Development of a Tool for Assessing the Requirements for Vessel Traffic System in US Ports and Waterways

a preliminary report to

The United States Coast Guard

by

THE GEORGE WASHINGTON UNIVERSITY
INSTITUTE FOR CRISIS, DISASTER, AND RISK MANAGEMENT

July 6, 1998

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Table of Contents

PROBLEM DESCRIPTION

The Ports and Waterways Safety Act of 1972 directed the U.S. Coast Guard to maintain an "acceptable level of safety" in the ports and waterways of the U.S. The law established an explicit, but subjective, goal for the Coast Guard's historic waterway management function. The realization of this goal implies the ability to measure and to quantify both the level of risk in any waterway and the risk reduction value of safety interventions such as aids to navigation systems, pilotage, and vessel traffic systems. In particular, it has been difficult to establish justifiable criteria for selecting ports requiring vessel traffic systems and for determining the level of sophistication of the vessel traffic management system required. In September 1996, Congress directed the USCG to reexamine the Vessel Traffic Service acquisition with focus on meeting user needs. The USCG sponsored a National Dialogue Group on VTS that developed factors for consideration, but did not establish measurable criteria.

This report outlines a process for developing a port evaluation tool to be used as the basis for a systematic approach for identifying ports in need of new VTS technology and for establishing the level of technology required. The tool is based on the technologies of eliciting and structuring the judgment of experts representing port users, and combining this knowledge base with available quantitative data to estimate the current level of safety in a port and the potential reduction in risk achievable through a VTS intervention. The first expert panel session was been completed at the GWU Management Decision Center in Ashburn, VA on July 6, 1998. This report outlines the technique used and the results of the session.

The level of investment for a VTS should be determined by the possible risk reduction resulting from that investment. A potential decision matrix is shown in Figure 1.

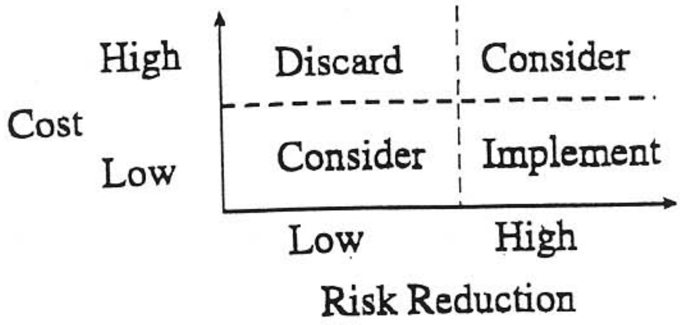

Figure 1. The trade-off between cost and risk reduction.

To rate the safety improvement of a VTS implementation accurately would require a full risk assessment. This would be too costly and too lengthy a process to perform for each port or waterway under consideration. The alternative is a small timeframe, low cost approach that gives rough estimates of the safety improvement.

Figure 2 shows a taxonomy of the events that lead to a maritime accident. The effect of the organizational and situational factors is also shown. The assessment tool should take the role of these factors into account.

