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MODELING RISK IN THE DYNAMIC ENVIRONMENT OF MARITIME TRANSPORTATION

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ABSTRACT

The Washington State Ferries are one of the largest ferry systems in the world. Accidents involving Washington State Ferries are rare events. However, low probability, high consequence events lead to difficulties in the risk assessment process. Due to the infrequent occurrence of such accidents, large accident databases are not available for a standard statistical analysis of the contribution of perceived risk factors to accident risk. In the WSF Risk Assessment, a modeling approach that combined system simulation, expert judgement and available data was used to estimate the contribution of risk factors to accident risk. Simulation is necessary to capture the dynamic environment of changing risk factors, such as traffic interactions, visibility or wind conditions, and to evaluate future scenario's that are designed to alter this dynamic behavior for the purposes of risk reduction or improved passenger service. This paper describes the simulation component of the model used in the Washington State Ferries Risk Assessment.

1 INTRODUCTION

The Washington State Ferries (WSF) 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.

Technology changes are occasioning new operational and human factors requirements in the Washington State Ferries. A new class of high-speed ferries, called the Chinook class, is being introduced. These passenger-only ferries have new navigation, engineering, and control system technology and 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 human response times, which will require different standards for personnel selection, training, drills and procedures aboard these vessels. A more detailed discussion of the changes occurring in the WSF and their operational environment is given in Grabowski et al. (2001).

In light of these changes, 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 in the WSF Risk Assessment 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.

Due to the inherent dynamic nature of maritime transportation systems, simulation can provide critical input to decision makers challenged to capture and analyze future scenario's changing such maritime transportation systems. This paper describes the simulation part of the model used in the Washington State Ferries Risk Assessment. The overall model built around the system simulation is discussed in Section 2. The simulation and the data used to create it are discussed in Section 3. The model used to count interactions in the simulation is outlined in Section 4. Some results obtained using the simulation are presented in Section 5, along with more general results of the combined model. Section 6 summarizes the findings of the study and highlights the use of simulation and its effect on the success of the project.

2 MODELING MARITIME RISK

When a Washington State ferry is underway there is a possibility, however unlikely, that something could go wrong. This is a fact inherent in many of the activities found in our day to day lives. A day to day situation in the running of the WSF is called an Opportunity for Incident (OFI). Obviously some situations are more "risky" than others. As an example, a ferry traveling on a clear day with no other traffic nearby is at a lower "risk" than a ferry in foggy conditions with many other vessels nearby. This variability in "risk" levels across situations requires that the following questions are answered in order to model collision risk in the WSF system:

- How often do the various OFI's occur?
- For a particular OFI, how often do triggering incidents occur?
- If a triggering incident occurs, how likely is a collision?
- If a collision occurs, what damage can be done to the ferry?
- If the ferry is damaged, what response time is required to avoid additional casualties?

Figure 1 shows a taxonomy of the models developed to answer these questions. For each OFI, there are associated variables that may be considered contributing risk factors to that situation. The variables considered in the WSF Risk Assessment are listed in Table 1.

The first question that must be answered to assess the system-wide risk is how often do the various possible situations, as defined by the variables considered, occur, i.e. what is the frequency of the various possible OFI's? Data is available from the United States Coast Guard logging arrivals of deep-draft vessels to the Puget Sound area and ferry schedules are published by the Washington State Ferry Service, but this does not tell us how often interactions between these vessels occur and in what conditions. Thus a computer simulation was built to model the movement of maritime traffic in the area pertaining to the Washington State Ferry System.

