The Washington State Ferries Risk Assessment

Appendix I:
Historical Data Analysis Results

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Prepared for:

Blue Ribbon Panel on Washington State Ferry Safety

and

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Washington State Ferries Risk Assessment Project

Puget Sound Event Database Analysis

Prepared for:
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Section 1: Puget Sound Event Database Analysis

The Washington State Ferries Risk Assessment project has as its goal assessing the adequacy of passenger and crew safety in the Washington State Ferry system, and determining the need for additional risk reduction interventions. The study's purpose is to evaluate the level of risk present in the Washington State Ferries, and develop recommendations for prioritized risk reduction measures which can improve the level of safety in the Washington State Ferry system.

One of the primary tasks of the Washington State Ferries Risk Assessment project was to evaluate safety performance in the Puget Sound marine transportation system over the past 10 years, and to compare the safety performance of the Washington State Ferries for the same period of time with that of the broader marine transportation system. In order to evaluate system performance, a database of accidents, incidents, and unusual incidents in Puget Sound and the San Juan Islands for the years 1988-1998 was constructed, and the database was analyzed to determine trends of statistical significance. This document describes that analysis.

The document begins with a description of data challenges in conducting maritime risk assessments. It then describes the database constructed, and the analysis effected using the database. A discussion of the treatment of human and organizational error in risk assessment, and during this project, is then presented, followed by conclusions and recommendations.

Section 2: Data Challenges in Maritime Risk Assessment

The nation's ports, waterways and navigable rivers used to support ship navigation differ from each other significantly. Data to support risk analyses must reflect those differences, and must reflect the complexity and intricacies of the local operating environment.

Reliable data about a range of identified risk factors is needed to support complete risk analyses. However, there are considerable difficulties with data to support risk analyses in the marine environment, which have been identified for a variety of agencies over the past decade (National Research Council, 1994; GAO 1996a, 1996b). Considerable marine safety data are collected under protocols established by the Coast Guard. Although these data are useful, they do not provide the resources necessary to address trends related to vessel construction, outfitting, manning, technical systems, and maintenance, or to develop a full understanding of all safety needs (National Research Council, 1994). In addition, a variety of agencies, organizations and individuals capture data from and about the safety of the US marine transportation system. The resulting data sets are in many cases overlapping, inconsistent, and of differing formats and degrees of completeness (National Research Council, 1994; 1999). In general, limited information is available in the U.S. marine transportation system about traffic flows, seasonal variations, daily variations, trouble spots, trouble conditions, problem vessels, commodity flows, effectiveness and utility of navigation support systems such as VTS and on-board electronic equipment, causal factors, and other essential information. Some of this information is collected in varying degrees but is not widely used to plan or guide safety programs (National Research Council, 1999).

Thus, analysis of safety data in support of marine transportation risk assessment requires considerable effort in gathering different data files, integrating and normalizing the data into a common, consistent and technically sound format, and in testing the resulting database for completeness, integrity, reliability, and maintainability. These needs for improved safety data and systematic performance assessment have been indicated in a variety of General Accounting Office (GAO) and National Research Council studies, and are the rationale for the current (1999) U.S. effort to develop a prototype marine safety incident reporting system.

2.1 Human and Organizational Error

Human and organizational error plays a critical role in safety performance in large scale systems (Grabowski & Roberts, 1996; 1997, 1999). Analyzing human and organizational error in risk assessments is also a complex enterprise. Four sources of human factors information related to human performance in complex domains can provide background information for analytical treatments of human and organizational error: (1) human reliability databases, (2) event analyses, (3) reporting systems, and (4) subjective assessments and verbal reports. In the Washington State Ferries Risk Assessment, human reliability databases and event analyses were utilized during the data analysis; a maritime incident reporting system is currently under design by the U.S. Coast Guard and the Maritime Administration (June 1999), slated for completion in calendar year 2000. Subjective assessments and verbal reports were utilized for contextual information during the data analysis, but were not formally analyzed.

2.2 Human Reliability Databases

Researchers in marine transportation are likely to be aware of specialized periodicals such as *Professional Mariner, Marine Technology,* and *Marine Log*, and the proceedings of the biannual meetings of the International Symposium on Aviation Psychology and the International Conference on Experimental Analysis and Measurement of Situational Awareness (Garland & Endsley, 1996). The *Proceedings of the Human Factors and Ergonomics Society* also publishes several papers on aerospace systems, including vessel and air traffic control. The same *Proceedings*, together with the Society's journal, *Human Factors*, publishes many papers on human performance issues (e.g., workload, models of human error, perceptual processes, decision making, shift work, workspace design) that are directly related to problem areas in marine transportation, as well as other large scale human-machine systems.

In the early 1980's, with the exception of the technique for human error rate prediction (THERP), the American Institute for Research (AIR) data store, and laboratory studies, databases containing human error probabilities were unavailable. This is primarily because a large-scale effort directed at gathering quantitative failure data had not been initiated (Gertman and Blackman, 1994, p. 109).

Even today, very few publicly accessible databases exist. The only U.S. government-sponsored data store available and specifically developed for human reliability analysis (HRA) is the Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR) (Gertman, et al., 1990; Reece & Gertman, 1992). Most utility companies rely on consulting firms or data generating techniques to provide them with human reliability analyses for probabilistic risk assessments.

Today, there are only a few sources of HRA data that are available in the open literature. These sources of current HRA data include NUCLARR, the human error assessment and reduction technique (HEART), the Technique for Human Error Rate Prediction (THERP) (Swain & Guttmann, 1983), the human error rate assessment of intention-based errors (INTENT), maintenance failure data collected in the 1960's, and simulator data collected from Oak Ridge and Sandia National Laboratories (Gertman & Blackman, 1994). In the Washington State Ferry Risk Assessment, HRA data from nuclear risk assessment data sources was used in comparative analysis to bound the human error probabilities (HEP's) used for analysis.

2.3 Event Analyses

Event analyses are a technique used to analyze human error in accident analyses. However, because of the multiple causes of most accidents in highly redundant systems, such as those involved in aviation and marine transportation, event analyses are often ambiguous in revealing human factors causes (Diehl, 1991). The occurrence of marine and aviation accidents that are directly attributable to operator error, such as the runway collision at Los Angeles International Airport (National Transportation Safety Board, 1991), or the grounding of the passenger vessel *Royal Majesty* off Nantucket, is extremely rare. Operational errors, such as loss of required separation between aircraft or vessels, are more common but still relatively infrequent (Rodgers, 1993; National Research Council, 1994, 1999). In addition, the low frequency of accidents (vs. the occurrence of errors that do not result in accidents) imposes particular constraints on the observation of precipitating conditions and statistical inference.