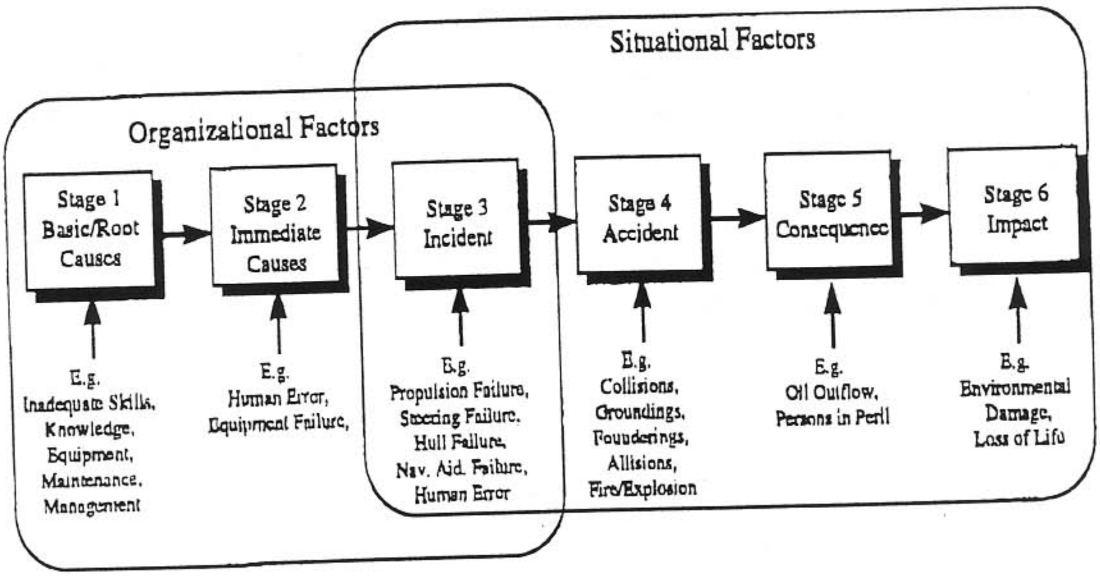

Figure 2. A taxonomy of the accident event chain.

The safety improvement can then be estimated by considering the effect of the VTS implementation on the accident event chain, as shown in figure 3.

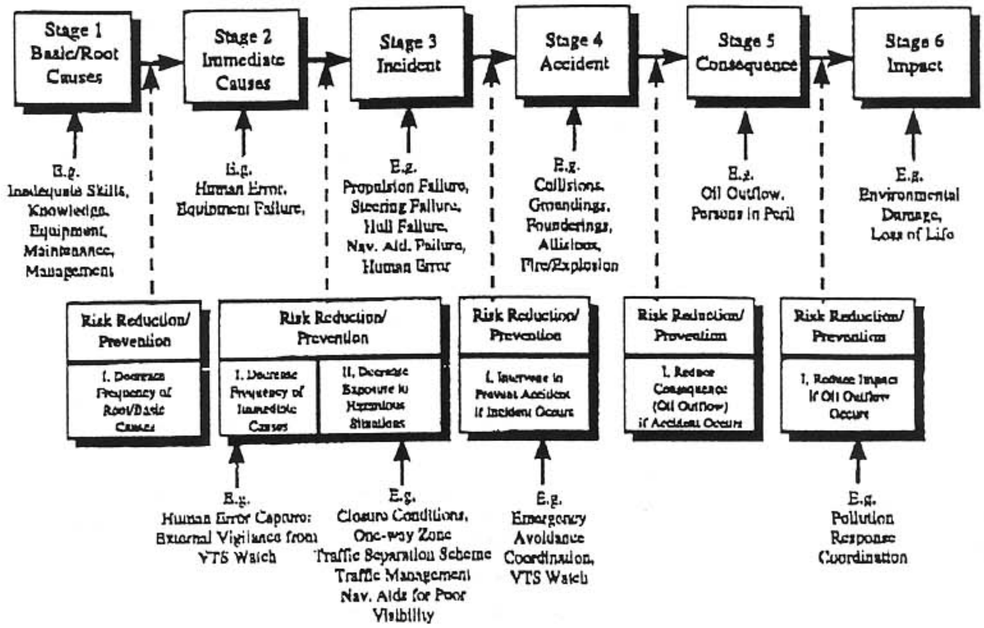

Figure 3. The role of a VTS in improving system safety.

OBJECTIVES

The objective of this project is to develop a computer based set of tools that can be used by the USCG to assess the VTS requirement for each of the major Ports and Waterways in the United States. Two questions must be considered to assess the requirement:

1. What are the environmental, safety and economic consequences of having or not having a VTS within the port given the currently implemented safety systems?
2. What is the level of investment that can be justified by the improvement in the system safety?

To this end the decision support tools must allow experts to:

- identify the dominant risk factors and subjectively evaluate both the probability of each risk factor occurring and the consequence if it does occurs; and
- identify and subjectively evaluate the current risk reduction interventions.

The questions to be considered in determining the dominant risk factors include:

- What are the existing or likely future conditions in the port with respect to traffic density, traffic patterns and complexity or traffic or vessel movements?
- What are the sizes, types and numbers of vessels operating in the port area?
- What is the history (including the causes) of accident, casualties, pollution incident and other vessel safety problems within the port area?

- What are the physical limitations of the port?
- What types and amounts of hazardous or environmentally sensitive cargoes are transported within the port?
- What are the prevailing conditions and extremes of weather and oceanography in the port?

