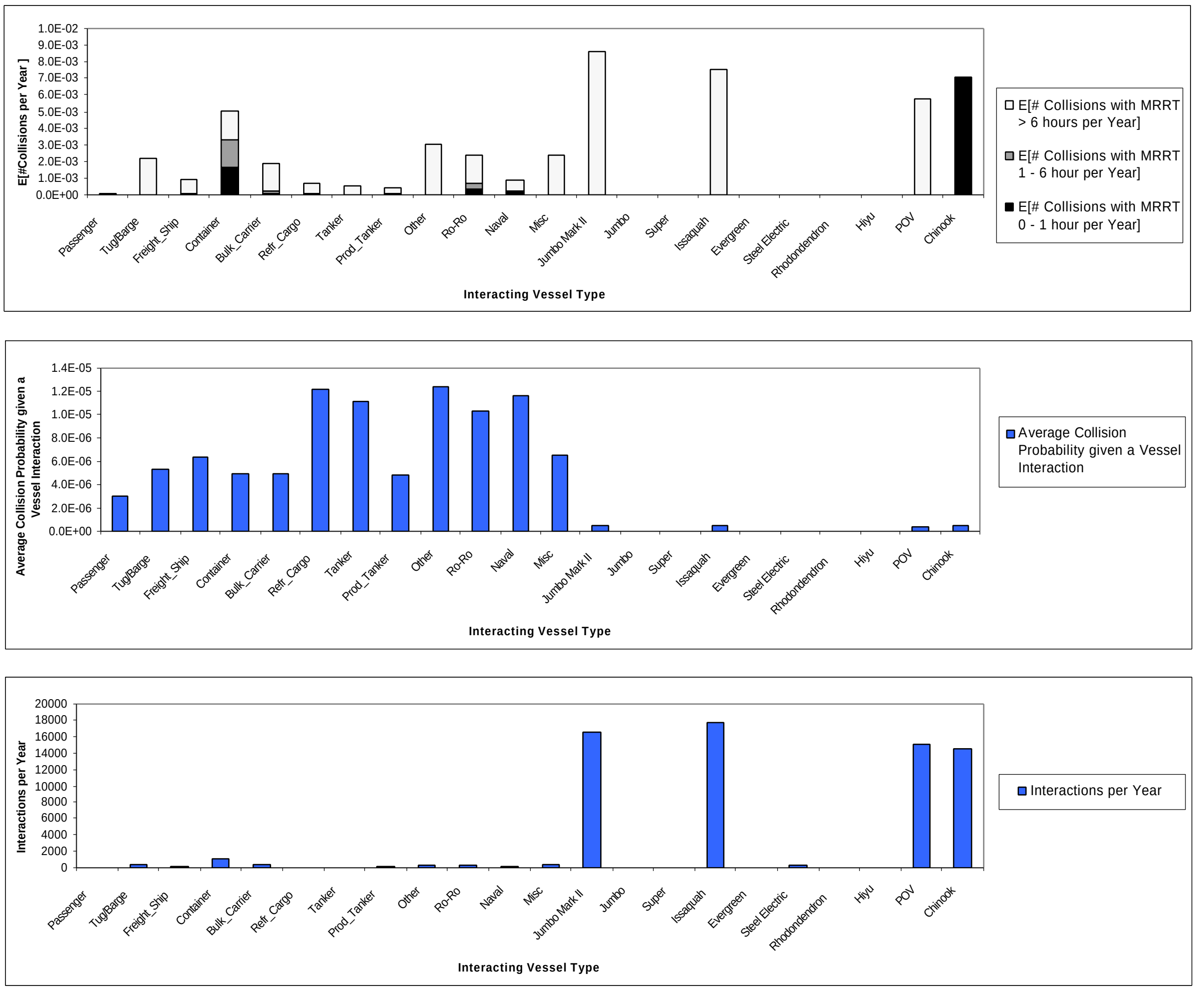
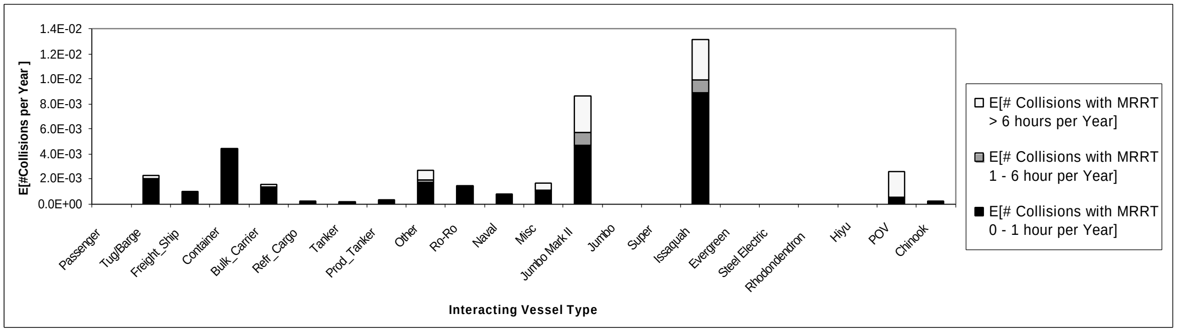
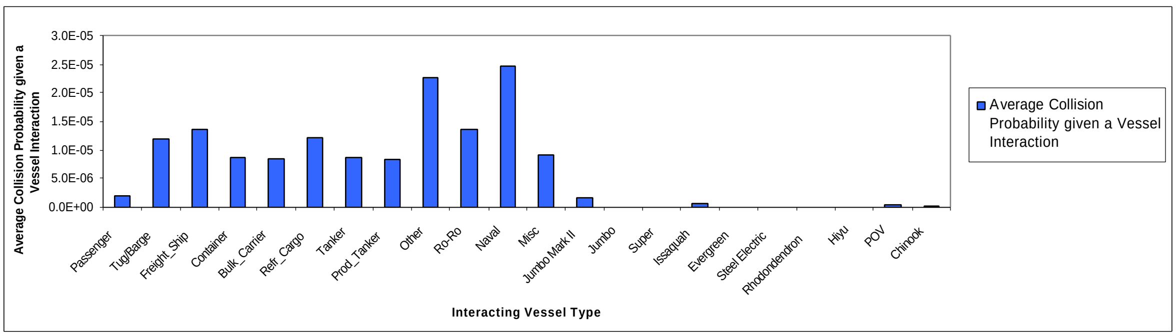