Despite these difficulties, event analyses are undertaken in order to analyze and categorize the types of errors which occur during an accident. Event analyses utilize taxonomies, or categorization schemes, to classify errors. For instance, in aviation, McCoy and Funk (1991) developed a taxonomy of operator errors based on a model of human information processing using National Transportation Safety Board (NTSB) aircraft accident reports. They found that the air traffic control system was a contributing or probable cause in 6 of 38 accidents they reviewed for the 1985-1989 period. When the search was extended back to 1973, they found a total of 29 examples of air traffic control involvement. The errors were related to attention, memory, perception (the validity of the operator's world model), and response selection (including the issuing of clearance, coordination, and a variety of other procedures). From an analysis of operational errors, Redding (1992) reported that failure to maintain adequate situation awareness was the likely cause of most errors. As a result of their own review, McCoy and Funk argued for the design of error-tolerant systems (see Weiner, 1987, 1989), while still trying to prevent errors.

Similarly, Reason (1997) introduced a cognitive framework of human error that is illustrated in Figure 1. In this taxonomy, unsafe acts result from two types of activities: errors, which are unintended actions; and violations, which are intended actions. Errors can be of three types: *decision errors*, encompassing both rule-based and knowledge-based errors; *skill-based errors*, or *perceptual errors*. Violations can be either of two types: *routine*, which are common place abrogations of policies, rules and/or procedures that are condoned by management, or *exceptional violations*, which are not condoned by management.

Human and Organizational Error Taxonomy

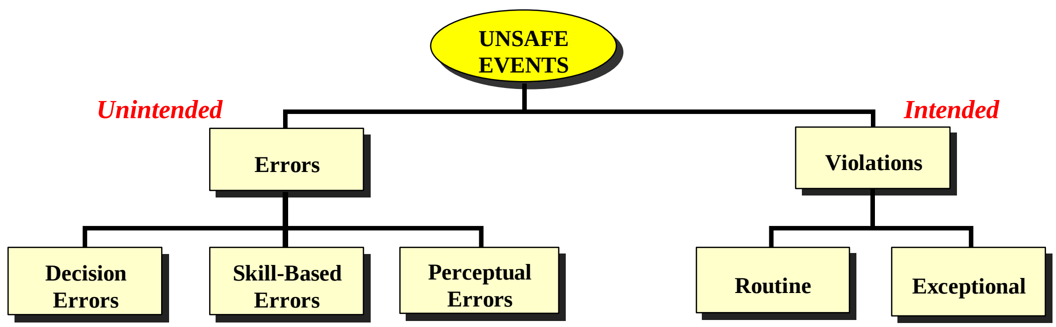


Figure 1 Reason Human and Organizational Error Taxonomy

Section 3. The Puget Sound Event Database

Event analyses utilizing taxonomies provide a starting point for assessing the role of human and organizational error in accidents. However, there are limitations to the use of event analysis. Event analysis is a post-hoc process, and the data that are available for analysis have frequently been filtered through a conceptual system that is reflected in the classification structure of the database itself. What data are collected at the time of a given incident are determined largely by the questions posed during the evidence gathering process. In aviation, Rodgers (1993) has indicated that it is necessary to be able to review the dynamics associated with air traffic situations (and not just the error-related event itself) when examining operational errors (Rodgers and Duke, 1994). In marine transportation, event analyses are constrained by the quality of the data gathered, the maturity of the associated reporting system, and the training and background of the investigator and reporter (who may not be the same person). Thus, until maritime reporting systems mature, especially in their treatment of human and organizational error, there are limitations associated with the use of available maritime data for human error analysis.

3.1 Data Definitions

In an environment where different agencies collect different data, in differing formats, for differing purposes, the need for consistent and common data definitions and formats is acute. The Puget Sound event database utilized a common set of data definitions and formats, to facilitate data sharing and promote understanding of the data and its structure.

The event database contains information about accidents, incidents, and unusual incidents in Puget Sound for the period 1988-1998:

Accidents are defined as occurrences that cause damage to vessels, facilities, or personnel, such as collisions, allisions, groundings, fires, explosions, or founderings.

Incidents are defined as undesirable events related to control or system failures which can be detected or corrected in time to prevent accidents; incidents can also be prevented from developing into accidents by the presence of redundant or back up systems. Examples of incidents include propulsion failures, steering failures, navigational equipment failures, and other equipment failures.

Unusual incidents are defined as events of interest to the safety of navigation that are deemed to be unusual by a participant or a reporting organization. In the event database, unusual events were provided by the US Coast Guard Vessel Traffic Services (VTS), the Washington State Department of Ecology, and the Washington State Ferry System.

3.2 Data Approach

Because of the difficulties associated with data for marine transportation risk assessment (detailed in Section 2.1), a protocol for establishing reliable data was adopted. First, where local data was available and reliable, it was utilized. National and international data, where appropriate and available, were used for comparative purposes during the analysis. In the Washington State Ferry Risk Assessment, this meant that a total of 37 different data files, containing information about maritime events in Puget Sound from 1988 to 1998, were used for analysis. These sources are listed in Table 1.

Second, because no one comprehensive, reliable, accessible, and independent source of failure, incident, or near miss data was available for Puget Sound, a comprehensive database of accidents, incidents, and unusual events in Puget Sound for the period 1988-1998, using the data from the 37 different data files, was constructed. In the Washington State Ferry Risk Assessment, this entailed developing a common database, using common data formats, structures, and definitions, to analyze the data contained in the 37 different input files.

Finally, where possible, all events in the database were verified by two independent data sources before inclusion; resolution of open items in the event database in most cases required manual reconciliation of archival data from several sources, which was consumed a significant amount of time. The resulting event database affords opportunities for data analysis that provide key insights to the effectiveness of various risk reduction measures.

3.3 Data Sources

A variety of organizations provided data as input to the event database, as illustrated in Figure 2. Each of these databases was in different formats, of different sizes, and captured different views of safety performance in the Puget Sound marine transportation system. Thus, in order to develop a robust and complete database of events in the Puget Sound marine transportation system, each of these databases needed to deconstructed, normalized, and integrated into a common database format, utilizing a common data definition language. Table 1 contains a detailed description of the databases received, the size of each of the files received, and the number of records received.

- A quick review of Table 1 shows that the size of input data files to the Puget Sound Event database was large. 37 different data files, comprising over 1 million records, and more than 35Mbytes of data, were received from 9 different organizations.