The method proposed uses the Analytic Hierarchy Process (AHP) approach and is implemented using the *Expert Choice* software package. The approach taken involves two steps and therefore two hierarchical models. The first step is to rank the risk in the ports or waterways around the United States. This involves identifying the major indicators of risk. This will include the traffic conditions, weather and waterway configuration indicators that lead to a high accident probability along with the factors that affect the impacts and consequences of accidents that may occur. Using this ranking, the ports or waterways at the top of the scale are identified as candidates for further study.

A second model evaluates the relative benefits to a port or waterway of the various levels of VTS implementation. The hazard identification, hierarchical model development and expert judgment codification that are involved in the approach should be performed for the critical ports identified by the first model. The second model will assess the current risk, known as the baseline risk, and then estimate the effect on the risk of each level of VTS implementation.

A MODEL FOR RANKING PORT RISK

The aim of this model is to rank the accident risk in a list of ports or waterways. The model must, therefore, include the major contributors to or indicators of accident risk. Hierarchical models are used to break down a complex value, such as risk, into its constituent parts. The first level of the tree consists of the criteria that make up this complex value. In our case, the value to be modeled is the accident risk in a port or waterway. As stated previously, risk can be defined as the probability of an unwanted event times its impacts or consequences. The criteria that make up the risk are, therefore, the criteria that effect the accident probability and the criteria that effect the impacts or consequences.

Figure 4 shows the risk model. The value to be assessed is shown in the dark gray box at the top of the tree. The criteria are shown in light gray. The criteria that effect the accident probability are the traffic conditions, the traffic composition, the weather conditions and the waterway configuration. The criteria that effect the impacts or consequences are also included.

The final level of the hierarchy tree consists of measures of the criteria. These measures are either data driven or estimable by experts. For instance, the traffic volume and density can be obtained from vessel transit logs, whereas there is no well-defined measure of environmental sensitivity. For measures that cannot be directly measured, qualitative descriptions of the levels of the criteria will be used and an expert panel will be asked to

