THE ANALYSIS OF ESCORT REQUIREMENTS FOR TANK VESSELS IN PRINCE WILLIAM SOUND

John R. Harrald, Jason Merrick, Thomas A. Mazzuchi, and J. Rene Van Dorp
The George Washington University
2101 Academic Way, Suite 220B
Asburn, Virginia 20147-2604

ABSTRACT: *The Prince William Sound Risk Assessment was a joint project of Det Norske Veritas (DNV), Rensselaer Polytechnic Institute (RPI), and The George Washington University (GWU). The aim of the project was to assess the baseline risk of the system and then to test the effect of proposed risk interventions on the system risk. DNV used a fault tree approach to assess the accident risk, while GWU used a combination of a discrete-event simulation and expert judgment techniques. However, neither of these approaches was found to be sufficient to assess the effect of alternative escort schemes on the system risk. In this paper, three alternative escort schemes are considered for outbound laden tankers in the PWS oil transportation system: continuous escort with two escort vessels, standby coverage, and a combination of a single continuous escort and standby vessels. The approach used takes propulsion and steering failure events sampled from the GWU system simulation and simulates the drift path of the tanker. The drift model incorporates the effect of the dynamically simulated wind, the momentum of the tanker and the current. The advantages and disadvantages of each escort scheme are compared.*

Introduction

The Prince William Sound Risk Assessment was a joint project of Det Norske Veritas (DNV), Rensselaer Polytechnic Institute (RPI), and The George Washington University (GWU). The Prince William Sound Risk Assessment project had three primary objectives: (1) to identify and evaluate the risks of oil transportation in PWS; (2) to identify, evaluate, and rank proposed risk reduction measures; and (3) to develop a risk management plan and risk management tools that could be used to support a risk management program. The PWS Risk Assessment Final Report was submitted in January 1997 to the PWS Steering Committee composed of the PWS shipping companies (ARCO, Sea River, BP, Chevron, and Tesoro), the PWS Regional Citizens Advisory Council (RCAC), the Alaska Department of Environmental Conservation (ADEC), and the U.S. Coast Guard (USCG). The results of the risk assessment and the system simulation risk model developed by GWU are described in the 1997 Oil Spill Conference Proceedings (Harrald *et al.*, 1997). At the conclusion of the risk assessment, the steering committee asked GWU to use the system simulation risk model to investigate if changes to the existing escort procedures could reduce the risk of pollution from both outbound laden and inbound ballasted tankers.

USCG regulations (33 CFR 168) and industry procedures (PWS Vessel Escort and Response Plan) require a continuous escort for all laden tankers in PWS. With the exception of a few tank vessels that arrive with a partial cargo, this requirement applies only to outbound tankers and inbound tankers are not escorted. Industry procedures, as specified in the Vessel Escort and Response Plan, require two or three escort vessels depending upon the tanker size. The PWS risk assessment determined that under certain conditions, the escort vessels would not be able to "save" a disabled tanker at Hinchinbrook Entrance. An enhanced capability tug was stationed at Port Etches on Hinchinbrook Island to guard against this potential. The presence of a tug at Hinchinbrook led to the question of whether an escort made up of one continuous escort, a second close escorting tug through the Valdez Narrow, Valdez Arm, and Hinchinbrook entrance, and standby escorts covering the transit through the Central PWS would provide a more effective escorting scheme.

The objectives of the analysis performed by GWU were:

1. To verify that the proposed escort system was an improvement from the baseline
2. To serve as a new baseline for future risk
3. reduction measures assuming the implementation of the proposed escort scheme

The proposed escort scheme

The analysis. In the proposed escort scheme (Figure 1), two escorts are provided for outbound tankers everywhere but the Central PWS. In the Central PWS, one close escort is provided with another on standby. Thus the effective number of escorts parameter is somewhere between one and two for outbound tankers. For inbound tankers, nearby escorts (including the standby vessels) provide some coverage. This will not always be the case as the escorts may be busy escorting laden tankers and be too far from an inbound tanker to make a save. Thus the effective number of escorts parameter is somewhere between zero and one for inbound tankers.

The following questions need to be answered to verify the proposed escort scheme:

1. What is the effect on the expected number of drift groundings of having a single close escort and a standby escort through the Central PWS for outbound laden tankers?
2. What is the expected number of drift groundings for inbound tankers under the proposed escort scheme?
3. What is the change in collisions from the Revised Base Case provided by the proposed escort scheme?