Figure 10. Seattle-Bremerton car ferries – 1998 Scenario (Note: 1.0E-3 is scientific notation for 0.001)





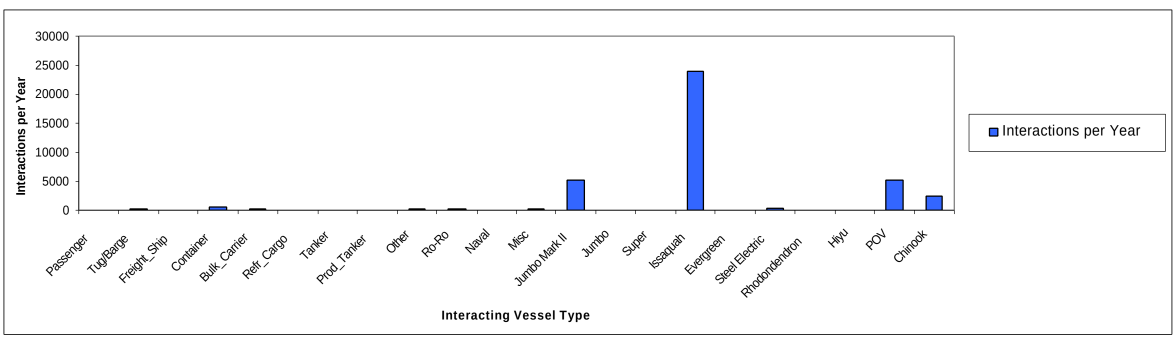


Figure 11. Seattle-Bremerton passenger-only ferries – 1998 Scenario (Note: 1.0E-3 is scientific notation for 0.001)

However, it can be seen from the results for scenario 4 that the fleet-wide introduction of ISM will compensate for the increase in risk caused by the introduction of new technology. ISM may lead to 16% reduction in the total statistical frequency of collisions from scenario 2. Moreover, the increase in statistical frequency of collisions with a MRRT of less than 1 hour is reduced from 36% to less than 14%. From this analysis, it may be concluded that, even with the introduction of an additional high-speed ferry, the implementation of ISM can result in an overall reduction of system collision risk. It should be noted, however, that the above analysis of fleet-wide ISM is based upon the expected reduction of human error related incidents as discussed in Appendix II.

Table 4. A comparison of the 4 scenarios by expected number of collisions

		Statistical Expected Number of Collisions per Year			
	Scenario Desciption	**MRRT 0-1**	**MRRT 1-6**	**MRRT>6**	**TOTAL**
Scenario 1	**No Chinook, No Jumbo Mark II**	0.025	0.016	0.141	**0.182**
Scenario 2	**1 Chinook, 2 Jumbo Mark II**	0.055	0.015	0.152	**0.223**
Scenario 3	**2 Chinook, 2 Jumbo Mark II**	0.075	0.013	0.133	**0.221**
Scenario 4	**2 Chinook, 2 Jumbo Mark II + Fleetwide ISM**	0.063	0.011	0.113	**0.187**

		Percent Change from Scenario 2			
	Scenario Desciption	**MRRT 0-1**	**MRRT 1-6**	**MRRT>6**	**TOTAL**
Scenario 1	**No Chinook, No Jumbo Mark II**	-55.5%	5.7%	-7.2%	**-18.3%**
Scenario 2	**1 Chinook, 2 Jumbo Mark II**	0.0%	0.0%	0.0%	**0.0%**
Scenario 3	**2 Chinook, 2 Jumbo Mark II**	36.4%	-15.1%	-12.9%	**-0.8%**
Scenario 4	**2 Chinook, 2 Jumbo Mark II + Fleetwide ISM**	13.7%	-23.0%	-25.8%	**-15.8%**

		Average Time between Collisions (in Years)			
	Scenario Desciption	**MRRT 0-1**	**MRRT 1-6**	**MRRT>6**	**TOTAL**
Scenario 1	**No Chinook, No Jumbo Mark II**	40.6	63.8	7.1	**5.5**
Scenario 2	**1 Chinook, 2 Jumbo Mark II**	18.1	67.5	6.6	**4.5**
Scenario 3	**2 Chinook, 2 Jumbo Mark II**	13.3	79.5	7.5	**4.5**
Scenario 4	**2 Chinook, 2 Jumbo Mark II + Fleetwide ISM**	15.9	87.6	8.8	**5.3**

4.4 Historical Rates for Allision, Grounding and Fire / Explosion Accidents

The term allision is specific to the maritime area. Specifically, an allision is a collision with the dock, while the term collision is restricted to the striking of two vessels while underway. A grounding is a contact with the shore or bottom. The potential vulnerability to these accidents is determined by the internal factors described above and by factors external to the system, such as high levels of traffic congestion, the emergency coordination and response capabilities of external organizations, and the intentional or unintentional presence of hazardous materials on board.