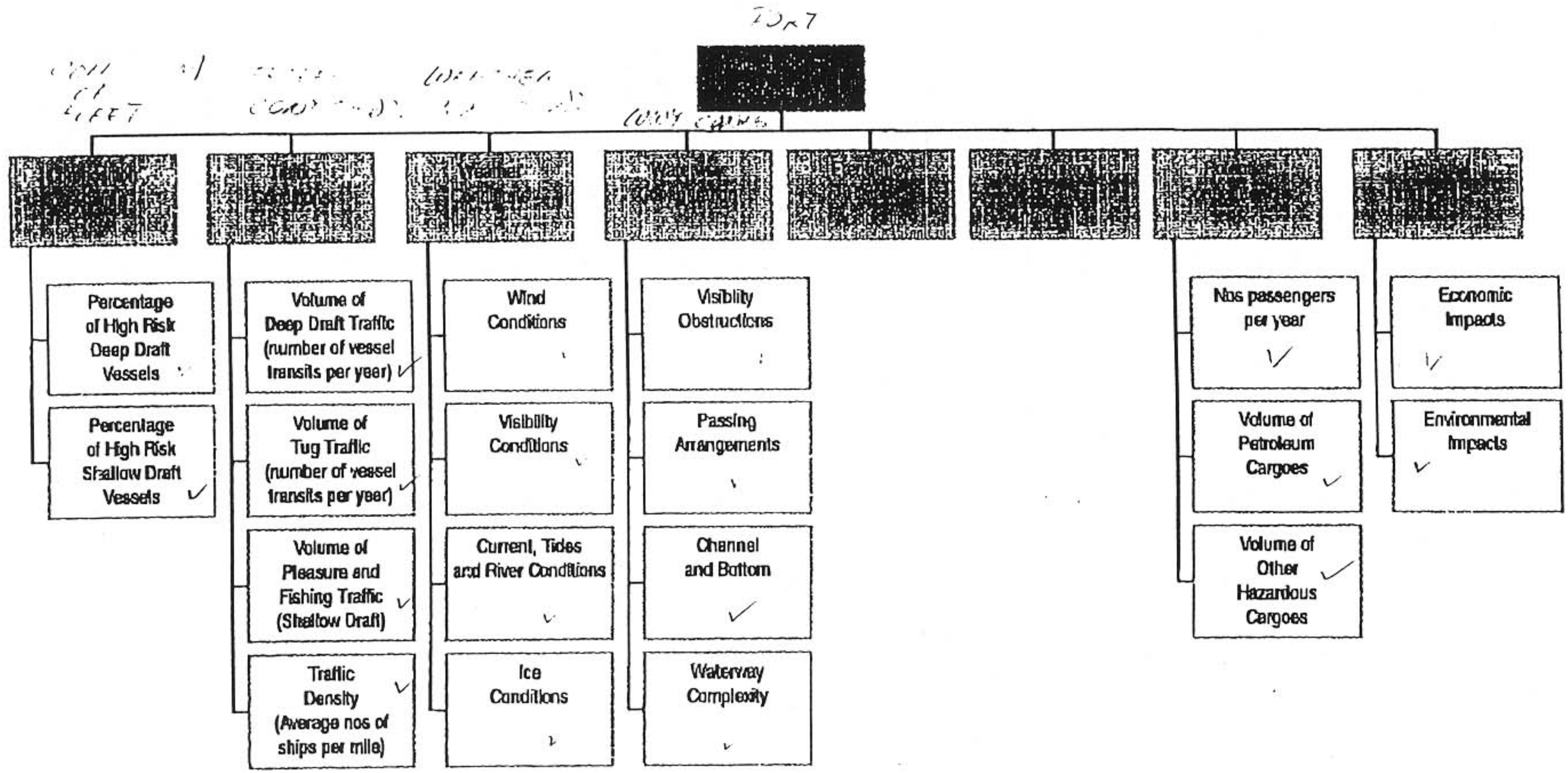

Figure 4. A hierarchical model of risk in a port or waterway.

make pairwise comparisons of the risk contribution of each level of the criteria. The qualitative descriptions used are taken from the report to the Coast Guard by the National Dialogue Group on VTS.

For each criterion and for each criterion measure, weights will be elicited from an expert group. These weights will indicate the importance of the criteria or measures to the risk in the port or waterway. The tree is then computed from the bottom up using the pairwise comparisons and weights to obtain a ranking of the relative risk of the list of ports and waterways. The historical accident and incident rate will be used to validate and then calibrate the model.

THE ELICITATION METHOD

The Best Case Ports or Waterways

Each of these minimum levels of the criteria corresponds to a situation in a port or waterway around the United States.

Criteria	Minimum Level	Example Port
Fleet Composition	**Low %s of high risk vessels**	**San Diego Valdez/PWS**
Traffic Conditions	**Low volume and density of traffic**	**Valdez/PWS Fort Lauderdale/ Port Everglade**
Wind Conditions	**Infrequent severe winds, poor visibility. Current negligible and no ice.**	**San Diego Los Angeles/ Long Beach Hampton Roads**
Waterway Complexity	**No blind turns or intersections. Meetings and overtaking are accomplished with ease. Deep water outside of channel or T.S.S. or no channel is needed. Straight run with no crossing traffic.**	**Fort Lauderdale/ Port Everglade Los Angeles/ Long Beach**
Potential Consequences	**Low nos. of passengers and low volumes of petroleum and other hazardous cargoes.**	**Columbia River Wilmington St. Mary's River**
Potential Impacts	**Small human population, but little or no other consequences. Not an environmentally sensitive area.**	**St. Mary's River Port Canaveral**

Table 1. A description of the port representing all best cases.

The Worst Case Ports or Waterways

Each of these maximum levels of the criteria corresponds to a situation in a port or waterway around the United States.

Criteria	Minimum Level	Example Port
Fleet Composition	**High %s of high risk vessels**	**Lower Mississippi** **Houston/Galveston**
Traffic Conditions	**High volume and density of traffic**	**Lower Mississippi** **Houston/Galveston** **Mouth of Ohio River**
Weather Conditions	**Severe winds and poor visibility frequently occurs without warning. Currents run across the channel or make turn points difficult or treacherous. Ice in the traffic lanes.**	**Anchorage** **Valdez/PWS** **St. Mary's River**
Waterway Complexity	**Distances and communications are severely limited by geography. Movements restricted to one way traffic in some areas. Hard or rocky bottom lines the channel edges. Converging waterways with crossing traffic.**	**New York Harbor** **Berwick Bay** **San Francisco** **Mouth of Ohio River**
Potential Consequences	**High nos. of passengers and high volumes of petroleum and other hazardous cargoes.**	**New York Harbor** **Houston/Galveston** **Valdez/PWS**
Potential Impacts	**Large fishery or port operations with dependent community. Environmentally sensitive area with wetlands, fisheries and endangered species.**	**San Francisco** **Valdez/PWS** **Puget Sound** **New York Harbor**

Table 2. A description of the port representing all worst cases.