Table 1 Data sources, File Sizes, Number of Records

Table 1
Data sources, File Sizes, Number of Records
Puget Sound Event Database, 5-14-99

		5-14-99 Database	
Table	**Description**	**Size (KB)**	**Records**
cirt	Marine Casualty and Pollution Master Record (beginning 1992)	7,637	**102,971**
civt	Marine Casualty Vessel Supplement Record (beginning 1992)	1,405	**81,208**
cift	Marine Casualty Facility Supplement Record (beginning 1992)	120	**28,852**
cevt	Marine Casualty Event Table (beginning 1992)	570	**58,404**
ccft	Marine Casualty Causal Factor Table (beginning 1992)	689	**62,787**
ccgt	Marine Casualty Collision and Grounding Table (beginning 1992)	76	**11,709**
csft	Marine Casualty Structural Failure Table (beginning 1992)	57	**1,176**
cfct	Marine Casualty Flooding and Capsizing Table (beginning 1992)	286	**3,983**
cpct	Marine Casualty Personnel Injury & Death Table (beginning 1992)	666	**10,570**
cfet	Marine Casualty Fire and Explosion Table (beginning 1992)	219	**1,052**
cwxt	Marine Casualty Weather Supplement Record (beginning 1992)	564	**3,303**
vcas	Vessel Casualty Table(1980-1991)	606	**69,006**
pcas	Personnel Casualty Table(1980-1991)	294	**20,953**
vidt	Vessel Identification Table	3,702	**8,127**
vidt2	Vessel Identification Table	143	**95**
vidt	Vessel Identification Table(beginning 1980)	633	**407,644**
mcrt	Marine Casualty Response Table (beginning 1992)	3,759	**31,035**
vdft	Marine Vessel Table (beginning 1980)	968	**833**
sarmis1	Search and rescue data (1987 – 1996)	1,520	**20,462**
sarmis2	Search and rescue data (1987 – 1996)	1,520	**20,462**
sarmis3	Search and rescue data (1987 – 1996)	1,520	**20,462**
sarmis4	Search and rescue data (1987 – 1996)	1,520	**20,462**
sarmis5	Search and rescue data (1987 – 1996)	1,520	**20,462**
sarmis6	Search and rescue data (1987 – 1996)	1,520	**20,462**
cg 1	Accident records (1994)	260	**203**
cg 2	Accident records (1994)	742	**2,400**
cg 3	Pollution records (1994)	1,530	**3,312**
cg 4	Personnel casualty records (1994)	1,640	**2,062**
Trip-Cancel	WSF Trip cancellation data (1997-1998)	0	**684**
Trip-Cancel	WSF Trip cancellation data (1997-1999)	0	**9,028**
2692	Coast Guard Marine Casualty records (1998)	0	**8**
835	Coast Guard Marine Inspection reports (1998)	0	**62**
Routes	WSF Route data	0	**45**
Vessel	WSF Vessel data	0	**29**
Ecology	Events data (1992 – 1998)	0	**491**
TBUI	Unusual Incident data (1988 – 1997)	0	**1,747**
TBUI Vessel	Vessel data	0	**1,497**
Total		**35,686**	**1,048,048**

Input data was received from the following organizations:

- the Washington State Ferries, which provided accident, incident and unusual incident data;
- the Washington State Department of Ecology, which provided accident, incident, and unusual incident data;
- the US Coast Guard Vessel Traffic Services (VTS), which provided unusual incident data;
- The Puget Sound Pilots Association, which provided transit and background information;
- the U.S. Army Corps of Engineers, which provided transit and traffic data;
- the Puget Sound Marine Exchange, which provided transit and traffic data;
- the U.S. Navy, which provided transit, traffic, and background information;
- and the Washington State Ferries System, the U.S. Coast Guard Vessel Traffic Service, and the U.S. Department of Transportation Volpe Transportation Systems Center, all of which provided transit and traffic data.

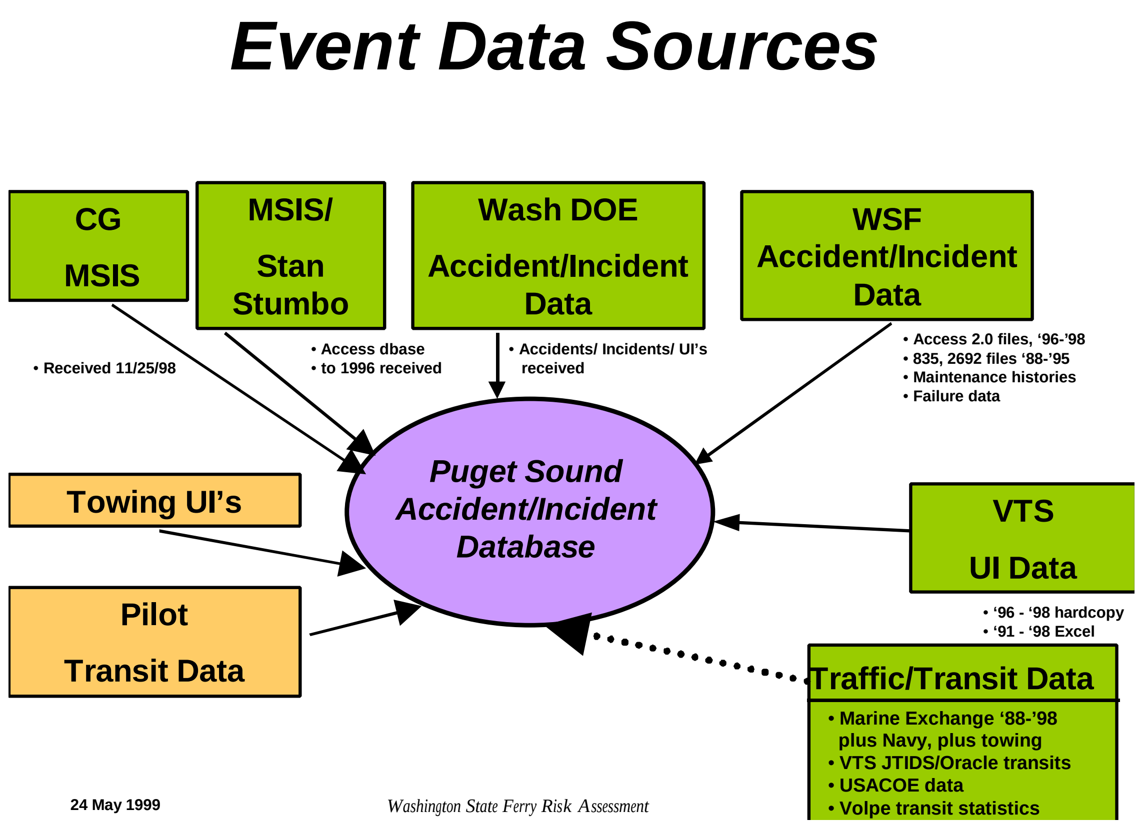


Figure 2 Puget Sound Event Database Sources

Section 4. Data Analysis

Once the Puget Sound event database was constructed, an analysis of accidents, incidents, and unusual events that occurred in Puget Sound from January 1, 1988 to December 31, 1998 was undertaken. During the analysis of the event database, time series analyses, Duncan's multiple range tests, tests of hypotheses on a proportion and non parametric paired comparisons using the Wilcoxon signed-rank test, along with regression analyses, were performed. In this section, highlights of the analysis are presented.

4.1 Findings

The Puget Sound marine transportation system is a moderately active port: a total of 1429 events (accidents, incidents, and unusual events) are recorded in the database for the 1988 - 1998 period.

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).