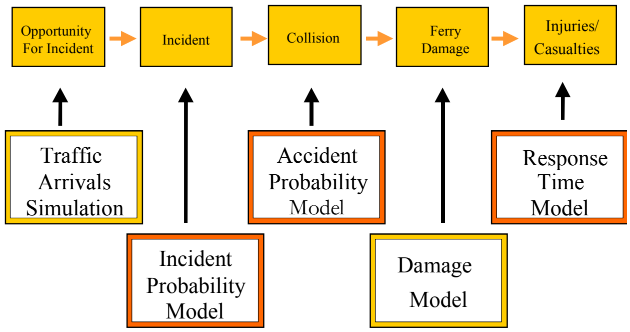

Figure 1: The Overall Framework of the Model used in the WSF Risk Assessment

Table 1: The Variables Considered in the Collision Risk Model

Variable Name	Some Examples of Possible Values
Ferry Route	Seattle-Bremerton, Anacortes-Sidney
Ferry Class	Issaquah, Jumbo, Chinook
1st Interacting Vessel Type	Container, Bulk Carriers, Other Ferries
Type of 1st Interaction	Crossing, Meeting, Overtaking, Passing
Proximity of 1st Interacting Vessel	Less than 1 mile, From 1 to 5 miles
2nd Interacting Vessel Type	Deep Draft, Shallow Draft, High Speed Vessel
Type of 2nd Interaction	Crossing, Meeting, Overtaking, Passing
Proximity of 2nd Interacting Vessel	Less than 1 mile, From 1 to 5 miles
Wind Speed	0 knots, 10 knots, 20 knots
Wind Direction	Perpendicular to Ferry, Along Ferry
Visibility	Less than half a mile, More than half a mile

The simulation was built to accurately represent the operation of the Washington State Ferries, the other vessels in the area and the environmental conditions at any given time. Using this simulation, a counting model was developed that observed and recorded snapshots of the study area at regular intervals and counted the occurrences of the various OFI's. The simulation is called the OFI generator and the counting model is called the OFI Counter.

The simulation is only the first part of the five part model. As shown in Figure 1, the incident and accident probabilities require the use of data analysis and expert judgment techniques, while the damage and response time models were created based on engineering collision models. For a discussion of the overall project and a brief review of each part of the model, the reader is referred to van Dorp et al. (2001). More details of the expert judgment techniques and a discussion of the necessity of using simulation in maritime risk assessment are given in Merrick et al. (2000), which describes a prior study, the Prince William Sound Risk Assessment. The simulation techniques discussed herein are an extension of those used in the previous project.

3 THE SIMULATION

The approach used in the WSFS Risk Assessment relies upon the premise that risk is a dynamic property of the system. Harrald et al. (1992) discuss the need for dynamic modeling in the assessment of risk in the maritime area. The system risk at any given time is the summation of the risk posed by each of the vessels in the system. As vessels pass through the system, the waterway and organizational characteristics of the vessels (i.e. the OFI's) in the system change with time, thus changing the level of risk in the system. To be able to estimate the risk of the system over time, a model must capture the dynamic nature of the transportation system. Such a model allows for the examination of variations to the present system without disruption of the current system. Proposed risk interventions that change the dynamics of the current system can be evaluated in the simulation rather than tested in real life. When studying systems in which risk is a key component, this ability is a major benefit.

3.1 Modeling Ferry Traffic

The simulation region was defined using NOAA Electronic Nautical Charts for the Pacific Northwest: Puget Sound to Canadian Border, Region 15.

The simulated movements of the Washington State Ferries were drawn from the Fall, Spring and Summer schedules for 1997. The class of ferries used for each scheduled run were taken from the WSF Vessel Assignments for 1998. The speed of movement of each ferry class was taken from the vessel specifications in conjunction with ferry service rules. As an example of such a rule, to reduce wake damage in Rich Passage the Chinook must increase its speed to near maximum. The vessel speeds were verified in ship rides with the ferry captains. A group of 6 relief captains, each with over 20 years of experience, met with the simulation team. In this meeting, the ferry routes were drawn on nautical charts and possible route deviations discussed for bad weather conditions. These routes were used as inputs to the simulation.

Under certain conditions, scheduled ferry runs may be canceled. The primary cause of cancelations is mechanical problems on the scheduled ferry. The ferry cancelation logs for 1997-1998 were supplied and analyzed to determine a probability of cancelation for each ferry class. Cancelations resulting from mechanical failure were programmed to occur randomly in the simulation in accordance with the frequencies experienced by the Washington State Ferries in 1997-1998. Cancelations can also be caused by the wind and sea conditions. The ferry captains interviewed gave the risk assessment team possible scenarios in which a captain might decide to cancel a trip. These scenarios were programmed into the simulation and used as environmental cancelation rules.

