Contingency, Emergency, Crisis, and Disaster Management: Defining the Agenda for the Third Millenium
Proceedings: Sixth Annual Conference of The Emergency Management Society
Giampiero E.G. Beroggi, Editor

Assessing Risk in the Washington State Ferry System

John R. Harrald
Institute for Crisis, Disaster and Risk Management
The George Washington University
Washington, D.C. 20052
harrald@seas.gwu.edu
Martha Grabowski
Rensselaer Polytechnic Institute
Rene Van Dorp
The George Washington University
Jason Merrick
Virginia Commonwealth University

Abstract
The State of Washington operates the largest passenger vessel ferry system in the United States. The probability of accidents (collisions, groundings, allisions, fires and explosions) in this system was assessed using a dynamic simulation methodology that extends the scope of available data with expert judgment. The potential consequences of collisions were modeled in order to determine the requirements for on board and external emergency response procedures and equipment. The system simulation was used to evaluated potential risk reduction measures. Detailed risk management recommendations have been developed and provided to the Washington State Ferry System and to the Washington State Transportation Commission

Keywords: Risk assessment, risk management, simulation, maritime safety

1. Introduction

The Washington State Ferry system is the largest ferry system in the United States. In 1997, total ridership for the ferries serving the central Puget Sound region was nearly 23 million, a 4 percent increase over 1996 ridership, and more passengers than Amtrak handles in a year. The region's 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).

The State of Washington put the current ferry system in place in 1951 to connect King and Snohomish counties with Kitsap County, saving travelers the long drive around Puget Sound via the Tacoma Narrows Bridge, and to provide mainland access to Vashon Island and Whidbey Island. Figure 1 shows the ferry routes for the central Puget Sound region. This map illustrates the ferry system's role in linking together the Washington State highway system in the Puget Sound region (Puget Sound Regional Council, 1998).

In 1997, the Bainbridge Island-Seattle route carried the most riders by far with almost 6.9 million riders (30% of the Puget Sound total). The Mukilteo-Clinton route was next with 4.4 million (19%), followed by Edmonds-Kingston with 4.3 million (19%), Fauntleroy-Vashon-Southworth with 3.3 million (15%), Bremerton-Seattle with 2.5 million (11%) and Pt. Defiance-Tahlequah with 830,000 (4%). The Seattle-Bremerton passenger-only boats, in place since 1986, carried 285,000 riders, while the Seattle-Vashon passenger-only boats, running since 1990, carried 281,000.

Figure 1
Washington State Ferry System Map

The State of Washington established an independent Blue Ribbon Panel to assess the adequacy of requirements for passenger and crew safety aboard the Washington State Ferries. On July 9, 1998, the Blue Ribbon Panel engaged a consultant team from The George Washington University and Rensselaer Polytechnic Institute/Le Moyne College to assess the adequacy of passenger and crew safety in the Washington State Ferry system, 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.

This paper provides a description of the project team's approach, results, and recommendations. In addition, this status report provides discussion of four additional topics:

- fundamental changes occurring in and around the Washington State Ferry system, which are occasioning new organizational, technical, and management requirements,
- the impact of these changes on the level of safety in the WSF system,
- the methodologies used to assess risk and to evaluate risk reduction interventions, and
- the resulting requirements for the system.

2. Risk Assessment

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* (National Research Council, 1996; p. 27).

Risk assessment products and processes 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.

3. Risk Factors in the Washington State Ferry System

Risk propensity in large scale systems has its roots in a number of factors. One cause of risk is that the activities performed in the system are inherently risky (e.g. mining, manufacturing, airline transportation); another is that the technology is inherently risky, or exacerbates risks in the system (e.g. heavy equipment, locomotives, and cables). Yet a third cause is that the individuals and organizations executing tasks, using technology, or coordinating both can propagate human and organizational errors. In addition, organizational structures may unintentionally encourage risky practices (e.g. lack of formal safety reporting systems or departments 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 (Grabowski & Roberts, 1996; 1997).