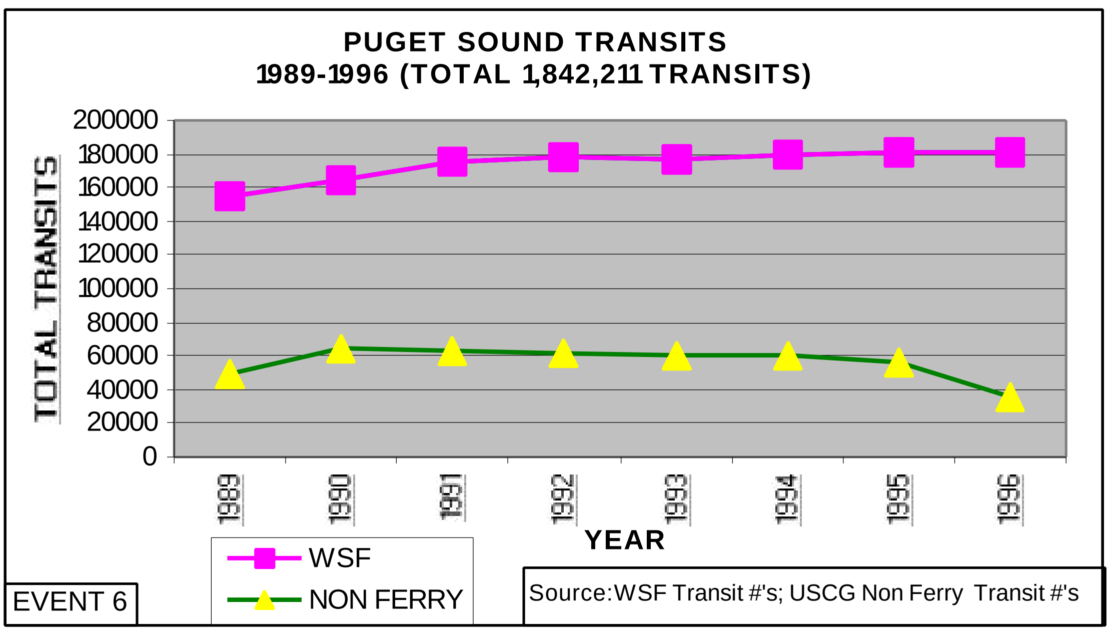
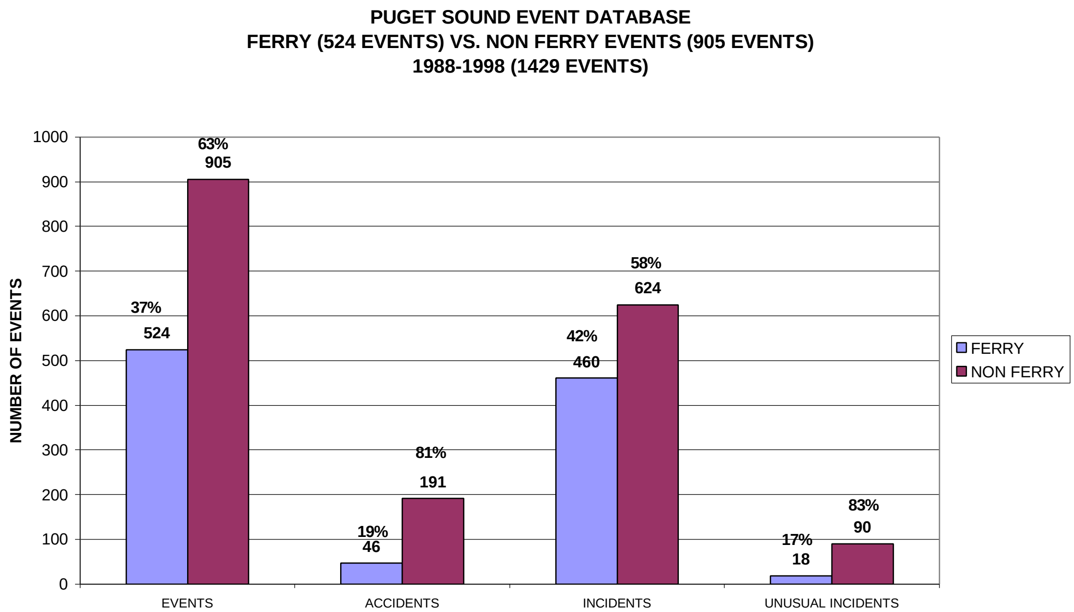


Figure 3 Transits in Puget Sound, 1989 - 1996

Traffic in the Puget Sound marine transportation system has been relatively stable over the past 10 years.

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. Figure 3 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 3. In contrast, non ferry transits per year declined gradually, particularly after 1994. This has been the result of trends to build larger and sail fewer 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.



EVENT 3

Figure 4 Ferry vs. Non Ferry Events in Puget Sound, 1988 - 1998

Most of the events which happened in Puget Sound over the past ten years have been precipitating incidents (propulsion failures, steering failures, other equipment failures), rather than accidents (collisions, allisions, groundings, fires and explosions, and founderings).

Of the events which have happened over the past ten years, most of them have happened to Washington State Ferries, which represent 75-80% of the traffic in the Sound.

Of the 1429 events that occurred between 1988 and 1998, 75% of those events were incidents, 16% accidents, and 9% unusual incidents. This illustrates that most of the events occurring in the Puget Sound marine transportation system are precipitating events (propulsion failures, steering failures, other equipment failures), rather than accidents. This finding also contrasts with other ports in the United States, which have different event profiles. For instance, events in the port of Houston/Galveston from 1991-1996 had a very different pattern: of the 1920 events which occurred between 1991 and 1996, 75% were accidents--pollution events, allisions and groundings--rather than incidents. Patterns of event occurrences in a port or waterway provide important clues as to the utility of candidate risk reduction measures.

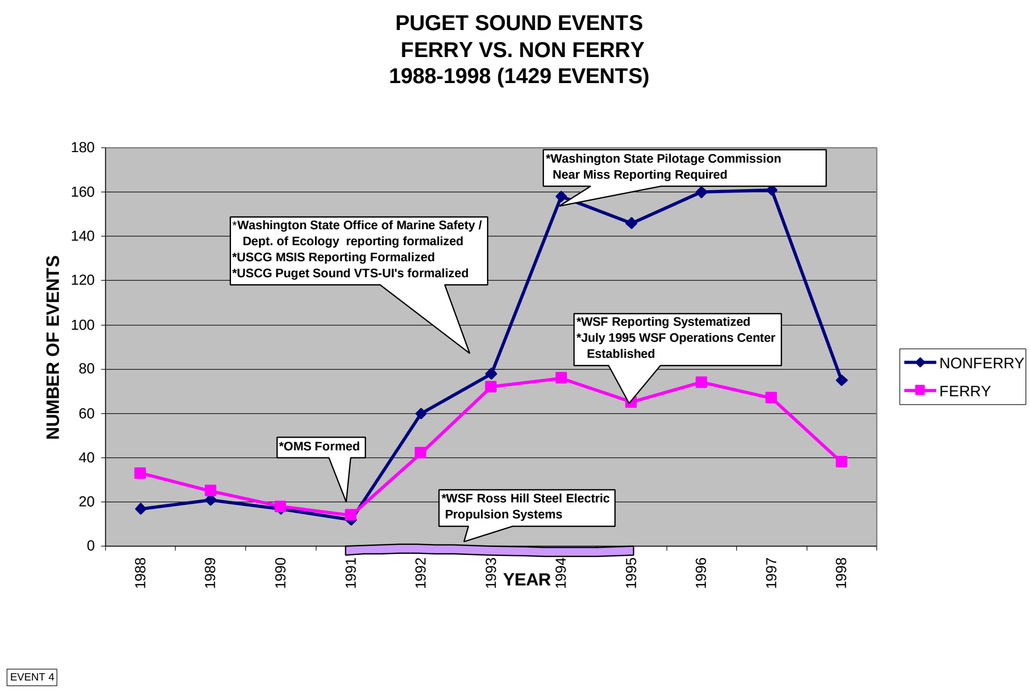


Figure 5 Puget Sound Events, Ferry vs. Non Ferry Events, 1988-1998

Despite the fact that Washington State Ferry vessels comprise 75-80% of the traffic on Puget Sound, there have been significantly fewer ferry events, compared to non-ferry events, over the past ten years.