An allision may occur on any docking of a ferry at a ferry terminal. In the following, a discussion is made of the historical occurrence of allisions examining the ferry classes and ferry terminals involved**.** Since Washington State ferries operate in the deepest waters in the United States, grounding is not a major hazard on most routes. However, the likelihood of grounding is a concern in Rich Passage (Seattle-Bremerton route), at the Keystone Harbor entrance (Port Townsend-Keystone route), and on the San Juan Island routes. The Washington State ferries meet all federal fire prevention and fire control standards. These standards are adequate to ensure a high probability of controlling a "routine" engine room, car deck, or galley fire. However, the ferries are vulnerable to an intentional (e.g. terrorist) or unintentional (e.g. illegal cargo) explosion on the car deck, or to a fire following a collision.

4.4.1 Allision Analysis Results

In the accident data for the period 1988-1998, there were 26 allisions of Washington State ferries. In two cases, the ferry terminal at which the allision occurred could not be determined. The occurrences of allisions over the period were categorized by the class of ferry involved and the ferry terminal at which it occurred. However, making specific conclusions regarding the allision risk for ferry terminal/class combinations is misleading. If a particular ferry class docks at a particular ferry terminal a large number of times then the number of allisions will be higher than for smaller numbers of dockings. Thus we must normalize this allision data by dividing by the number of dockings made in this period. The number of dockings was counted in the simulation.

Figure 12 shows the accidents per docking statistic for each ferry terminal and ferry class. It can be seen in figure 12 that the highest allision per docking rate are in order.

- Issaquah class ferries at Orcas terminal
- Steel Electric class ferries at Lopez terminal
- Super class ferries at Anacortes terminal
- Passenger-only ferries at Vashon terminal
- Passenger-only ferries at Seattle terminal
- Issaquah class ferries at Bremerton terminal
- Steel Electric class ferries at Keystone terminal

It should be noted that the overall allision per docking is in the order of 1 in every 90,000 dockings and the highest rate for Issaquah class ferries at Orcas terminal is in the order of 1 in every 2500 dockings. Although allisions do not have a high potential for serious injury or death, they are indicators of potential mechanical and human failures that could cause more serious accidents. All allisions should, therefore, be carefully examined and their causes corrected.

4.4.2 Grounding Analysis Results

In the accident data for the period 1988-1998, there were 6 groundings of Washington State ferries. 2 groundings occurred in the San Juan Islands (specifically Elwha Rock and Cattle Pass), 2 groundings occurred at Keystone Harbor, 1 grounding occurred in Rich Passage and 1 occurred at Vashon Island.

There are only certain geographical areas in the study area in which grounding accidents may occur. Groundings have occurred in each of these areas, referred to henceforth as grounding zones. However, we must, once again, be careful to normalize the grounding accidents.