Several factors that contribute to risk propensity in large scale systems are present in the Washington State Ferry system. Tasks in the WSF system—navigation, vessel loading, arrivals and departures--are distributed across a large geographical area, are time-critical, and contain elements of embedded risk (vessel navigation in congested waters, in reduced visibility, carrying passengers on time-critical schedules). The technology used in the system—vessels, equipment, 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, the Washington State Ferry organizational culture can send confusing or contradictory messages to members about risk tolerance in the system (e.g., safety bulletins that celebrate the number of accident free days while the organization's collective bargaining agreements define crew schedules and rotations which require operators to work 12 hour engineering watches or back-to-back deck watches).

Characterizing risk in the WSF system presents some challenges. First, because the WSF system is a distributed system, risk in the system can migrate, making risk identification and mitigation difficult. Second, because the WSF system is a large scale system with complex interactions between its members, incidents and accidents in the system may have long incubation periods, making risk analysis and identification of leading error chains difficult. Third, because the WSF system is comprised of members with their own individual goals, policies, and cultures--ashore, aboard ship, in the shipyard--developing a shared culture of reliability and shared commitments to reliability goals can be difficult. These risk factors make risk characterization in the WSF system challenging, and also provide important clues about effective risk mitigation in the WSF system.

Accident types that are a potential threat to the WS ferries include *collisions*, *fire/explosion*, *allisions*, and *groundings*. 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.

Increasing traffic congestion in Elliott Bay (Seattle Harbor) and summer-time traffic in Friday Harbor (in the San Juan Islands, a popular vacation destination) increases the potential risk of collision. Car ferries are designed to survive most potential collisions and the probability of a collision of a ferry with a vessel crossing the shipping lanes is low. However, a few collision scenarios involving certain classes of car ferries and large, fast vessels, and almost all scenarios involving passenger-only ferries could result in potentially catastrophic consequences.

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.

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 risk modeling and statistical analysis currently in progress will provide quantitative estimates of risk for each of the areas of vulnerability described above and will provide estimates of magnitude for the internal and external causal factors described.

4. Changes that will affect risk in the Washington State Ferry System

The WSF system is facing a number of important changes. First, its regulatory environment**,** which has been relatively inactive, has changed significantly with the implementation of 46CFR 199 (Subchapter W). The WSF system is required by these regulations to address the response to catastrophic accidents and the requirements for ensuring that passengers could survive such accidents. Specifically, the regulations will require the WSF system, within five years, either to equip all 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. A major objective of this Washington State Ferry risk assessment, therefore, to assist in determining the most effective method of complying with this regulatory directive. In addition, the International Maritime Organization (IMO) has enacted implementation of the Standards for Training and Certification of Watchkeeping (STCW) for all vessels above 200 GT and has begun the process of developing a High Speed Code for vessels. To date the WSF has been exempt from STCW requirements and is in full compliance with all prevention regulations. The focus on high speed ferries could change this status.

A second set of changes in the Washington State Ferry system stem from pressures to develop a seamless, intermodal transportation system in Washington State, and simultaneous increases in the volume and mix of riders on the ferries. Because increasing numbers of Washington State residents are riding the ferries to work, and because connections to other transportation modes (bus, bicycle, car) from the ferries are critical to the success of such an intermodal system, the WSF system is being pressured to perform in ways different from those of the past, to measure and report its performance in different ways, and to increase the fluidity with which connections to other transportation modes are made from the ferries.

A third set of changes in the Washington State Ferry system stems from new technology being introduced into the system to address some pressures for faster transport—passenger only ferries. These new technologies are being introduced into an aging fleet, with some consideration given for how best to mix new and old vessels, new and old technology, new and old operational dynamics, and varying degrees of sophisticated automation.

5. A Framework for Risk Assessment

Risk may be defined as the probability of an unwanted event times the impact of that event. In this study, the unwanted outcome is an accident (a collision, fire, explosion, foundering, grounding, or allision) involving a Washington State ferry. The potential impacts may include deaths, injuries, and economic losses that occur as an immediate or delayed consequence of an accident. In order to reduce risk, we must understand the events and situations that could lead to such an accident and/or exacerbate the consequences of an accident. Figure 2 shows the maritime risk taxonomy used by the study team and illustrates the importance of organizational and situational factors in both the occurrence and severity of an accident.