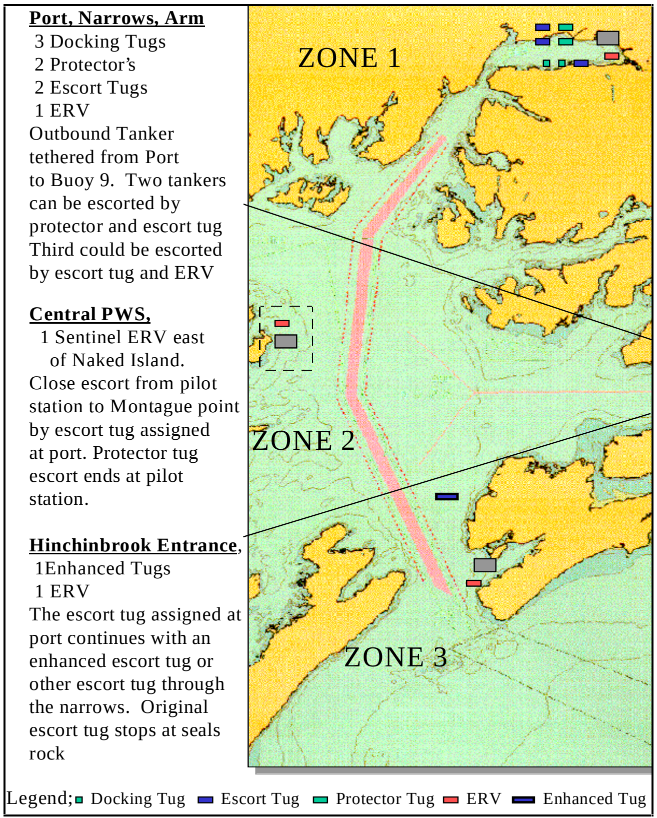

Figure 1. A schematic of the proposed escort scheme—proposed incorporation of protector class tugs.

A two-phase analysis was conducted to answer these questions:

Phase 1 attempts to bound the answers to these questions. Once the bounds have been obtained, a more accurate and detailed analysis may be required to answer some of the questions posed.

Phase 2 would attempt to answer question 1, given above, by sampling propulsion and steering failure situations in the System Simulation and modeling the effectiveness of the proposed escort scheme in each sampled situation using a dynamic simulation of the drift path of the tanker and the escort response.

Phase 1—Obtaining upper and lower bounds. Two sets of simulation runs were necessary to bound the number of accidents under the new Escort Scheme. The difference between the two runs is the assumption of the effective number of escorts for inbound and outbound tankers. Table 1 gives the assumptions for the effective number of escorts in the two runs.

Table 1. Assumed effective escorts.

	Outbound tankers		Inbound tankers	
Location	**Run 1**	**Run 2**	**Run 1**	**Run 2**
Port	2	2	1	0
Narrows	2	2	1	0
Valdez Arm	2	2	1	0
Central PWS	2	1	1	0
Hinchinbrook Entrance	2	2	1	0
Gulf of Alaska	2	2	1	0
Anchorage	2	2	1	0

Table 1 shows that the assumed number of escorts for outbound tankers differs only in the central PWS; Run 1 assumes that the standby escort is always as effective as a second close escort, while Run 2 assumes that it is not as effective. Run 1 assumes that the standby escort vessels are equivalent to one close escort for inbound tankers, whereas Run 2 assumes that they provide no coverage.

The results obtained from these two runs are shown below. For accident scenarios where the results differed, the number that was verified by further analysis is shown. If the minimum or lower bound is used then it is marked with an L and if the maximum or upper bound is used then it is marked with a U.

The answers given by these runs to the questions posed are as follows:

Question 1: What is the effect on the expected number of groundings of having a single close escort and a standby escort through the PWS for outbound laden tankers? Under the proposed escort scheme, the effective number of escorts in the Central PWS for outbound laden tankers is between that obtained with one close escort and two close escorts. Thus the expected number of drift groundings and powered groundings in the Central PWS for outbound laden tankers will be less than or equal to the result obtained from Run 2 and greater than or equal to the result obtained from Run 1.

From the simulation runs performed, it was estimated that the expected number of drift groundings per year of outbound tankers in the Central PWS is between 1.6E-03 (for one effective escort) and 2.7E-03 (for two effective escorts) (Table 2). If the sentinel escort can reach the disabled tanker to assist in a save 80% of the time then the number of accidents will be the same as the Revised Base Case. If it can be shown that the sentinel can assist more than 80% of the time the actual expected number of drift groundings would be very close to the lower bound of 1.6E-03. This will be studied in Phase 2 of this analysis. The total expected number of drift groundings per year of outbound tankers for all locations is between 8.2E-03 and 9.3E-03 of outbound tankers, with the lower bound being the true number if the sentinel escort can assist over 80% of the time in the Central Sound.