3.2 Modeling Other Traffic

To simulate the movements of other traffic types, vessel arrivals logs were analyzed. The Canadian Coast Guard operate a Vessel Traffic Service (VTS) at Tofino. This service monitors and logs the transits of deep-draft traffic entering and leaving the Straits of Juan de Fuca. The Tofino traffic arrivals logs for 1994 to 1997 were obtained from the Washington State Department of Ecology. These logs contained some 67,000 recorded transits. The transits were grouped by vessel type, departure location and destination. All transits from or to locations outside the study area were assumed to be through the Straits of Juan de Fuca or the Straits of Georgia depending on the location.

With the specific vessel types on specific routes grouped, a statistical analysis was performed to infer an arrival process that could be used to model the arrivals in the simulation. The arrivals of each vessel type were analyzed for effects of the time of day and seasonal variation. No such effects were indicated. 246 separate arrival processes were modeled to represent the arrivals of commercial vessels into the study area. The United States Coast Guard (USCG) also has a Vessel Traffic Service in Seattle that covers the Puget Sound and San Juan Islands. The traffic logs for 1994 to 1998 were supplied to the risk assessment team and were used to verify the completeness of the Tofino data.

The VTS personnel that monitor traffic in the study area have necessarily developed a detailed knowledge of the movements of traffic in this area. VTS personnel assisted the risk assessment team in developing route specifications for all deep-draft traffic. In addition, federal regulations requires the use of a Puget Sound Pilot on any transit of a deep-draft vessel beyond Port Angeles. Thus each deep-draft vessel in the simulation area is under the control of one of the pilots. As a result, members of the Puget Sound Pilots Association were utilized in developing data on the speed of movement in the various areas of the

Puget Sound and the San Juan Islands as well as to verfiy the vessel routes.

The US Navy supplied yearly counts of the number of transits performed by various types of naval vessels from each of the sites used in the study area. Upon discussion with Naval personnel, it was discovered that for security reasons the departures of naval vessels are purely random. Thus arrivals totaling the counts supplied were sampled at random throughout a simulated year. Specifically, the inter-arrival times were assumed to be exponentially distributed with a mean rate equal to the counts supplied per year.

3.3 Modeling Wind and Visibility

Figure 2 shows the locations of the various data sources used in modeling environmental conditions. National Oceanographic and Atmospheric Administration (NOAA) weather buoys are located at Smith Island, near the entrance to Admiralty Inlet, and at West Point, near Seattle. These weather buoys record wind speed and direction at one-hour intervals. Their location is of importance to ensure the accuracy of the readings for specific areas, so the readings taken reflect the wind experienced on the water at a given location.

The data sources at Sidney, Friday Harbor, Keystone, Seattle and Tacoma come from airports. These readings include the wind speed and direction along with visibility information. However, the readings are taken at various intervals with some lengthy gaps. Five years of data was obtained from each location (1993 through 1997). This data was then used in the simulation to replicate the weather conditions historically observed. In the simulation, weather conditions at a specific location were determined by assigning that location to the nearest weather data source. Missing observations in the data were handled by defaulting to the nearest alternative location.

3.4 Validation of the Simulation

The simulation was validated visually by ferry captains, VTS personnel and Pilots. Several suggestions made by these persons were used to improve the accuracy of the simulation. Each group stated that for the simulated period observed, the situations observed could well have been taken from real life.

4 THE INTERACTION COUNTING MODEL

The simulation itself does not tell us how often each possible situation occurs. A snapshot of the simulation is taken every 2½ minutes of simulation time and the OFI's observed are recorded in an event database. This data recording process is coded into the simulation program itself.

To count OFI's that can lead to a collision, we need only consider interactions between ferries and other vessels (including other ferries). Figure 3 shows a snapshot of Elliott Bay in the simulation. In Figure 3, there are 4 moving ferries represented by the triangles. Which pairs of ferries could be considered an interaction? This depends on the time until the vessels meet and the type of interaction.