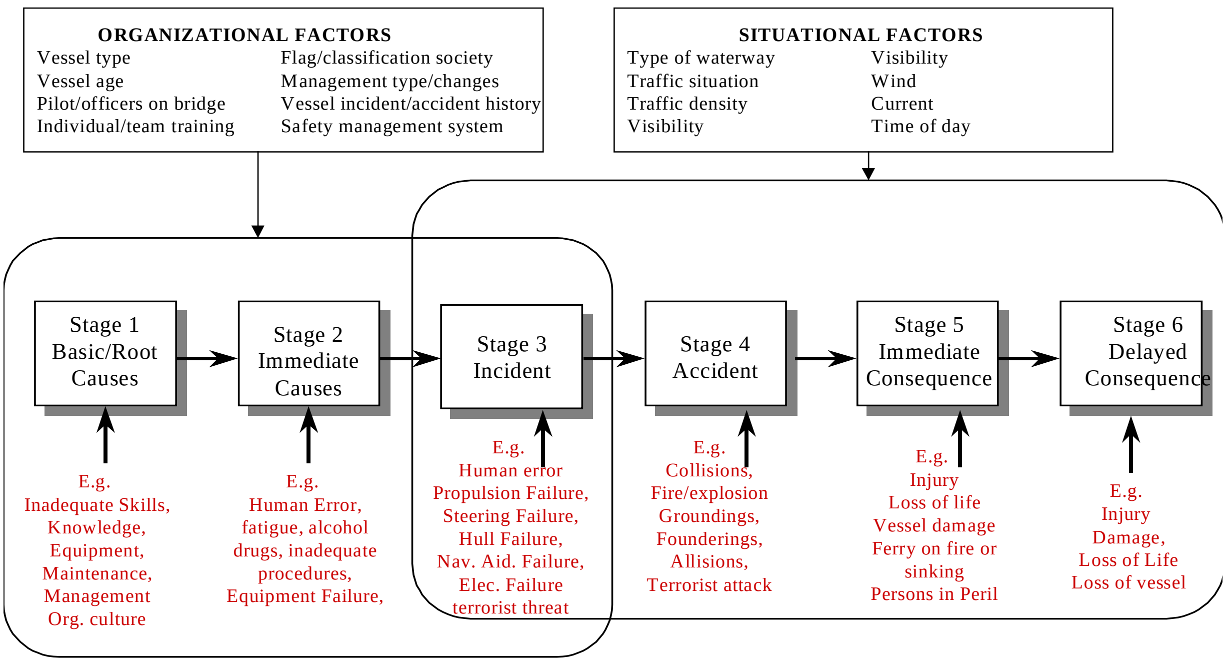


Figure 2
The Accident Event Chain.

In the Washington State Ferry Risk Assessment, the average likelihood of system events was estimated using historical data and expert judgment. A data base containing ten years of incident, accident, and transit data for Puget Sound and the inland waters of the State of Washington was been created for this project using USCG, State of Washington, Marine Exchange, Corps of Engineers, and Ferry system data. These data allow a performance assessment of waterway users in Puget Sound, and comparison of the WSF system with the performance of other waterway users and provide insight into the nature of risk in the system. The situational and organizational factors that influence the probability of occurrence of events in the causal chain lead to dynamic fluctuations in system risk. Modeling the system requires extensive collection of traffic and situational data.

6. Risk Management

The objective of risk management is to take actions and implement policies and procedures that reduce the threat to life, property, and the environment posed by hazards. The structuring and evaluation of risk management alternatives is based on a two step process. The first step is to identify risk reduction interventions based on the accident event chain shown in Figure 2. This results in four classes of interventions intended to reduce the likelihood of occurrence of accidents, and two classes of intervention that reduce the consequences of accidents that do occur.

7. Steps in the WSF Risk Assessment

The Washington State Ferry Risk Assessment project was comprised of seven primary tasks:

1) Examining and assessing the performance of the Washington State Ferry system,
2) Developing a series of models and a simulation that represent the system,
3) Assessing the potential survivability and stability of each ferry class under feasible collision and fire scenarios,
4) Evaluating emergency plans and procedures of the Washington State Ferry system and other organizations (e.g. the U.S. Coast Guard) with responsibility for responding to an emergency involving a Washington State ferry,
5) Determining baseline levels of risk in the system through use of the models and simulation,
6) Articulating prioritized risk reduction measures designed to improve safety in the Washington State Ferry system, and
7) Presenting a set of risk management recommendations to enhance safety in the Washington State Ferry system.

A description of the critical modeling tasks is contained in the following section.