The expected number of powered groundings per year of outbound tankers in the Central PWS is between 9.8E-04 and 1.4E-03. The total expected number of powered groundings per year of outbound tankers in all locations is between 6.8E-03 and 8.0E-03. A human error or navigational aid failure causes the occurrence of a powered grounding. The standby escorts are positioned such that if an outbound tanker misses one of the two turns in the Central Sound, then it will be traveling towards the standby vessel. Thus the standby escort provides effective external vigilance and is in position to assist if a save is necessary. Thus for outbound tankers in the Central Sound, the expected number of powered groundings is close to the lower bound found by this analysis. This corresponds to no change in powered grounding accidents for all locations.

Thus from these runs we effectively bound the answer to this question. The total expected number of groundings of outbound tankers is somewhere between no change and a 12% increase from the Base Case determined in the PWS Risk Assessment depending on the effectiveness of the standby escort in the Central Sound. This does not, however, give an exact estimate of the expected number.

Question 2: What is the expected number of groundings for inbound tankers under the proposed escort scheme? Under the proposed escort scheme, the effective number of escorts for inbound tankers is between zero and one. Thus the expected number of groundings in each location for inbound tankers will be less than or equal to the result obtained from Run 2 and greater

Table 2. Percentage change from the Revised Base Case in average number of accidents (outbound).

Location	Drift grounding	Powered grounding	Foundering	Structural	Collision	Total
Port	0%	2%	0%	0%	12%	8%
Narrows	-1%	1%	-1%	-1%	0%	-1%
Arm	-1%	-1%	0%	0%	-1%	-1%
Central Sound	-3%^{L}	2%^{L}	-3%^{L}	-2%^{L}	-6%^{U}	-4%
Hinchinbrook	-1%^{U}	-3%	-1%	0%	-24%	-10%
Gulf	-1%	-1%	0%	0%	3%	0%
Anchorage	0%	0%	0%	0%	0%	0%
Total	-1%	0%	-1%	-1%	-2%	-1%

than or equal to the result obtained from Run 1. Thus from these runs we may bound the answer to this question.

From the simulation runs performed, it was estimated that total expected number of drift groundings per year for all locations is between 1.1E-02 and 3.0E-02 of inbound tankers (Table 3). In Phase 2 of the analysis, drift-grounding simulations will be used to verify that the sentinel escort system provides coverage for inbound tankers in the Central Sound equivalent to one close escort. The degree of coverage provided by the sentinel escort system in other locations is not demonstrated, thus the upper bound of the number of accidents must be assumed in locations other than the Central Sound. However, even if the standby escorts provide no effective escorts in areas other than the Central Sound, the efficiency of the new system will reduce the expected number of drift grounding accidents. If coverage equal to one close escort is provided by the standby escorts in all locations then the reduction in accidents for inbound tankers is large.

The total expected number of powered groundings per year of inbound tankers in all locations is between 6.0E-03 and 8.0E-03. Even using the upper bound of the number of accidents this is an overall reduction of 17%. This is due to decreased interactions with other vessels, specifically escort vessels, outbound tankers and fishing vessels, and decreases even without effective tanker coverage.

Question 3: What is the change in collisions from the Revised Base Case provided by the proposed escort scheme? The expected number of collisions given by either run will be the same for outbound tankers. This number will give an accurate estimation of the average number of collisions under the new escort scheme.

However, it can be seen from Table 1 that the expected number of collisions increases in the Port (11%), Arm (2%) & Narrows (2%). Taking the Port as an example, the expected number of collisions with tankers and SERVS vessels increases by 38% while the expected number of collisions with other vessels decreases by 6%. Under the new escort scheme, the tankers actually interact less with other vessels, but more with other tanker related vessels. This interaction previously happened in Hinchinbrook Entrance and the Central Sound, but it has been transferred to the Port, Valdez Arm and the Narrows. The expected number of collisions of outbound tankers is reduced in the Central Sound and Hinchinbrook Entrance and thus the total expected number of collisions of outbound tankers in all locations under the proposed escort scheme is reduced by 2% from the Revised Base Case.