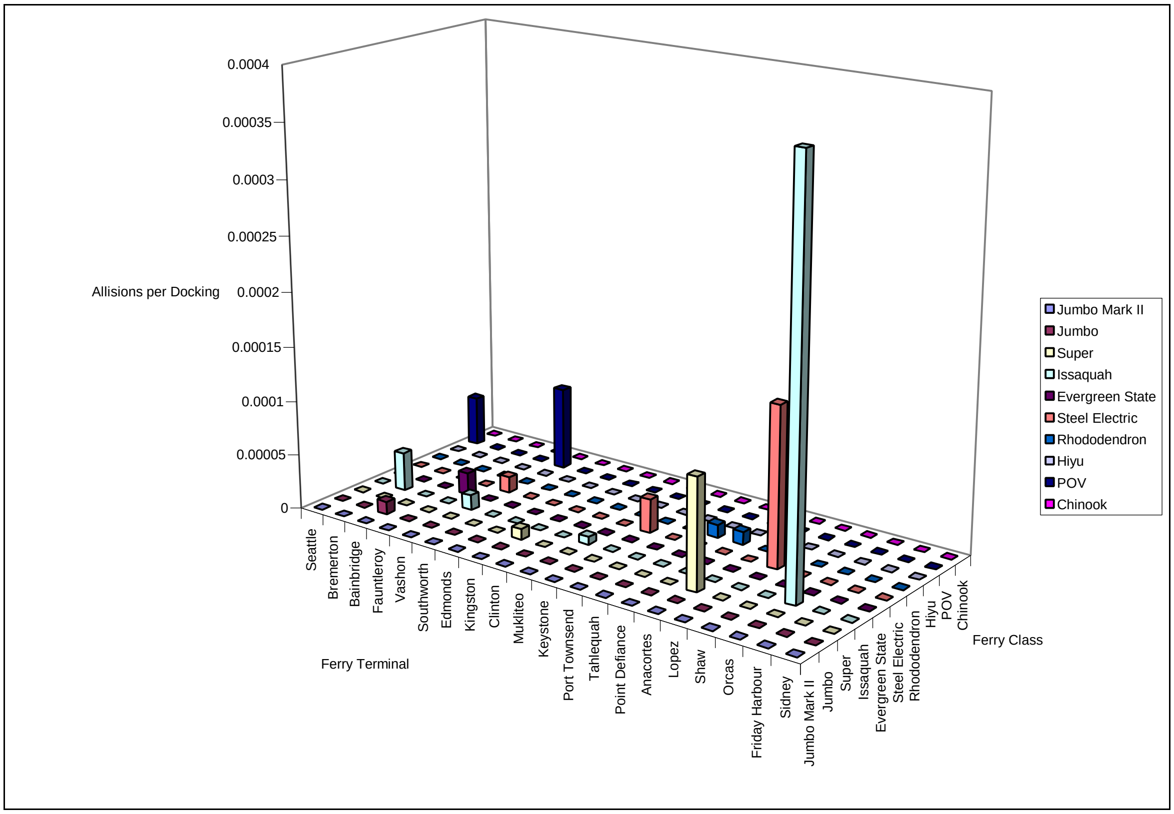


Figure 12. Allisions per docking by ferry terminal and ferry class

There will be more grounding accidents in a particular grounding zone if the ferries transit that area more frequently. Thus the time spent in each grounding zone was counted in the simulation and the grounding rate per hour calculated. The grounding rates, are in order, 0.00037 per transit hour in the Keystone grounding zone, 0.000056 per transit hour in the San Juan Islands grounding zones, 0.000026 per transit hour in the Vashon Island grounding zone and the 0.000019 per transit hour in Rich Passage.

The total rate of groundings per operational hour spent in these grounding zones is 1 in every 22,000 operational hours. It is apparent that the entry into the terminal at Keystone leads to the highest grounding risk. The strong currents in Admiralty Bay make this approach difficult, leading to the high grounding rate. The strong tidal forces were listed as the primary cause for the two grounding accidents that occurred in the period 1988-1998. Washington State Ferries are aware of this problem and efforts are underway to improve the design of the terminal and improve operating procedures.

4.4.3 Fire/Explosion Analysis Results

In the accident data for the period 1988-1998, there were 9 fires/explosions on the Washington State ferries. Of these 9, 2 occurred on Evergreen State class ferries and 3 on the Issaquah class ferries. The other 4 occurred, one each, on the Hiyu, Jumbo, Steel Electric and Super class ferries. It should be noted that the single fire on the Super class ferry was actually on a motor home on board the ferry.

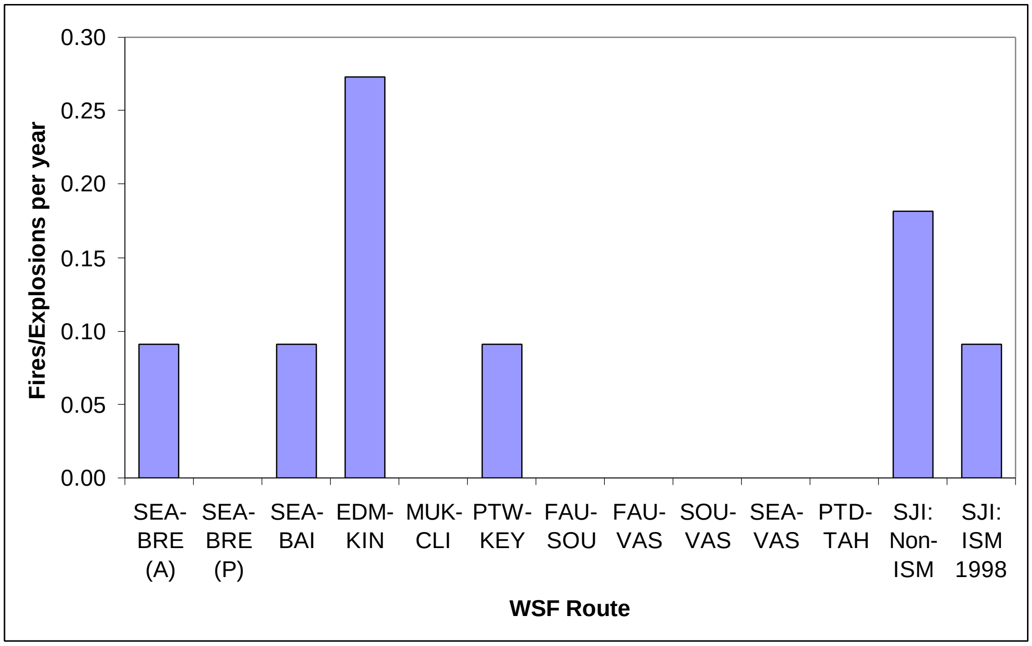


Figure 13. Fires/Explosions accidents per year by ferry route.

Of interest is the distribution of the occurrence of fires and explosions across the ferry routes. Figure 13 shows the historical rate of fires/explosions per year by ferry route. It can be seen that the most fires/explosions have occurred on the Edmonds-Kingston route and then the San Juan Islands routes.

Examining the fire/explosion rate per transit hour for the various ferry classes, the higher rates are observed on the Evergreen State class and the Hiyu. The two occurrences on the Evergreen State class were crank case explosions, while the single occurrence on the Hiyu was an electrical fire. Although the highest number of events was on the Issaquah class ferries, this is also the most highly used class.