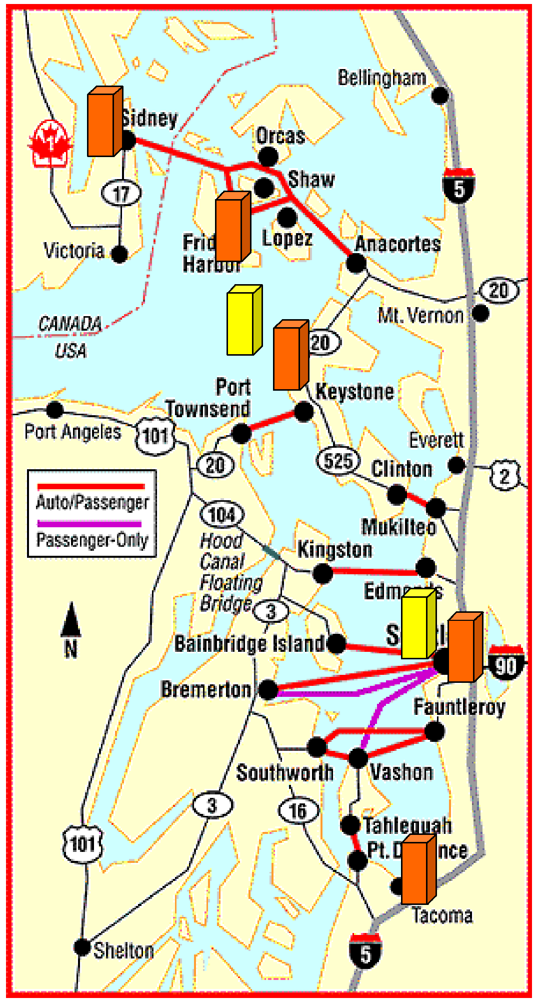

Figure 2: The Locations of the Environmental Data Sources

We are also interested in distinguishing between different types of interactions, as they will affect the risk of a collision. More specifically, if a ferry is within 15 minutes of another vessel and (1) the vessel crosses the ferry track within 1 mile in front of the ferry, or (2) the vessel crosses the ferry track within 0.5 miles behind the ferry, an interaction is counted. If the previous scenario does not hold, but the current distance between the vessel and the ferry is less than 1 mile, an interaction is counted. This counting model is based on a Closest Point of Approach (CPA) type arguments and stems from the considerations that a ferry captain will make when considering interactions with other vessels.

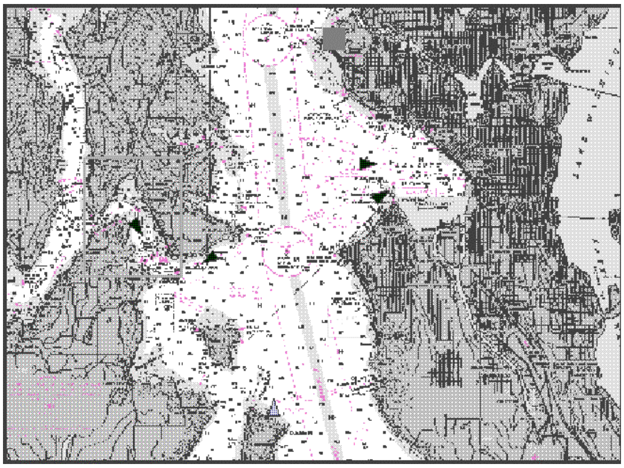

Figure 3: A Snapshot of the WSF Simulation Program

In addition, vessels close in at different speeds, thus in evaluating a situation involving other vessels, the captain is interested in which will arrive first, not necessarily which is closest. Experts with maritime experience outside the ferry service and a group of ferry captains from the Washington State Ferry Service provided input for this methodology.

4.1 Defining Types of Interaction

Figure 4 shows the various types of interactions as defined by the course the other vessel in relation to the ferry. If the other vessel is moving in the opposite direction from the ferry then it will be a meeting situation. If the other vessel is moving in the same direction as the ferry, it will be an overtaking situation (this means the other vessel is moving faster than the ferry). If the vessel is coming from either side and crossing the path of the ferry, in front or behind, then it will be a crossing situation.