The total expected number of collisions of inbound tankers under the proposed escort scheme is between 2.7E-02 and 3.0E-02, which is between a 26% and a 18% decrease from the Revised Base Case. This is due to reductions in the number of collisions with other tankers and escort vessels.

Conclusions from Phase 1. For outbound tankers, the uncertainty that remains after Phase 1 analysis has been performed is in the number of drift grounding accidents caused by disabled tankers in the Central Sound. If the sentinel escort, which is underway east of Naked Island, can assist in a save 80% of the time then the number of accidents of outbound tankers will be the same as in the Revised Base Case.

The total expected number of accidents of inbound tankers is reduced by a minimum of 18% from the Revised Base Case, while the oil outflow from accidents of inbound tankers also reduces by a minimum of 18%. Assuming an 80% intervention rate for the standby vessel in areas other than the Central Sound, the expected reduction in inbound accidents would be approximately 35%.

In this analysis, a range is obtained for the expected number of drift groundings, powered groundings and foundering in the Central Sound for outbound tankers and in all locations for inbound tankers. In Phase 2, analysis was performed to determine more precisely the expected number of drift groundings of outbound tankers in the Central Sound.

Phase 2—Simulation analysis of drift groundings in the Central Sound. In Phase 1 of this analysis, the expected number of drift groundings of outbound tankers in the Central sound was bounded. The expected number was found to be between 1.6E-03 and 2.7E-03 per year. The lower bound is that obtained when the outbound tankers are assumed to have two close escorts (or

Table 3. Percentage change from the Revised Base Case in average number of accidents (inbound).

Location	Drift grounding	Powered grounding	Foundering	Structural	Collision	Total
Port	-2%^{U}	-1%^{U}	-2%^{U}	-1%^{U}	1%^{U}	0%
Narrows	0%^{U}	3%^{U}	0%^{U}	0%^{U}	7%^{U}	3%
Arm	-6%^{U}	-14%^{U}	-5%^{U}	-5%^{U}	-17%^{U}	-14%
Central Sound	-66%^{L}	-42%^{L}	-25%^{L}	-15%^{L}	-38%^{U}	-49%
Hinchinbrook	0%^{U}	-9%^{U}	0%^{U}	0%^{U}	-26%^{U}	-9%
Gulf	0%^{U}	0%^{U}	0%^{U}	0%^{U}	1%^{U}	0%
Anchorage	7%^{U}	1%^{U}	5%^{U}	4%^{U}	-3%^{U}	3%
Total	-18%	-17%	-9%	-6%	-18%	-18%

equivalent), while the upper bound is obtained by assuming that the outbound tankers have only one close escort (or equivalent). The actual escort coverage for outbound tankers in the Central Sound is one close escort and one standby escort. Thus the remaining question is: "What percentage of times will the standby escort provide equivalent coverage to a second close escort?"

The proposed technique for this analysis was a static vector analysis. However, it was believed that this approach would not accurately model the dynamic nature of a drifting tanker and may lead to inaccurate answers. Thus a drifting tanker simulation was used to count drift times. A worst case current was assumed of 1 knot to the west. Some examples of drift paths are shown in Figures 2 and 3. Figure 2 shows an example of the shortest drift path, while Figure 3 shows one of the longest drift paths.

Two counts were kept in the simulation:

1. The time until the standby escort reaches the drifting tanker
2. The time until the drifting tanker runs aground assuming no assistance from the escorts

The second count assumed that no assistance would be provided to the drifting tanker by the single close escort and thus represents a worst case.

Figure 4 shows the distribution of times sampled between the occurrence of the propulsion or steering failure and the standby escort reaching the disabled tanker. The response times are almost always less than 1.5 hours. In Figure 5, the distribution of times sampled between the occurrence of the propulsion or steering failure and the disabled tanker running aground (assuming that no assistance was given by the escorts). 15% of the drift times are above 12 hours and are thus not shown in Figure 5.

The time of interest is the difference between these two times; this represents the time that the standby escort has before the disabled tanker runs aground. This is the time available to assist the close escort in making a save.