The Elicitation Technique

Experts were asked to compare criteria in pairs. For instance, the first comparison was traffic composition and traffic conditions. The criteria were defined for them and examples of the worst and best cases given for illustration. The experts were then asked to imagine a port that consisted of the worst cases in the two criteria. For instance, considering traffic composition and traffic conditions, Port Galveston is a worst case for both. The experts were then told to consider changing one criterion to a best case level and given a port to imagine for the best case. They were asked which criteria they would most like to reduce to the best case level and by how much. A graphical comparison was made of the two criteria.

This process was repeated for each pair of criteria to obtain the weights at the top level of the tree. The expert choice tool used gives a measure of consistency between all the comparisons made. The experts achieved a rating of 0.03, which is very good.

A similar technique was used for the sub-criteria level. However, as there were at most four sub-criteria under each criterion, all sub-criteria were compared at one time. The experts were again asked to consider a port with the sub-criteria at worst case levels and compare which they would most like to reduce to the best case.

RESULTS OF THE EXPERT PANEL SESSION

Criteria Weightings

The weights elicited for the top-level criteria are shown in table 3.

Criteria	Weight
FLEET	0.10
TRAFFIC	0.12
ENV. CDN	0.24
WATERWAY	0.35
CONSEQ.	0.09
IMPACTS	0.11

Table 3. The criteria and their elicited weightings.

The waterway configuration was considered to be the largest contributor to risk in a port, with environmental conditions second. The other criteria were considered relatively similar in contribution to risk. Figure 1 shows the criteria ranked by their elicited risk.

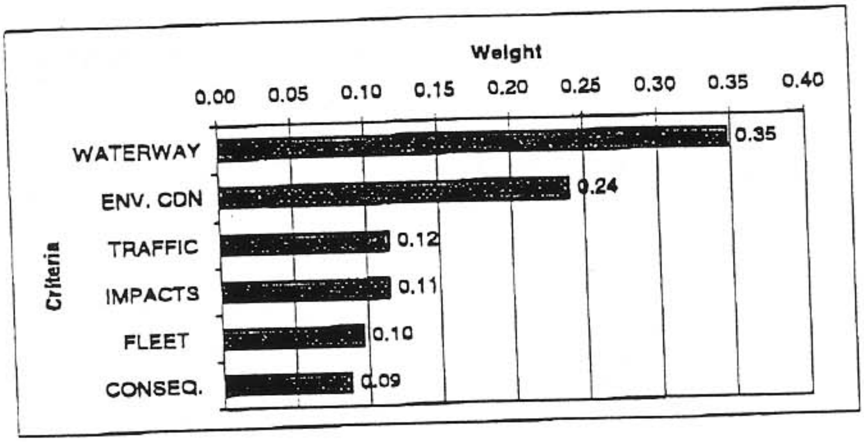

Figure 5. The criteria ordered by the elicited weights.

Sub-criteria Weightings

The weights elicited for the top-level criteria are shown in table 4.

Criteria	Sub-Criteria	Weights
COMPOSITION	DP DRAFT	0.0328
	SH DRAFT	0.0633
TRAFFIC	DDFT VOL	0.0032
	TUG VOL	0.0082
	REC&FISH	0.0174
	DENSITY	0.0864
ENV. COND.	WIND	0.0590
	VISIBLTY	0.0703
	CURRENTS	0.0597
	ICE	0.0506
WATERWAY	OBSTRUCT	0.0903
	PASSING	0.0278
	CHANNEL	0.0903
	COMPLEX	0.1390
CONSEQ.	PASSENGR	0.0493
	PETRO	0.0123
	HAZCARGO	0.0251
IMPACTS	ECONOMIC	0.0197
	ENVIRON	0.0388
	HEALTH	0.0563

Table 4. The sub-criteria and their elicited weightings.