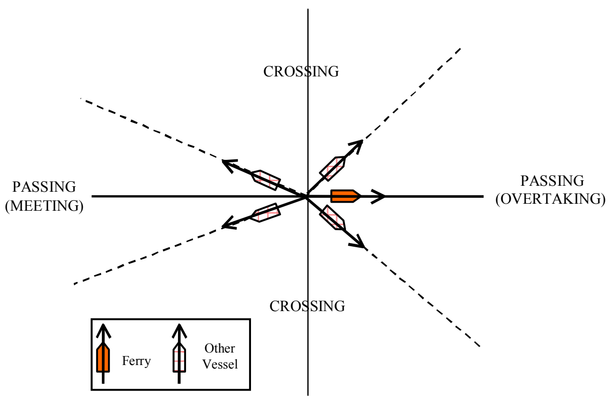

Figure 4: The Type of Interaction Defined by Interacting Angle

4.2 Recording Vessel and Waterway Attributes

Within the simulation program, the snapshot of the simulation at a specific time is analyzed to determine whether an interaction is occurring. For each interaction determined, the information in Table 1 is recorded. Notice that the vessel closest to the ferry is recorded as well as the second closest vessel, as this is a complicating factor in the interaction with the first vessel. Each OFI is recorded in an OFI database. The factors recorded for each OFI are the factors that determine the probability of a triggering incident and the probability of a collision in the incident and accident probability models.

4.3 Estimating Collision Frequencies

A specific OFI is defined by the factors in Table 1. By counting the number of times each OFI occurs in ten years of simulation, the frequency of occurrence of each OFI may be determined. By multiplying this frequency by the probability of a collision for that OFI, calculated from the accident probability model, the statistical frequency of collisions with a specific set of attribute values is determined. By adding together the expected frequencies of collisions with specific sets of attribute values, the overall statistical frequency of collisions can be determined.

However, although the total frequency of collisions per year is of interest, the power of the model comes from the inclusion of risk factors in the model. As an example, suppose we wished to compare the statistical frequency of collisions across ferry routes. To determine the frequency of collision involving ferries on the Seattle-Bainbridge Island route, for instance, we can add together the collision frequencies for collision caused by all OFI's where the route is Seattle-Bainbridge. A similar calculation can be performed for each of the other routes and thus a comparison of collision frequencies by ferry route can be made. A similar comparison can be made sorting by ferry class, 1st interacting vessel type or any combination of the attributes in Table 1.

5 RESULTS OF THE RISK ASSESSMENT

Several recent additions to Washington State Ferry fleet have included the Chinook class high-speed, passenger-only ferries and the Jumbo Mark II class car ferries. The inclusion of these vessels into the ferry service operation has lead to a re-assignment of vessels to routes. Such re-assignments change the system dynamics and thus can cause changes to the levels of risk present in the system and thus require separate consideration.

Before the introduction of the new vessels, the Washington State Ferry fleet had remained relatively stable for 10 years. This period corresponds to the period for which the study team assimilated and analyzed accident and incident data for the WSF System area. Thus we first examine the collision risk for this period, called Scenario 1. This is followed by a discussion of collision risk after the introduction of the two Jumbo Mark II class ferries and the Chinook, called Scenario 2.

5.1 Scenario 1 – Prior to 1997

For Scenario 1, the simulation was programmed to represent the assignments of vessels to routes that existed prior to the introduction of the two new classes of vessels. The ferry schedule used for Scenario 1 was taken from the Fall 1997, Spring 1997 and Summer 1997 sailing schedules published by the Washington State Ferries.

There are two main questions that these models must answer. Firstly, how often do various interactions occur and with what types of vessel? Secondly, for a particular interaction, how likely is a collision? The first question is answered by examining the number of interactions per year, information that is supplied by the simulation model. The second question is answered by the average collision probability given an interaction, which is derived from the collision probability model. These conditional probabilities are estimated using the methods discussed in van Dorp et al. (2001) and Merrick et al. (2000).

Figures 5 to 7 show the three key quantities: the number of interactions per year, the average collision probability given an interaction and the expected number of collisions per year for each ferry route. Figure 5 shows that the highest number of interactions per year are on, in order, the Seattle-Bainbridge ferries, the Edmonds-Kingston ferries, the Seattle-Bremerton car ferries, the Seattle-Bremerton passenger-only ferries and the Fauntleroy-Vashon. These are the main commuter routes in and out of Seattle.

Figure 6 shows that the highest average collision probability per interaction is on Edmonds-Kingston route. This is because a large proportion of the interactions is with non-WSF vessels in the main traffic lanes. 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.