Even assuming that the tanker is not being slowed at all by the single close escort, the second escort will be with the drifting tanker for at least one hour 96% of the time. This calculation is

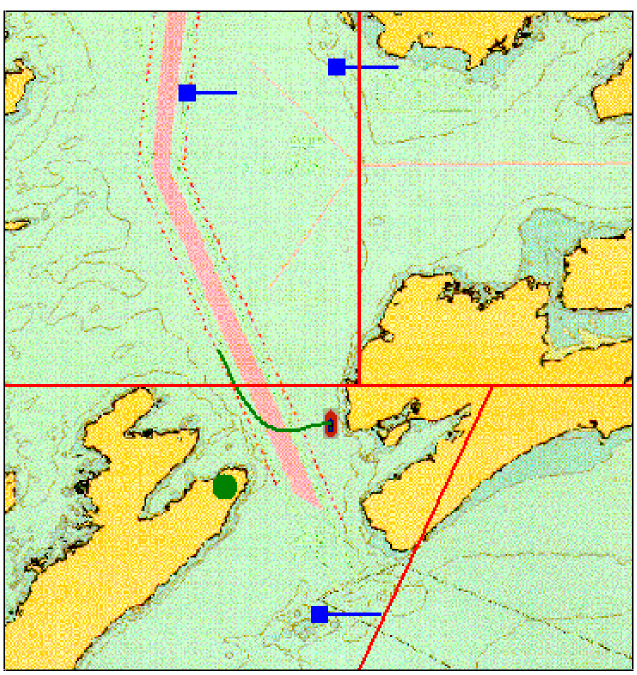

Figure 2. A short drift time scenario.

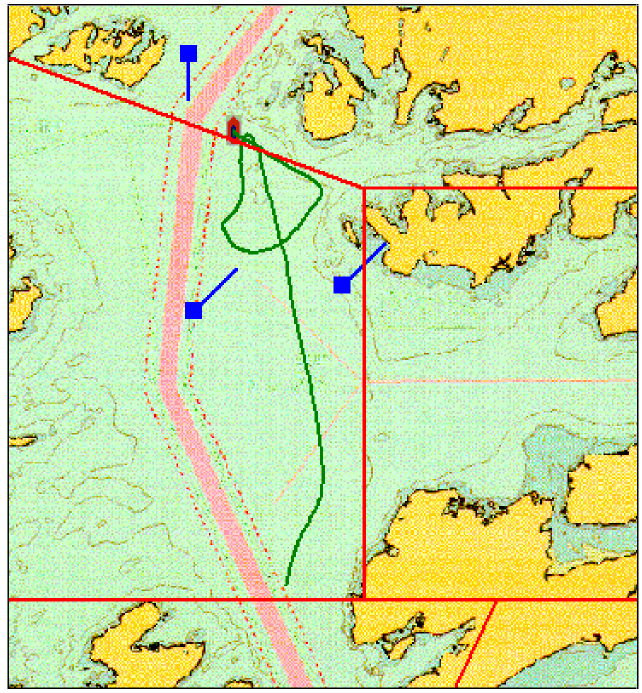

Figure 3. A long drift time scenario.

made assuming that the current is at its highest speed of 1 knot towards Naked Island and assuming that the escorts have no slowing effect on the drifting tanker until the save is made. In almost all sampled situations, the second escort will reach the disabled tanker with much longer than an hour to assist in the save. It should be noted that each of the escorts has the ability to hold any tanker in the PWS calling fleet in any conditions seen in the Central Sound once a line was attached.

The results of the two-phase analysis

1. The save coverage for groundings supplied by the proposed escort system to outbound tankers is equivalent to that supplied by the old escort scheme, with two or three continuous escorts to Hinchinbrook. In Phase 1, an upper and lower bound was obtained for the long-term average number of drift groundings of outbound tankers in the Central Sound. The lower bound was obtained by assuming that there were two close escorts, while the upper bound assumed that there was only one close escort. In Phase 2, it was demonstrated through simulations of the tanker drift path that the save coverage for drifting tankers is equivalent to two close escorts at least 96% of the time. Thus the actual long-term average is statistically equivalent to the lower bound.

For powered groundings, the escort vessel underway east of Naked Island is in position to intercept a tanker that has missed the first turn in the Central Sound for outbound tankers. The additional escort at Hinchinbrook Entrance comes out to meet the approaching outbound tanker, positioning itself at the boundary between zones 2 and 3 and thus can intercept the tanker if it misses the second turn in the Central Sound. Thus the effect of the standby escort on the number of powered groundings is the same as if it were in close escort. It may be concluded that the standby vessel and single close escort of outbound tankers through the Central Sound gives equivalent coverage to that in the Revised Base Case.