4.5 Comparison of the Level of Safety to other Transportation Modes

The process of comparing accident rates is difficult and sometimes misleading since the selection of how rates are expressed determines the relative ranking. For example, when comparing transportation modes air travel is by far the safest when the comparison is made using accidents per mile traveled or per trip as the basis for ranking, but is presented as less safe when ranked according to accidents per hour traveled. The range of accidents included also drives the comparison— does comparisons include all accidents, accidents above a certain damage threshold, accidents with fatalities, accidents with more than 10 fatalities, etc.

Taking these caveats into account, the WSF historical record may be compared to other transportation modes. The Washington State Ferry system experienced 46 accidents (26 allisions, 4 collisions, 9 fires, 1 flooding and 6 groundings) during the 11 year period 1988-1998. None of these accidents involved a fatality. Only 27 of these accidents caused damage to a ferry or injury to a passenger (10 allisions, 2 collisions, 9 fires and 6 groundings) for an accident rate of 2.5 accidents/year. The total mileage traveled by the ferry system in one year is 1.4 million miles and the total number of annual transits is 167,000 transits (counting segments of routes as transits). The overall historical accident rate may therefore be expressed as shown in Table 5. Table 5 and shows that the WSF system level of safety is about half that of the historical record of commercial rail of 3.6 accidents per million miles traveled. When computed on an accident per mile basis, planes, however, are approximately 1,000 times less likely to have an accident than are trains and ferries. However, when an aircraft accident does occur its consequences are almost always fatal. The likelihood of an accident resulting in mass casualties in the rail or maritime domains is significantly less than it is for aviation.

Table 5. Accident Rates
All Accidents/Accidents with Significant Property Loss, Injury, or Death

Type of accident	Rate per year	Rate per Million Transits	Rate per million miles
Collision	0.18	1	0.1
Grounding	0.55	3.2	0.4
Allision	0.90	5	0.64
Fire	0.81	4.8	0.59
Flooding	.09	0.53	0.064
Total	2.5	14.5	1.8

The historical accident rates experience by the WSF are also consistent with the International Maritime Organization's stated acceptable level for major accidents (those which produce injuries or deaths) of approximately 1 accident per 100,000 operating transits (for transits times on the order of one hour).

4.6 Results from Evaluation of Risk Reduction Measures

4.6.1 Organization of Risk Reduction Measures

The objective of risk management is to choose cost effective risk interventions that impact all areas of the accident event chain. The project team collected risk reduction measures that have been proposed for this system and for other maritime systems, structured the measures, and evaluated the measures. The structuring and evaluation of risk management alternatives was based on a three step process.

1. The first step was to identify risk reduction interventions for each category of intervention shown in figure 3, earlier in the report. Table 6 shows the 40 potential risk reduction measures identified by the project team, their source, and their area of impact in the accident event chain. The sources of these measures were: interviews with ferry

system and Coast Guard personnel, the IMO High Speed Ferry Formal Safety Assessment for the United Kingdom, The Prince William Sound Risk Assessment, The Volpe Center Preliminary Risk Study of Puget Sound and the Strait of Juan de Fuca, and alternatives specified in 46 CFR Subchapter W.

2. The second step was to identify the functional area or organization responsible for implementing each potential risk intervention. The nine functional areas identified and the organizational elements responsible for their implementation are indicated below. The third column of Table 6 shows the 40 risk reduction interventions grouped in these functional categories.
   A. Safety Management– 1 measure (ferry system operations and engineering)
   B. Training and human resource policy and procedures– 6 measures (WSF operations and human resources)
   C. Ferry system operational policies, rules, and procedures– 6 measures (WSF operations)
   D. Ferry system maintenance policies, rules, and procedures– 3 measures (WSF engineering)
   E. Waterways management– 5 measures (USCG VTS, MSO)
   F. Information management– 3 measures (Ferry system operations, USCG, NOAA)
   G. Ferry system technological systems and equipment –8 measures (WSF engineering and operations)
   H. Ferry system emergency preparedness and response– 5 measures (WSF operations and engineering)
   I. External emergency response preparedness– 3 measures (USCG and other emergency response organizations)

3. The information in Table 6 was used to produce eight categories of measures grouped by their intended impact. These eight categories and the measures in each category are shown in Table 7 and have been evaluated for their effect on the statistical total frequency of collisions and on the frequency of collisions in each of the maximum required response time categories. Note that some measures appear in more than one risk reduction category.

Table 6. Potential Risk Reduction Interventions

Description of Interventions and objectives	Function	Impact
1. Expand ISM to entire fleet to reduce human and organizational errors and mechanical failures; to improve preparedness for and response to emergencies	Safety Mgt.	Reduce accident probability Reduce consequences
2. Evaluate STCW and WAC personnel standards for tankers and tank barge personnel to ferries (work hours, rest hours, training, orientation, record keeping)	Training & HR policy	Reduce accident probability
3. Increase watchstander and bridge team training to reduce human error, increase error capture. (including simulator training)	Training & HR policy	Reduce accident probability