A time series analysis shows that the number of events occurring in Puget Sound has risen steadily over the past ten years, particularly after 1991. However, patterns for Washington State Ferries and non ferry vessels differ, as seen in Figure 5. Thus, although the total number of events per year has risen for ferries and non ferries, the rates at which the occurrences have risen is significantly different: events involving non ferry vessels have risen significantly since 1993, at the same time that Washington State Ferry event occurrences have declined significantly.

Caution is required in reviewing the data illustrated in Figure 5, however, as external factors 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.

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 Ferry is highlighted.

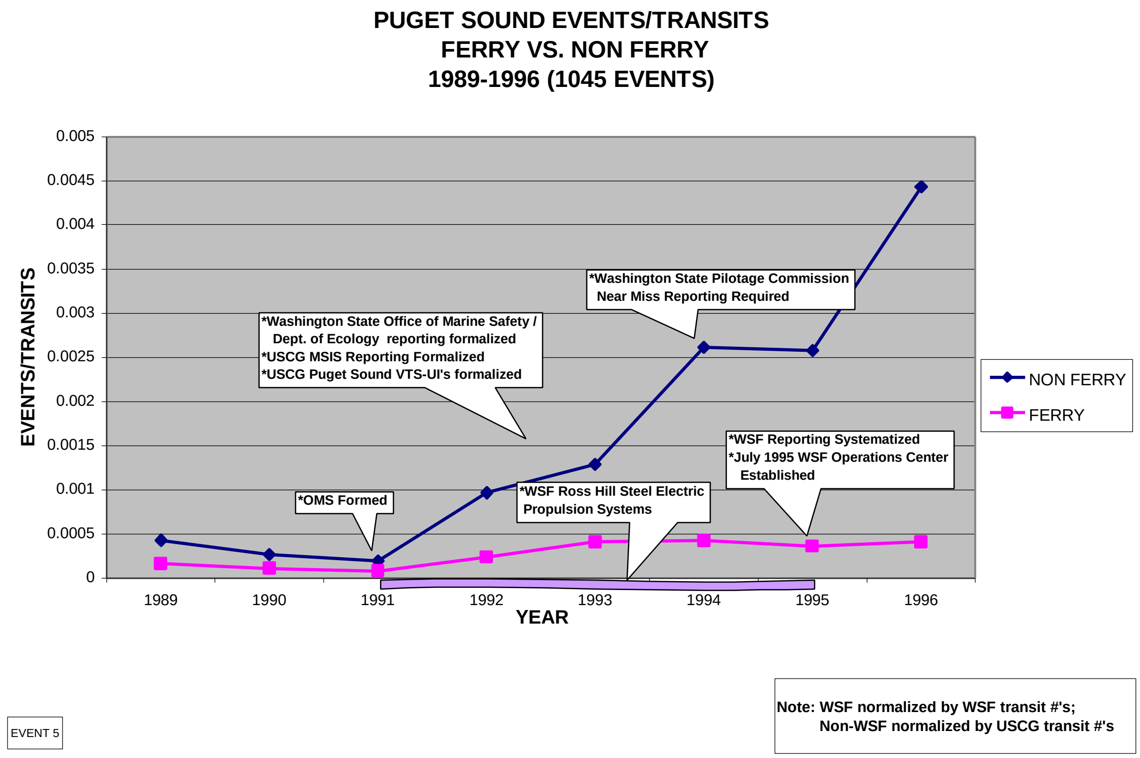


Figure 6 Puget Sound Events/Transit Ferry vs. Non Ferry Events, 1988-1998

Normalized event occurrence rates account for the fact that Washington State Ferry traffic represents 75-80% of the traffic in Puget Sound, and use events/transit statistics as a basis of comparison. As can be seen in Figure 6, events per transit rates for Washington State Ferry vessels, compared to non ferry vessels, are significantly different. Normalized event rates for non ferry vessels have been increasing since 1991; at the same time, events/transit rates for 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.

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 statistically 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 have been significantly different over the past ten years, and both patterns highlight the significant safety record of the Washington State Ferry system during the period.

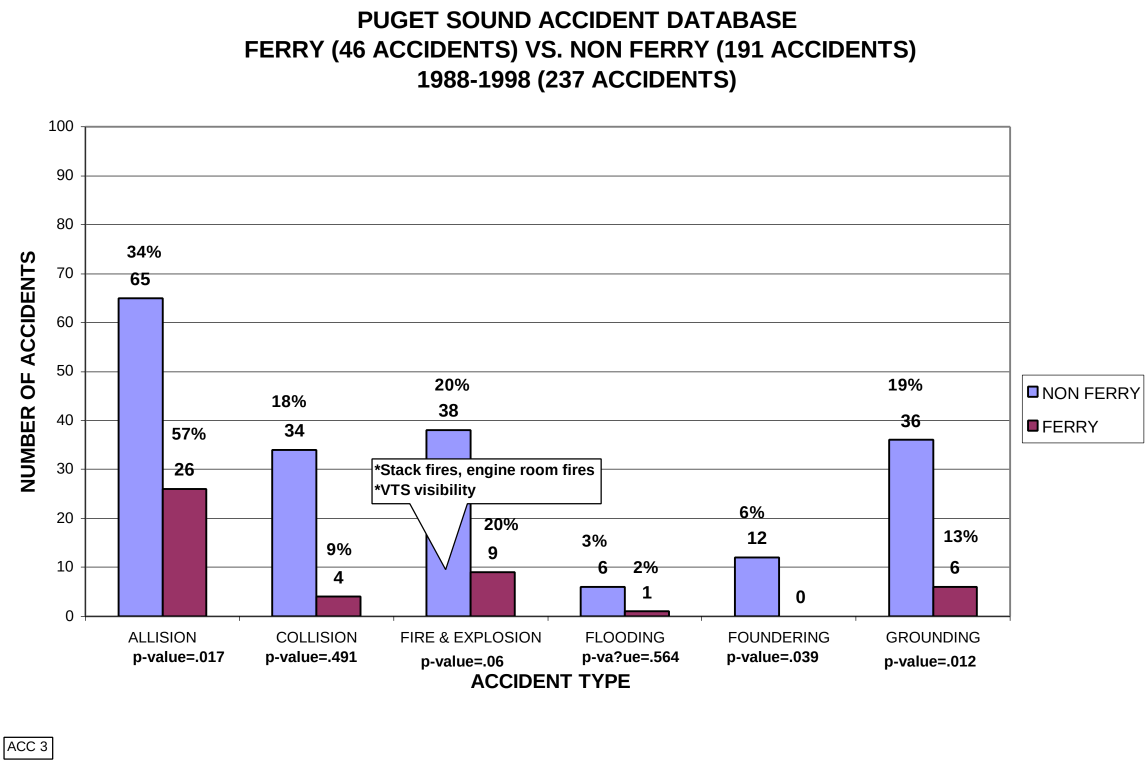


Figure 7 Puget Sound Accident Types, Ferry vs. Non Ferry, 1988-1998

There have been very few accidents in the Puget Sound marine transportation system over the past ten years. The Washington State Ferry accident record is statistically significantly better than the accident record for non ferry vessels for the period 1988-1998.