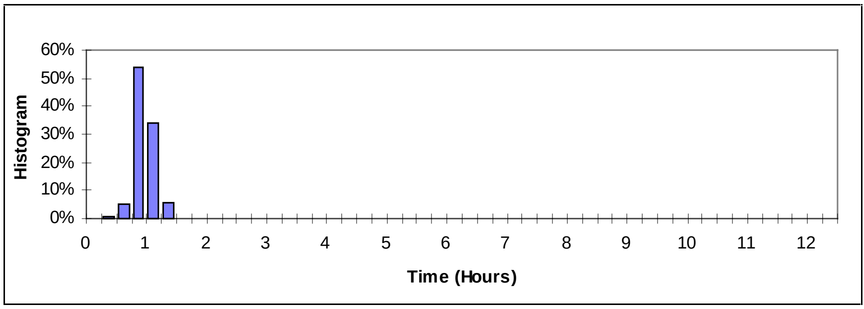

Figure 4. The distribution of times the standby escort took to reach the drifting tanker.

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Figure 5. The distribution of times between the failure event and the tanker running aground.*15% of the sampled drift times were over 12 hours.

2. The long-term average number of collisions remains the same for outbound tankers but has been reduced by at least 18% for inbound tankers. For outbound tankers, a 12% increase in collisions in the Port is offset by decreases of 24% and 6% in Hinchinbrook Entrance and the Central Sound, respectively. This is because one of the SERVS vessels that leaves dock with the outbound tanker turns back at the pilot station instead of at Hinchinbrook Entrance as in the old escort scheme. For inbound tankers, the number of collisions with SERVS vessels and other tankers is reduced by the new scheme.

3. As the sentinel escort in the Central Sound is underway east of Naked Island for inbound tankers then the total reduction in drift groundings for inbound tankers is 18%, while powered grounding have been reduced by 17% respectively. The drift simulations performed for outbound tankers also show that the sentinel escort will provide coverage for inbound tankers in the Central Sound as it is underway. Thus the reduction in drift groundings for inbound tankers that has been verified so far is 18%. It is noted that as this sentinel is in operation at this time, coverage for inbound tankers and its associated risk reduction has already been realized.

4. The degree of coverage supplied by the standby escorts to inbound tankers in areas other than the Central Sound was not calculated in this analysis. The results of the drift grounding simulations performed in the Phase 2 analysis would imply that the escort vessel underway east of Naked Island would provide coverage equivalent to one close escort for inbound tankers in the Central Sound. The long-term average number of groundings depend on the % of times that the standby escorts can give effective coverage to inbound tankers. The long-term average number of drift groundings of inbound tankers will be reduced by between 18% and 63%, while the long-term average number of powered groundings will be reduced by between 17% and 34%. The lower of each of these ranges corresponds to the standby escort providing no coverage to inbound tankers except in the Central Sound, while the higher reduction corresponds to the standby escorts providing coverage equivalent to one close escort in all locations. The number of accidents is shown to increase in the Anchorage location. This increase is caused by a small increase in the number of times the tanker must go to Anchorage. However, the actual number of accidents in this location is relatively small and this increase is not significant.

To summarize, the effect of the proposed escort scheme:

- The long-term average of the total number of accidents for outbound tankers is the same as the Revised Base Case and may be better if the new escort vessels are shown to give better save capability;
- The long-term average of the total number of accidents for inbound tankers is reduced by at least 18%.

The reduction will be significantly larger if simulations of inbound tanker drift paths can verify the degree of coverage given to inbound tankers in areas other than the Central Sound. The reduction justified thus far in the total number of accidents is 13%, while the reduction in the total oil outflow is 4%.

Significance of results

The results of the analysis described in this paper will help the PWS Tanker Association and the USCG to optimize the escort rules and procedures for Prince William Sound. The results also have implications for other ports where escorts are required (e.g., Puget Sound and The Strait of Juan de Fuca), and where standby vessels used in conjunction with or instead of continuous escorts may provide an equivalent or superior level of protection.

Biography

Dr. John Harrald is the Director of the Institute for Crisis, Disaster, and Risk Management and Professor of Engineering Management at the George Washington University. He served as a USCG officer for 22 years and received his Ph.D. from Rensselaer Polytechnic Institute.

Dr. Thomas A. Mazzuchi is Professor of Operations Research and Interim Dean of the School of Engineering and Applied Science at The George Washington University. He received his D.Sc. from The George Washington University

Dr. Jason Merrick is a Professor of Operations Research in the Department of Mathematical Sciences at the Virginia Commonwealth University. His specialty is computer simulation and probabilistic risk analysis. He received his D.Sc. from The George Washington University.

Dr. J. Rene Van Dorp is a Visiting Assistant Professor of Engineering Management at The George Washington University. He received his D.Sc. from The George Washington University.

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