4. Improve crew scheduling to improve bridge team and crew stability, to reduce fatigue, vessel familiarity, improve response	Training & HR policy	Reduce accident probability Reduce consequences
5. Improve selection, training, and orientation for new crew members	Training & HR policy	Reduce accident probability
6. Provide stringent selection and qualification, certification and re qualification standards for high speed ferries	Training & HR policy	Reduce accident probability
7. Create information infrastructure that facilitates communication of safety critical information	Information Management	Reduce accident probability
8. Standardize bridge layout and control systems	WSF Tech. Systems	Reduce accident probability
9. Provide distinctive lights and sounds to identify HSF	WSF Tech. Systems	Reduce accident probability
10. Review of traffic management procedures for High Speed Ferries with USCG VTS and Puget Sound Pilots	Waterways Management	Reduce accident probability
11. Increase vessel reliability through improved inspection and preventive maintenance, particularly safety critical systems	WSF maintenance Policy	Reduce accident probability
12. Provide adequate standby resources to increase availability of maintenance time	WSF maint. Policy	Reduce accident probability
13. Improve forecast and transmission of weather, visibility information	Information Management	Reduce accident probability
14. Implement "no blame" incident reporting system	WSF operations	Reduce accident probability
15. Increase vessel bridge team during periods of severe weather or reduced visibility	WSF operations	Reduce accident probability
16. Restrict ferry transits during high wind and/or low visibility conditions	WSF operations	Reduce accident probability
17. Establish Regulated Navigational area in Rich Passage to manage small boat traffic	Waterways Management	Reduce accident probability
18. Manage ferry traffic movement in Rich Passage, Elliott Bay, San Juan Islands during high traffic congestion periods.	Waterways Management	Reduce accident probability
19. Provide traffic lanes and approach controls for High Speed Ferries	Waterways Management	Reduce accident probability
20. Increase redundancy of safety critical systems	WSF Tech. Systems	Reduce accident probability
21. Establish Regulated Navigation Areas with speed controls crossing Ferry Routes	Waterways Management	Reduce accident probability Reduce consequences
22. Retrofit to improve compartmentation on selected ferry classes	WSF Tech. Systems	Reduce consequences
23. Identify critical openings, fittings and spaces and fit alarms	WSF Tech. Systems	Reduce consequences
24. Provide appropriate structural inspections of older auto ferries	WSF maint. Policy	Reduce consequences
25. Improve procedures for checking and inspecting vehicles for hazardous materials	WSF operations	Reduce consequences
26. Improve procedures for counting embarking passengers	WSF operations	Reduce consequences

27. Provide seat belts for passengers on HSF	WSF operations	Reduce consequences
28. Improve ability of master to be aware of damage and vessel behavior	Information Management	Reduce consequences
29. Improve survivability of passenger ferries by providing a second line of defense to hull breach (e.g. foam or air bags)	WSF Tech. Systems	Reduce consequences
30. Improve Fire Suppression systems on car deck and in engine room on auto ferries	WSF Tech. Systems	Reduce consequences
31. Provide adequate time for vessel drills and exercises, monitor exercise reports, verify adequacy of drills	WSF emerg. Preparedness	Reduce consequences
32. Improve instructions and signage and methods of informing and mobilizing passengers	WSF emerg. Preparedness	Reduce consequences
33. Improve evacuation procedures for evacuation to other ferries, other vessels, IBAs.	WSF emerg. Preparedness	Reduce consequences
34. Improve ability to account for and communicate with passengers during emergency	WSF emerg. Preparedness	Reduce consequences
35. Provide proficiency fire fighting training	Training & HR policy	Reduce consequences
36. Improve on board emergency response and evacuation through better plans and exercises	WSF emerg. preparedness	Reduce consequences
37. Provide adequate survival craft to meet Subchapter W requirements	WSF Tech. Systems	Reduce consequences
38. Develop joint contingency and response plans with USCG, Police, Fire, Rescue organizations including commercial tug operators	External Emergency preparedness	Reduce consequences
39. Coordinate external fire and rescue and assistance though table top and full scale exercises including commercial tug operators and the international tug of opportunity system (ITOS)	External Emergency preparedness	Reduce consequences
40. Improve coordination with emergency medical support	Ext. Emerg Preparedness	Reduce consequences

Table 7: Summary of Interventions Tested

Risk Reduction Case	Applicable Measures	Intervention	Assumed impact
1.	1	Adopt ISM fleet wide	Reduce human error incidents by 30% Reduce mechanical failures by 3.7% Reduce consequences by 10%
2.	2,3,4,5,6,7 8,9,12,14,15	Implement all human error reduction measures fleet wide	Reduce Human error incidents by 33.7%
3.	1,2,5,7,11 12,13,20, 24	Implement all mechanical failure reduction measures fleet wide	Reduce mechanical failure incidents by 50%
4.	10,19	Implement high speed ferry rules and procedures	Reduce Human Error Incidents on High Speed Ferries by 30%, Reduce Mechanical Failure Incidents on High Speed Ferries by 3.7%

5.	13,16	Implement weather, visibility restrictions	Reduce the interactions with other vessels in bad visibility conditions by 10%
6.	17,18	Implement Traffic Separation for High Speed Ferries	Reduce Interactions with High Speed Ferries within one mile by 50%
7.	21	Implement Traffic Control for Deep Draft Traffic	Set Maximum Allowable Traveling Speed in Admiral Inlet, North Puget Sound, Central Puget Sound, South Puget Sound at 15 knots.
8.	22,23,25, 27,30,37	Increase time available for response	Allocate 50% of the Collisions in the MRRT 1-6 hour Category to the MRRT > 6 hour Category

4.6.2 Results of Risk Reduction Intervention Classes

The 8 intervention classes described in Table 7 reduce accident probabilities and/or consequences by intervening in the causal chain as shown in Figure 14. All cases were tested, as described in Appendix II; to evaluate their effect on the statistical total frequency of collisions and on the statistical frequency of collisions in each of the maximum required response time categories. The measures were evaluated for their impact on reducing the total statistical frequencies of collisions, and the statistical frequency of collisions in each of the three MRRT sub classes. The consequence reducing impact of improving response effectiveness was not tested. Case 1, ISM, and case 2, human error reduction, differ only in that ISM also provides consequence reduction. Many of the measures in case 3 are subsumed in ISM.