Figure 7 shows that the routes with the highest expected numbers of collisions are those with the highest numbers of interactions. The highest expected number of collisions with a Maximum Required Response Time (MRRT) of less than 1 hour is on the Seattle-Bremerton passenger-only ferries then the Seattle-Vashon passenger-only ferries. These collisions with an MRRT of less than 1 hour can involve high-speed, passenger-only ferries or large non-WSF vessels, such as container vessels, ro-ro vessels and bulk carriers.

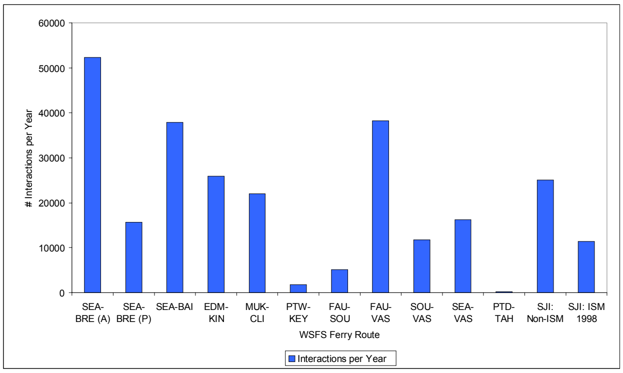

Figure 5: Number of Interactions per Year by Ferry Route under Scenario 1

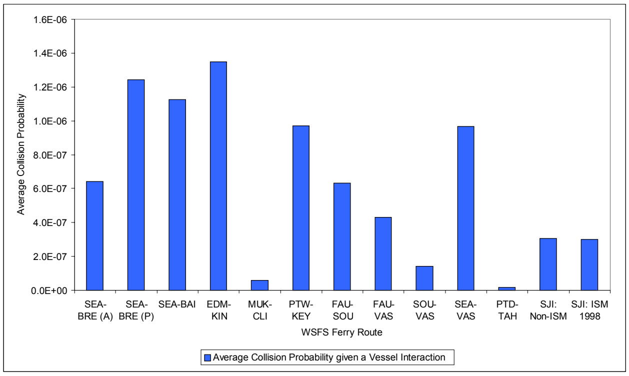

Figure 6: Average Collision Probability given an Interaction by Ferry Route under Scenario 1

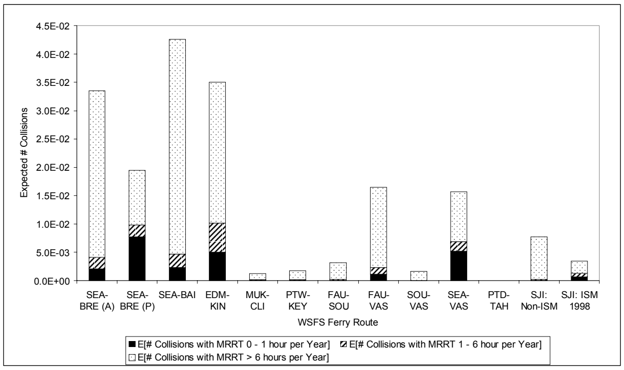

Figure 7: Expected Number of Collisions per Year by Ferry Route under Scenario 1

5.2 Scenario 2 – 1998

The Washington State Ferry Risk Assessment project started in July 1998. At this time, one Chinook class ferry had been delivered and was operating on the Seattle to Bremerton route. Two Jumbo Mark II class ferries also started service on the Seattle to Bainbridge Island route during 1998. To reflect this change to the system, a simulation scenario was developed with these new vessel assignments.

The simulation was programmed to represent the assignments of vessels to routes used after the introduction of the two new classes of vessels. The ferry schedule used for Scenario 2 was taken from the Fall 1998, Spring 1998 and Summer 1998 Sailing Schedules published by the Washington State Ferries. To understand the change in system risk from Scenario 1 to Scenario 2, we shall use the same format in examining the risk in Scenario 2.

Figure 8 shows the number of interactions per year for each ferry route. This figure reinforces the observation that the most congested area is Elliot Bay. The next most congested routes are the Fauntleroy-Vashon route, the Edmonds-Kingston route and the Clinton-Mukilteo route.

Figure 9 shows that the highest average collision probability per interaction is on the Seattle-Bainbridge ferries. 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 Edmonds-Kingston route, the Seattle-Bremerton passenger-only ferries, the Seattle-Vashon passenger-only ferries and the Port Townsend-Keystone ferries.