In total, 191 accidents were recorded in Puget Sound over the past ten years. Most of the accidents which have occurred have been allisions, primarily occurring to non ferry vessels, as seen in Figure 7.

Of the non ferry accidents, 34% were allisions, 18% were collisions, 20% were fires and explosions, and 19% were groundings (reading horizontally across the tops of the non ferry bars in Figure 7).

The accident pattern for Washington State Ferries is similar to that of non ferry vessels, although at a significantly lower level: Of the 46 WSF accidents recorded between 1988 and 1998, 57% (26 in total over the 10 year period) were allisions, 20% (9 in total) were fires and explosions, 13% (6 in total) were groundings, and 9% (4) were collisions. Thus, although the pattern for ferry vs. non ferry accident types has been similar in Puget Sound over the past ten years, the accident frequency rate for Washington State Ferry vessels has been significantly lower than for non ferry vessels.

Most of the Washington State Ferry accidents between 1988 and 1998 were allisions.

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. 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.

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

Table 2 WSF Collisions, 1988-1998

Washington State Ferries experience the most of the incidents in Puget Sound (43% of all incidents), driven primarily by the number of Washington State Ferry transits, and numbers of opportunities for equipment failures.

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, rather than accidents. Of the 538 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. The WSF events are summarized in Table 3.

As seen in Figure 8, Washington State Ferry incidents have generally increased since 1988, although they have decreased significantly after 1996. This decrease has been attributed to resolution of Ross Hill propulsion problems on the Steel Electric class ferries by 1996 (Figure 9). Thus, incidents in Puget Sound rose significantly from 1991 - 1996, and currently show a downward trend.

Event Type		Number of Events	Percentage
Accidents		**46**	**8.6%**
Incidents		**460**	**85.5%**
Unusual Incidents		**20**	**3.7%**
Unclassified		**12**	**2.2%**
Total Events		**538**	**100.0%**
Accidents	Allisions	26	56.5%
	Collisions	4	8.7%
	Fire & Explosion	9	19.6%
	Flooding	1	2.2%
	Grounding	6	13.0%
Total Accidents		**46**	100.0%
Incidents	Steering Failures	58	12.6%
	Propulsion Failures	190	41.3%
	Other Equipment Failures	212	46.1%
Total Incidents		**460**	100.0%
Unusual Incidents		**20**	**3.7%**
Unclassified		**12**	**2.2%**
Total Events		**538**	**100.0%**

Table 3 Washington State Ferry Events, 1988-1998

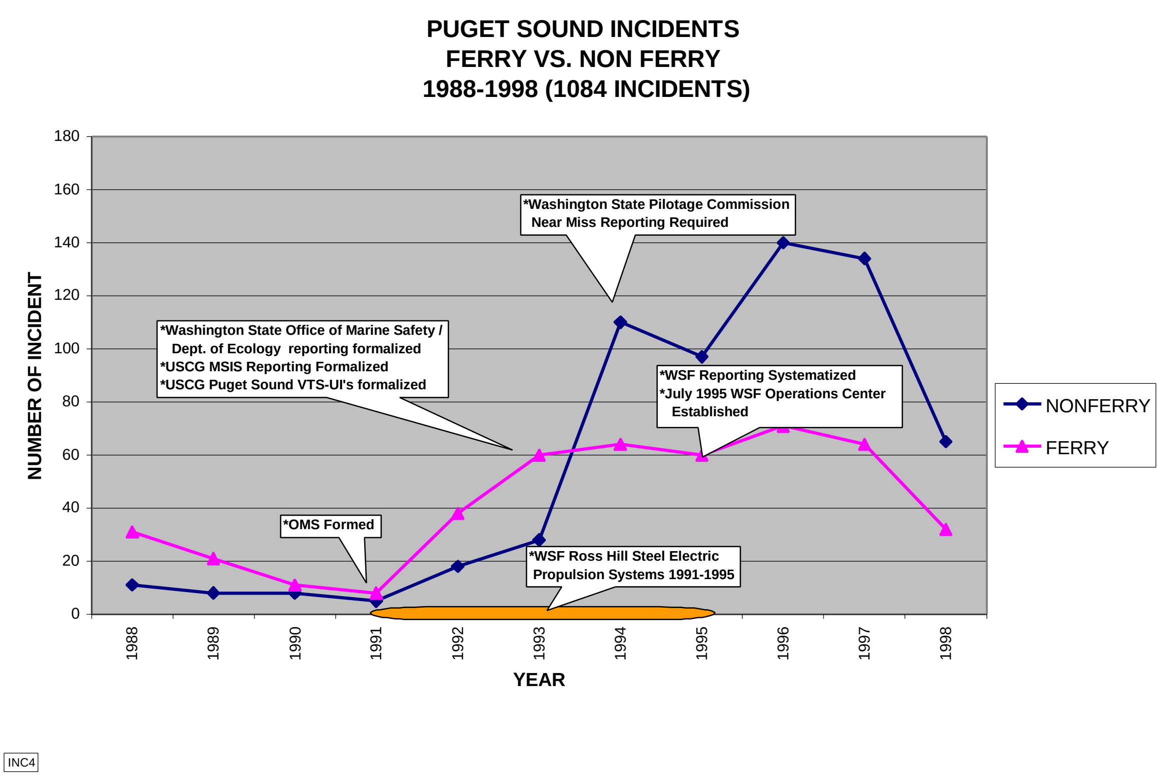


Figure 8 Ferry vs. Non Ferry Incidents, 1988-1998

Section 5. Human and Organizational Error Analysis

In order to analyze the role of human and organizational error in Washington State Ferry accidents, an event analysis of the 46 Washington State Ferry accidents which occurred between 1988 and 1998 was conducted. During this analysis, a total of 51 errors were identified, and then categorized using the Human and Organizational Error taxonomy described in Figure 1. This analysis was limited by the availability of accident narrative reports from the U.S. Coast Guard and the Washington State Ferry system; consequently, only partial results are presented here.