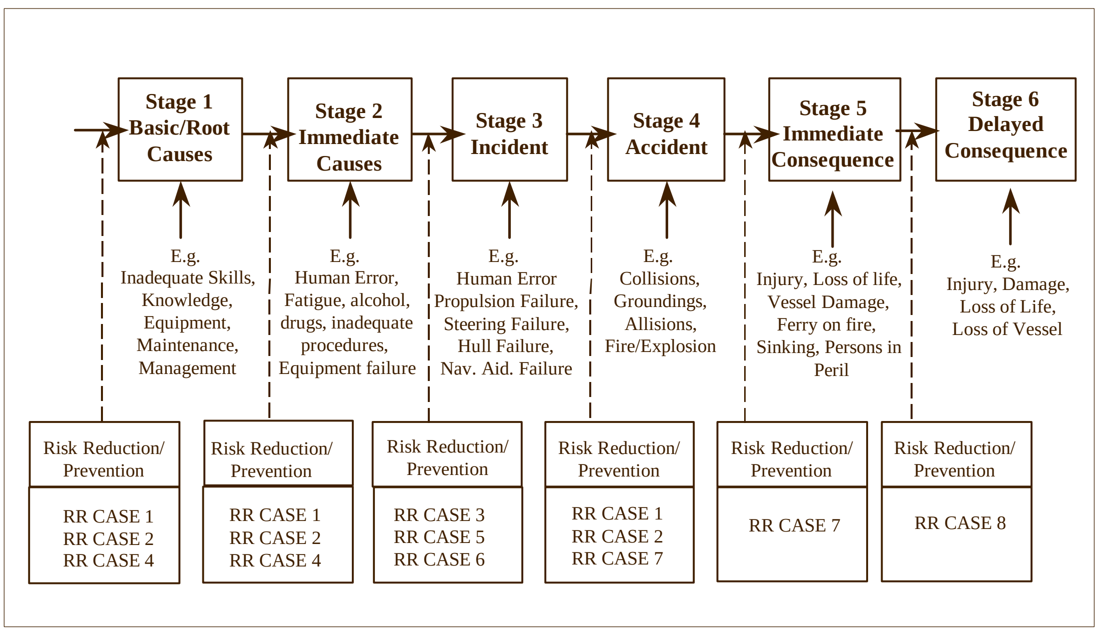


Figure 14. Impact of Risk Reduction Cases

Figure 15 shows the impact that each case would have on the baseline statistical frequency of collisions (1998 case or scenario 2) and on the impact of each collision subgroup (defined by maximum required response time).