Comparing Figure 10, for Scenario 2, with Figure 7, for Scenario 1, it can be seen that there is an increase in the proportion of collision with an MRRT of less than 1 hour. The highest expected number of collisions with a MRRT of less than 1 hour is on the Seattle-Bremerton passenger-only ferries. The other collisions in this category are with container vessels, ro-ro vessels and bulk carriers.

We have seen thus far that the introduction of the Chinook in Scenario 2 has lead to an increase in the statistical expected number of collisions with an MRRT of less than1 hour. This can primarily be explained due to both the added interactions of the Chinook and the assertion that collisions involving a Chinook fall in the 0 to 1 hour MRRT Category. However, it is of interest to see if the Chinook on a per interaction basis is in fact a “collision prone” vessel. Figure 11 shows the average collision probability given an interaction for the different classes of vessel. It can be seen that the average collision probability per interaction for the Chinook is roughly equal to that of the older passenger-only ferries and not the highest.

Figure 11 indicates that the highest average collision probabilities per interaction are on the Jumbo and Jumbo Mark II class ferries. In Scenario 2, these ferries are assigned to the Edmonds-Kingston route and the Seattle-Bainbridge route respectively and thus interact with a larger proportion of non-WSF vessels.

5.3 A Comparison of Scenarios

In the previous discussion we have seen that the Chinook class high-speed, passenger-only ferries are of concern due to the severity of a possible collision. In Scenario 1, there are no Chinook class ferries operating, while in Scenario 2, there is one Chinook class ferry. The other major difference between scenarios is the Jumbo Mark II ferries introduced in Scenario 2, but is absent from Scenario 1.

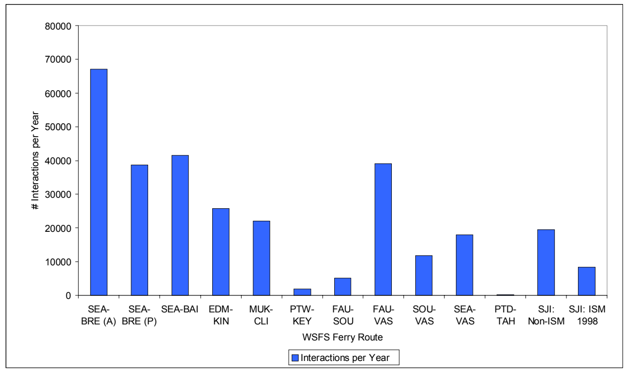

Figure 8: Number of Interactions per Year by Ferry Route under Scenario 2

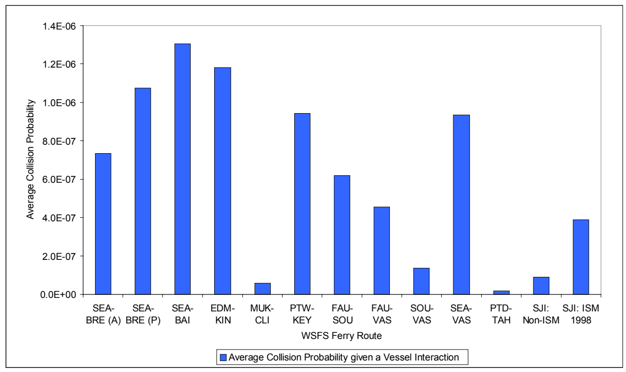

Figure 9: Average Collision Probability given an Interaction by Ferry Route under Scenario 2

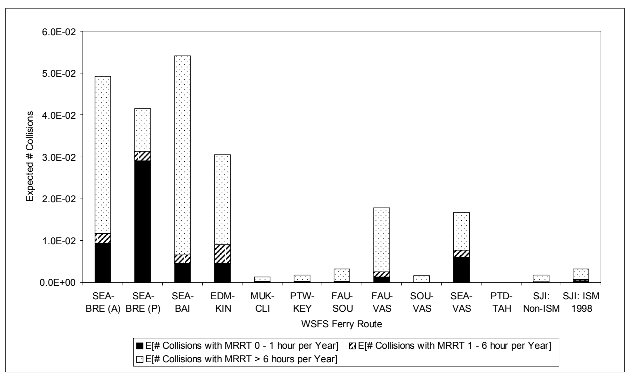

Figure 10: Expected Number of Collisions per Year by Ferry Route under Scenario 2