Developing Models and Simulations of the System The situational and organizational factors that influence the probability of occurrence of events in the causal chain lead dynamic fluctuations in system risk.. Identifying how and when these risk spikes occur is a fundamental objective of the use of dynamic system simulation as a risk assessment methodology. The simulation is used to count the occurrence of unique system states (or opportunities for incidents, OFI) as shown in Figure 4. Conditional probabilities are calculated from available data and expert judgment. Detailed pair wise comparison based expert elicitation sessions were conducted with WSF system masters and mates, Puget Sound Pilots, and US Coast Guard Vessel Traffic System watchstanders. The results of these sessions were used to construct a data base that allowed the calculation of conditional probabilities using a regression model.

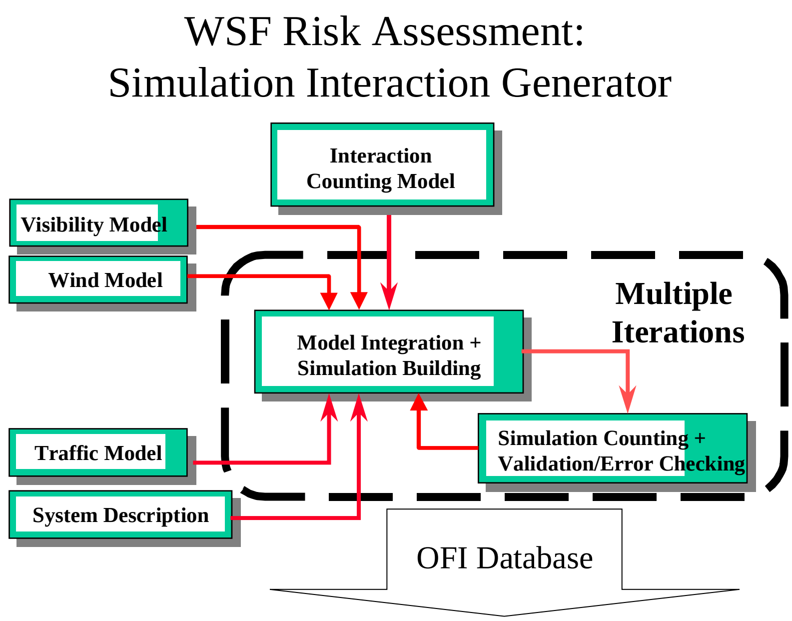


Figure 4

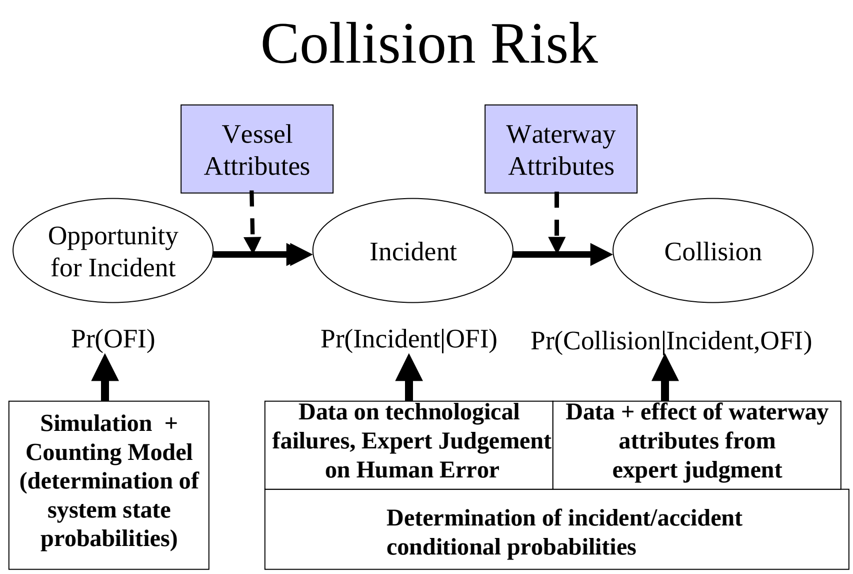
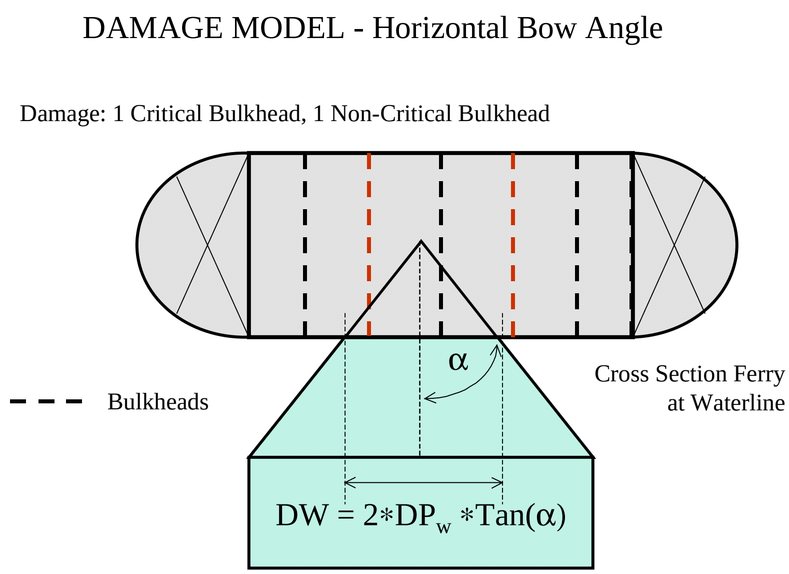