As seen in Figure 9, 68.6% (35 errors) of the errors which occurred during the accident were categorized as human error, and 31.4% (16 errors) of the errors were categorized as mechanical errors. This data provides an interesting contrast to the oft-quoted 80% human error figure used in many maritime studies. Thus, in this study, approximately 70% of the errors committed during accidents were related to human and organizational error.

None of the human errors identified were violations: all were unintended errors. However, two unusual incidents represented violations: one routine violation (i.e., a practice condoned by management), and one exceptional violation (not condoned by management).

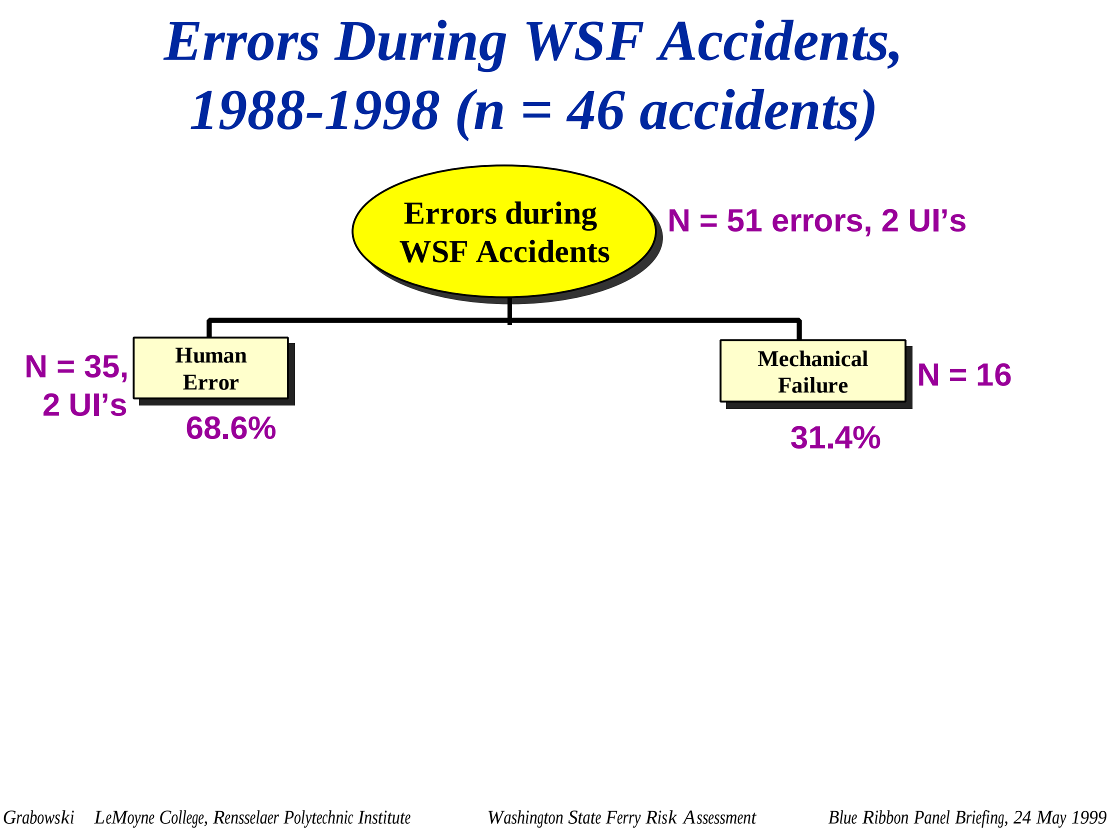


Figure 9 Human Errors During WSF Accidents, 1988-1998

Of the identified human errors, the largest percentage were perceptual errors: those related to misjudgments or misperceptions in situation awareness (Figure 10). A smaller percentage

(5.9%, n= 3 errors) were decision errors, either rule-based or knowledge-based. 7 errors (13.7%) were identified as skill-based errors, either attention or memory failures. Perceptual errors accounted for 25 errors, or 49% of the identified human errors in accidents between 1988 and 1998. However, caution is advised with the use of these percentages, as the human and organizational error analysis is still underway. Limited use can be made of the analysis concerning decision, skill-based, and perceptual errors, as the analysis was limited by the availability of accident narrative reports. The detailed human error analysis, thus, is still awaiting delivery of the complete set of accident narrative reports.

Comparative analyses are often used to provide benchmarks for assessing the contribution of human and organizational error in accident analyses. For instance, a comparative analysis of aviation accidents investigated by the National Transportation Safety Board (NTSB) between 1978 and 1990 was completed in 1994 (NTSB, 1994). 37 major accidents were reviewed, during which primary and secondary errors which occurred during a major accident were identified. Those errors were then allocated to the Reason human error taxonomy, in the same way that 51 errors identified during the 46 Washington State Ferry accidents were allocated. A comparison of the human and organizational error percentages for the NTSB aviation study and the partial analysis of Washington State Ferry accidents from 1988 to 1998 is seen in Figure 11. The aviation percentages are listed first, followed by the Washington State Ferry percentages. The human and organizational error analysis provides insights as to the effectiveness of various risk reduction measures.

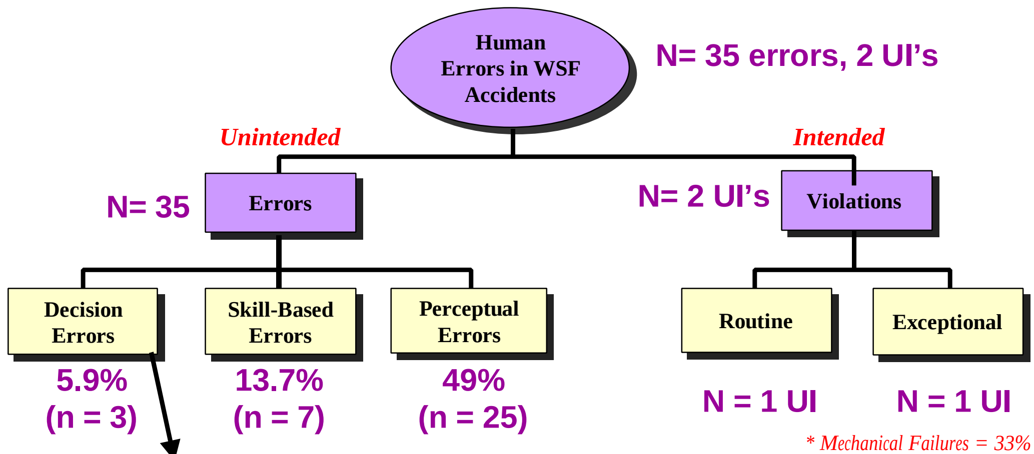
5.1 Limitations

Progress to date in human reliability analyses has been slow. There are several different issues that continue to plague the analytic use of human and organizational error data: uncertainty in human error probabilities, questions about the transferability of human factors data from different domains, and the compounding influence of environmental factors in accident data.

An additional problem is that the data and recommendations contained in the human engineering literature frequently have not been tailored to specific applications. Expert interpretation is often required to determine the applicability (particularly without further validation) of data to a specific research question. Although it is often possible for human factors specialists to extrapolate from the literature to a design application, whenever possible, usability testing (i.e., for user acceptability) should be conducted in a rapid prototyping or other simulation environment.