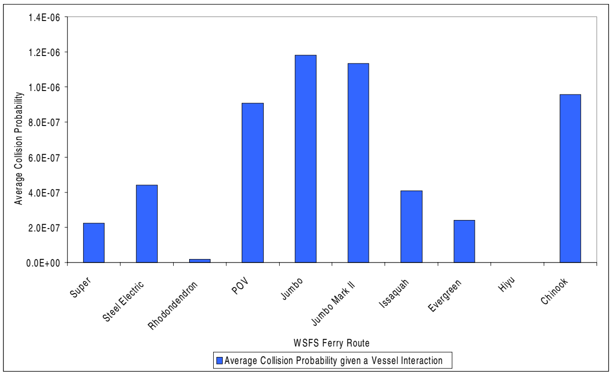

Figure 11: Average Collision Probability given an Interaction by Ferry Class under Scenario 2

Another scenario was considered. On Monday, June 8 1998, Washington State Ferries exercised their option to purchase a second Chinook Class high-speed, passenger-only vessel from Dakota Creek Shipyard in Anacortes, Washington. The second Chinook is projected to replace the passenger-only ferry currently operating on the Seattle to Bremerton route. This will mean that 2 Chinook Class vessels will be operating this route. The schedule used and the assignments of the other ferry classes were the same as specified in Scenario 2. This was called Scenario 3.

Table 2 shows the average time between collisions predicted for each scenario. Examining Table 2, we can see that the replacement of the older passenger-only vessel with a Chinook (Scenario 2 to Scenario 3) has a minimal effect on the average return time of all collisions. However, there is an decrease in the average return time of collisions with an MRRT of less than 1 hour, with an associated increase in the average return time of collision in the other 2 MRRT categories. Thus, although the replacement does not cause any more collisions to be predicted, the collisions that may occur will require faster response times.Through this analysis it becomes apparent that more stringent training and procedural requirements are necessary to minimize the risk contribution of the high-speed ferries.

Table 2: A Comparison of the Three Scenarios by Average Return Time

Scenario	MRRT 0-1	MRRT 1-6	MRRT >6	All
1	41	64	7.1	5.5
2	18	67	6.6	4.5
3	13	79	7.5	4.5

6 CONCLUSIONS

The simulation-based, risk models demonstrate that potential accidents have serious consequences and identify the dominant potential accident scenarios. 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 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%.

Another recent addition to WSF fleet have are the Jumbo Mark II class car ferries, capable of carrying 2,500 passengers. The inclusion of these vessels into the ferry service operation has lead to a re-assignment of vessels to routes. Such re-assignments change the system dynamics and thus can cause changes to the levels of risk present in the system and thus require the use of simulation in estimating their impact. 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.

During 1998, the ferries transiting the San Juan Islands and calling at Sidney, Canada were required to fall under SOLAS regulations and thus the International Safety Management (ISM) system was implemented on these vessels. The ferry service has developed its own Safety Management System to meet the requirements of an external ISM audit by Det Norske Veritas, a major shipping classification company. Washington State Ferries have received approval from the Washington State Legislature and the Washington State Transportation Commission for the fleet-wide implementation of the Safety Management System, thus the study team was asked to assess the impact of ISM on the collision risk.

Through additional analysis of human errors, the single most effective risk management intervention was found to be the fleet wide implementation of ISM. It was 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 the Chinook class ferries, the Jumbo Mark II ferries and the route assignment changes. Funds for fleet wide implementation have been approved by the Washington State Legislature as a result of this analysis. ISM will reduce both the probability of accidents and the consequences if accidents do occur. For additional discussion of the recommendations of the Washington State Ferries Risk Assessment and subsequent actions taken by the various stakeholders see van Dorp et al. (2001).

In summary, the use of simulation in assessing risk in the Washington State Ferries allowed the accurate representation of multiple scenarios reflecting past, present and future operating procedures of the ferry system. The risk models were well capable of answering the questions posed by the Blue Ribbon Panel, the Washington State Ferries and the Transportation Commission.

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