Figure 5

Assessing Ferry Survivability and Stability: Detailed collision models have been developed to model the impact of collisions of each ferry class with different potential colliding vessels, colliding speeds, and impact locations. Figure 6 illustrate the importance of location of impact, angle of impact, and horizontal bow angle in these calculations.

Figure 6



Determining Baseline Levels of Risk: The baseline level of risk was determined by estimating the likelihood of accidents based on the system simulation and on the analysis of data. The potential consequences of accidents was estimated based on historical data and the results of the structural analysis completed in task 3. These detailed results have not been cleared by the project sponsors and are not available for publication in this Proceedings Paper. They will, however, be presented at the TIEMS conference.

8. General Conclusions

Although specific findings have not been cleared by the project sponsor, the findings all support the following general conclusions.

An accident involving a Washington State Ferry that could produce potentially catastrophic consequences is a low probability event. However, low probability scenarios that would produce a high consequence accident are feasible, given the operating environment of the Washington State Ferry system. If such a low probability/high consequence event should occur, the WSF system would be evaluated on how it responds to the event as much (if not more) than on how it had attempted to prevent it. Emergency response and crisis management plans and procedures must adequately address these extreme scenarios.

Improvements and changes within the WSF system can enhance the safety culture and high reliability organization required to minimize the probability of occurrence of potentially high consequence accidents. These changes could include the use of team-based training, drills, and procedures; an integrated assessment of vessel crewing levels, schedules, and fatigue; improved maintenance and repair planning, scheduling, and facilities; improved information systems to facilitate effective communication of safety- and efficiency-critical information; fleet-wide adoption of the International Safety Management system; and performance evaluation systems with appropriate evaluation metrics and measurements, that are linked to safety and reliability goals, and incorporate incentives which encourage the development of a high reliability organization.

Improvements and changes can ensure that the WSF system and other organizations will be able to provide the effective, coordinated emergency and crisis response necessary to minimize the consequences of a potentially catastrophic accident. These changes may include increasing the quality and frequency of shipboard drills, enhancing the ability to coordinate an emergency response with the fire, rescue, and medical responders, and the improvement of the capability for mustering and evacuating passengers from a ferry under emergency conditions.

Management and operational systems and procedures that have provided an adequate level of safety in the past may not be adequate to meet the demands of a changing operating and technological environment. In particular, enhanced bridge team and crew training (e.g. through bridge team simulators) may be required to maintain the level of system safety in spite of dramatic internal changes (e.g. the adoption of high speed ferries) and external changes (e.g the increasing number of large, high speed container vessels and the introduction of high speed naval vessels).