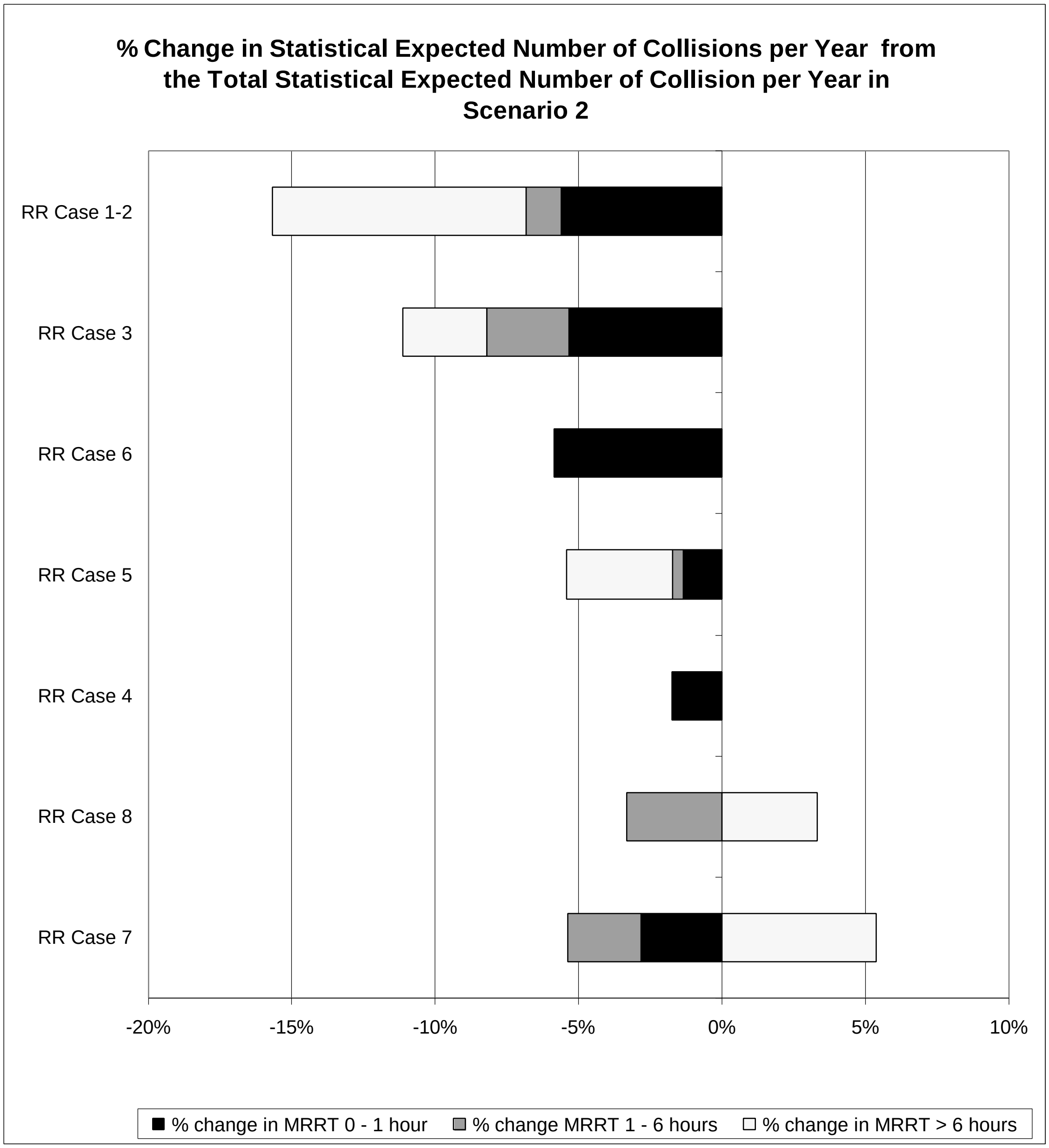


Figure 15. The Estimated Risk Reduction for the 8 Cases Tested.
(0% Corresponds to base case risk of 0.223 collisions/year or 1 collision every 4.5 years)

ISM fleet-wide implementation reduces the total statistical frequency of collisions by 16% and provides a proportionate reduction in the statistical frequency of most severe collisions, i.e. those requiring a response time of less than one hour. A 50% reduction in mechanical failures will result in an 11% reduction in statistical frequency of collisions. Risk reduction measure 6, the implementation of traffic separation rules and procedures for high-speed ferries, provides substantial reduction in the expected frequency of severe consequence collisions. Cases 5 indicates potential gains from waterways and route management by the U.S. Coast Guard and the Washington State Ferries. Case 4 indicated the benefits of rules and procedures similar to ISM on the high speed ferry only, resulting in a reduction in collisions requiring an immediate response. Case 8 models the effect of the addition of survival craft in terms of response time. As can be seen from figure 14, the impact of this intervention does not change the expected number of collisions. Survival craft buy time for response. As shown in Figure 15, the presence of survival craft changes the distribution of the total statistical frequency of collisions over the three maximum required response time categories; there is no change in the total frequency of collisions. The same holds for Case 7, where deep drafts vessel are restricted to travel at a speed less than 15 knots resulting in less severe damage penetrations in the event of a collision.

Implementing risk reduction measures is a trade off. The cost of implementing ISM fleet wide is $1.8 million and the annual cost is approximately $750,000. The cost of equipping all auto ferries with adequate survival craft has been estimated by the Washington State Ferries as approximately $4 million initial cost and $1 million a year (primarily in additional crew costs). Other costs are difficult to estimate. As discussed in Appendix I, the implementation of transit restrictions during periods of low visibility may result in service losses. All the waterway management interventions could result in longer transits and other delays.

4.7 Uncertainty in Risk Assessment

The rigorous analysis of the WSF Risk Assessment provides the basis both for determining that the system is currently operated in a safe manner as compared to other transportation modes and for identifying how the risk in the system could be reduced to even lower levels. The findings of a quantitative study must be interpreted with care, however, as uncertainty is introduced at various level of the analysis. Sources of this uncertainty include incomplete and/or inaccurate data, biased or uninformed expert judgment, modeling error, and computational error. Testing for the level of uncertainty in an analysis requires accounting for both parameter uncertainty and model uncertainty and their impact on the results and conclusions. This is referred to as an uncertainty analysis.

While the use of proper procedures such as rigorous data selection and cross validation, structured and proven elicitation methods for expert judgment, and use of accepted models, can reduce uncertainty and bias in an analysis, it can never be fully eliminated. The reader should recognize that the value of an analysis is not in the precision of the results per se, but rather in the understanding of the system through the identification of peaks, patterns, unusual circumstances, and trends in system risk and changes in system risk through risk mitigation measure implementation.

The methodology in this study has been reviewed for rigor and tested in operational settings. The methodology thus provides many safeguards to remove bias and to detect error. Although a formal uncertainty analysis has not been presented within these results, sensitivity of some of the more contentious modeling assumptions have been tested, specifically those involving high speed ferry collision MRRT classifications and those involving the damage model. Appendix II discusses the results of these sensitivity cases and shows that the results reported are robust, i.e. calculated results remain relatively stable, varying within an order of magnitude when modeling assumptions are changed.

APPENDIX I: HISTORICAL DATA ANALYSIS RESULTS.

This appendix is contained in a separate document. A copy of this document may be requested from the Washington State Transportation Commission.

APPENDIX II: RESULTS FROM COLLISON, ALLISION, GROUNDING AND FIRE/EXPLOSION ANALYSIS RISK MODELS.

This appendix is contained in a separate document. A copy of this document may be requested from the Washington State Transportation Commission.

APPENDIX III: DETAILED DISCUSSION OF MODELING METHODOLOGY AND ASSUMPTIONS.

This appendix is contained in a separate document. A copy of this document may be requested from the Washington State Transportation Commission.