The use of accident data for comparing performance in operational contexts is a problem that plagues many domains. In 1994, the National Transportation Safety Board (1994) noted that flightcrew performance during accidents is subject to the simultaneous influences of many operational context variables. Because of data limitations— a small number of accidents (due to their rarity), and missing data (due to the nature of the evidence in accident investigations)— the interactions between operational context variables and human performance is difficult to analyze (NTSB, 1994; p. 84). These type of problems also plague marine transportation, and make difficult complete analyses of the impact of human error on safety in large scale systems.

Human Error in WSF Accidents, 1988-1998 (n = 46 events)



MCCASE #	Date	Vessel	Accident Type	Narrative	Location
MC93017230	9/22/93	**Klahowya***	Allision	Oiler inexperienced @ throttle	Fauntleroy dock
MC91004921	9/16/91	**Sealth, Kitsap***	Collision	2 ferries collide in fog; imprudent s	Rich Passage
MC94019064	9/11/94	**Nis qually***	Grounding	Navigation error by master, using	Elw ha Rock, near Orcas Island

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Figure 10 Human Error in WSF Accidents, 1988-1998

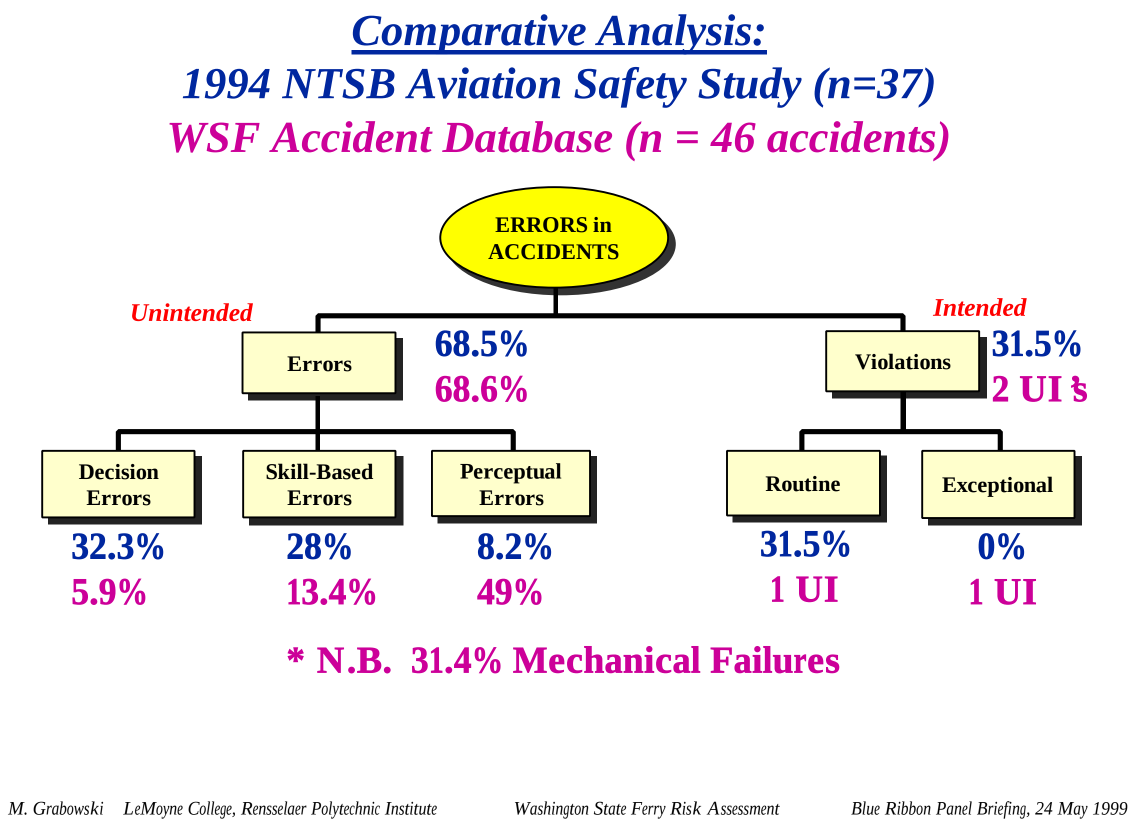

Figure 11 Comparison of Aviation HOE Analysis and Preliminary Washington State Ferry Analysis

Section 6: Summary and Conclusions

The purpose of the analysis of the event database was to identify relevant historical trends important to risk mitigation in the Washington State Ferries system. The report findings are summarized below.

1. Most events that have occurred in Puget Sound over the past ten years have been incidents, rather than accidents.

2. There have been very few accidents in Puget Sound over the past ten years. Most accidents that have occurred over the past ten years have been allisions experienced by tugs and tows.

3. Despite its traffic and transit volume, the Washington State Ferry system has enjoyed a significant safety record over the past ten years. The Washington State Ferry accident record is statistically significantly better than the accident record for non ferry vessels in Puget Sound over the past ten years.

4. Most events that occurred to Washington State Ferries over the past ten years have been incidents (propulsion failures, other equipment failures) rather than accidents.

5. Most of the incidents which have occurred in Puget Sound over the past ten years have occurred to Washington State Ferries. The incident rate is driven by the ferry transit volume, which increases the opportunities for incidents, primarily propulsion failures, to occur.

6. Almost 70% of the accidents which occurred to Washington State Ferry vessels were human error-related.

7. Organizational, environmental, and political forces and changes in Puget Sound complicate analysis of marine transportation data.

There are a number of implications which proceed from these findings. First, the recorded events for Washington State Ferries between 1988 and 1998 were predominantly incidents (steering failures, propulsion failures, and other equipment failures) rather than accidents, suggesting that risk mitigation measures focused at interrupting the error chain between the incident and accident stage of the framework for risk assessment would have more utility than risk mitigation measures focused on other stages of the error chain.

Similarly, risk mitigation measures associated with propulsion failures and other equipment failures, rather than those addressing steering failures, would have more utility than in the Washington State Ferry system, based on a historical analysis of system events. Performance and trend analysis of machinery, equipment, and personnel can greatly aid in assessments of effective risk reduction measures.

Human and organizational error is a significant component of accidents which have occurred in the Washington State Ferry system over the past 10 years. Of the errors which have occurred during accidents, almost 70% were human errors, compared to approximately

30% for mechanical errors. However, caution should be exercised with the use of these statistics, as the number of errors and the numbers of accidents is not large over the 10 year period (46 events, 51 errors identified).

The high percentage of human error contribution to accidents in the WSF system suggests that risk mitigation measures focused on addressing basic/root causes, as well as immediate causes, are of significant utility in the WSF system. Similarly, risk mitigation measures focused on personnel selection, training, and system safety issues, rather than on investments in capital equipment, would be of greater utility, based on the historical safety performance analysis. Analyses between aviation human error studies and the WSF data analysis show that the human error contribution to accidents are comparative.

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