Several initiatives within the WSF system are responding to these needs. The system has adopted the International Safety Management (ISM) system for its international routes and is considering fleet wide adoption. A first draft comprehensive emergency plan has bee developed by the ferry system operations department, the Mark II ferry project team developed crew training and qualification procedures, and a table top emergency response exercise that will test the systems ability to coordinate with the USCG and other organizations has been scheduled. These initiatives should receive the continued support of the WSF system 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 Washington State Ferry advisory committees)

Risk and Safety Management will become a central strategic function of the Washington State Ferry System. The nature of risk in the Washington State Ferry system, and the changes it is undergoing, occasion a new set of requirements for risk management and communication in the Washington State Ferry system, which fit into four categories:

- the creation of an *organizational culture* that will inherently mitigate risk by ensuring that small errors are not allowed to propagate into grave consequences (described by Roberts (1990) as a high performance organization),
- the improvement of *consequence management systems* to ensure that the impacts of a crisis or disaster will be controlled and minimized,
- 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, and
- the facilitation of the *information, planning, and leadership infrastructure* required to implement an effective risk management strategy.

References

Booz Allen and Hamilton, Inc. (1991) *Management of Vessel Refurbishment Programs*. Olympia, WA

Booz Allen and Hamilton, Inc. (1998), *Department of Transportation Ferry System Performance Audit*. Olympia, WA

Grabowski, M. & Roberts, K.H. (1996). Human and organizational error in large-scale systems. IEEE Transactions on Systems, Man, and Cybernetics. 26, 2-16.

Grabowski, M. & Roberts, K.H. (1997). Risk mitigation in large scale systems: Lessons from high reliability organizations. California Management Review, 39, 152-162.

Harrald, J.R. "A Strategic Framework for Corporate Crisis Management" *Safety Science*" (forthcoming).

LaPorte, T.R. (1982). On the design and management of nearly error free organizational control systems. In David L. Sills, C.P. Wolf, & Vivien Shelanski (Eds.) Accident at Three Mile Island: The human dimension. Boulder, CO: Westview Press, 185-200.

LaPorte, T.R., (1988). The United States air traffic system: Increasing reliability in the midst of rapid growth. In R. Mayntz & T.P. Hughes (Eds.) The development of large technical systems. Boulder, CO: Westview Press.

La Porte, T.R. & Consolini, P. (1991). Working in theory but not in practice: Theoretical challenges in high reliability organizations. Journal of Public Administration Research and Theory. 1, 19-47.

National Research Council (1996). Understanding Risk: Informing Decisions in a Democratic Society. Washington, D.C.: National Academy Press.

Perrow, C. (1984). Normal accidents: Living with high risk technologies. New York: Basic Books.

Puget Sound Regional Council, 1998. http://www.psrc.org/, May 1998.

Roberts, K.H. (1990). Some characteristics of high reliability organizations. Organization Science. 1, 160-177.

Roberts, K.H. and Grabowski, M.R. (1996). Organizations, technology, and structuring. In S.R. Clegg, C. Hardy, & W.R. Nord (Eds.) Handbook of organization studies. London: Sage, 409-423.

Rochlin, G.I., La Porte, T.L., and Roberts, K.H. (1987). The self designing high reliability organization: Aircraft carrier flight operations at sea. Naval War College Review. 40, 76-90.

Sagan, S. D. (1993). The limits of safety: Organizations, accidents, and nuclear weapons. Princeton, N.J.: Princeton University Press.

Weick, K.E. (1987). Organization culture as a source of high reliability. California Management Review. 29, 116-136.

Weick, K.E. (1990). The vulnerable system: An analysis of the Tenerife air disaster. Journal of Management. 16, 571-593.

Weick, K.E. (1993). The collapse of sense making in organizations: The Mann Gulch disaster. Administrative Science Quarterly. 38, 628-652.

Wenk, E., Jr., R. Storch, T. Laetz, E. Lichty, and C. Black. 1982. *Improving Maritime Traffic Safety on Puget Sound Waterways: A Technology Assessment*. Seattle, WA.

Biographies

John R. Harrald is the Director of the Institute of Crisis, Disaster, and Risk Management and a Professor of Engineering Management and Systems Engineering at The George Washington University. He is a Director of the Disaster Recovery Institute and of TIEMS.

Martha Grabowski is a Professor of Management Information Systems at Le Moyne College and a Research Associate Professor at Rensselaer Polytechnic Institute. She is a member of the National Research Council Marine Board and the US Coast Guard's Navigation Safety Advisory Council.

Rene Van Dorp is an Assistant Professor of Engineering Management and Systems Engineering at The George Washington University.

Jason Merrick is an Assistant Professor of Operations Research and Statistics at The Virginia Commonwealth University