Traffic Composition: The proportion of high-risk shallow draft vessels was considered approximately twice as important as the proportion of high risk deep draft vessels.

Traffic Conditions: The traffic density was considered by far the biggest contributor to risk. Volume was less important, with smaller vessels considered more risky in high volumes.

Environmental Conditions: Poor visibility was considered slightly more risky than the other sub-criteria, ice slightly less risky and severe winds and currents roughly equal.

Waterway Configuration: Waterway complexity was considered the most significant contributor to risk, with visibility obstructions and the channel and bottom equal. Passing arrangements were considered less significant because they were seen to be a result of the other sub-criteria.

Potential Consequences: High volumes of passengers were considered the largest risk, with non-petroleum cargoes next and then petroleum cargoes.

Potential Impacts: Health and safety impacts were considered the largest contributor to risk, then environmental impacts and then economic impacts.

Figure 2 shows the sub-criteria ranked by the elicited weights.

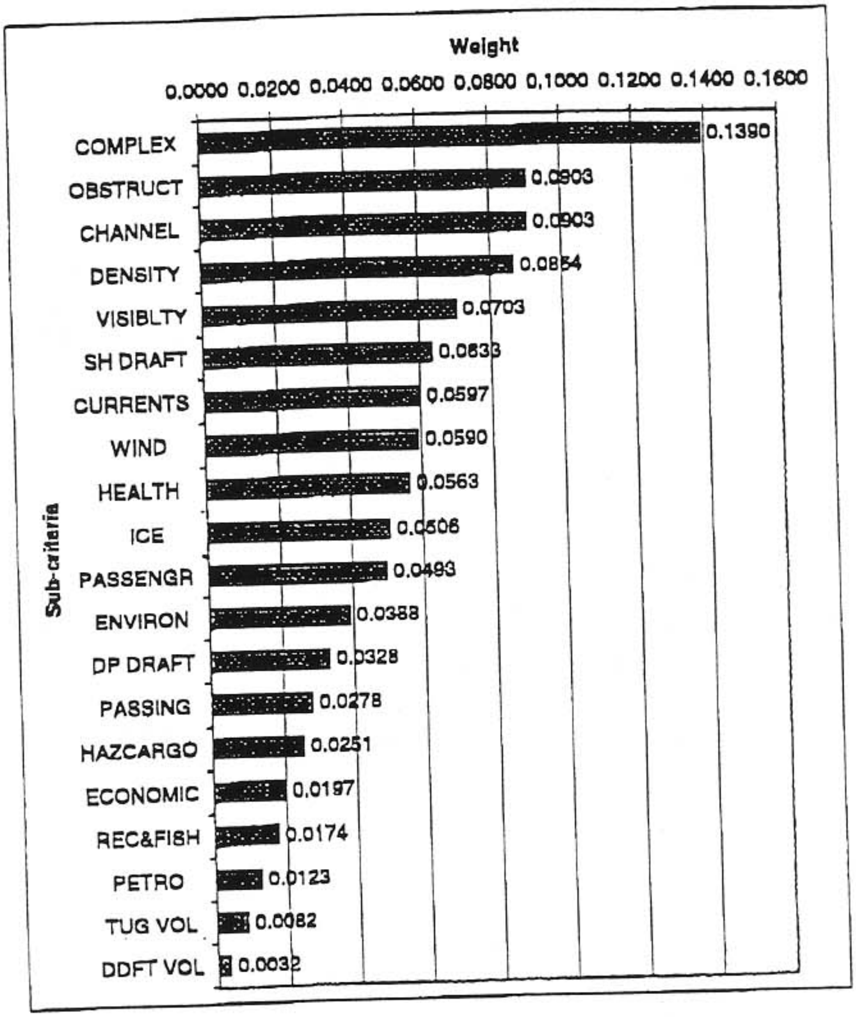

Figure 6. The sub-criteria ordered by the elicited weights.

A MODEL FOR ASSESSING RISK REDUCTION DUE TO A VTM

The aim of the second model is to assess the relative benefits of various levels of VTM implementation. The model is based on the upper level of the first model. Below each criterion from the first model, the possible levels of VTM implementation are listed. Figure 7 shows the model developed. The experts are asked to compare the levels of implementation considering the associated changes to the system for that criterion.

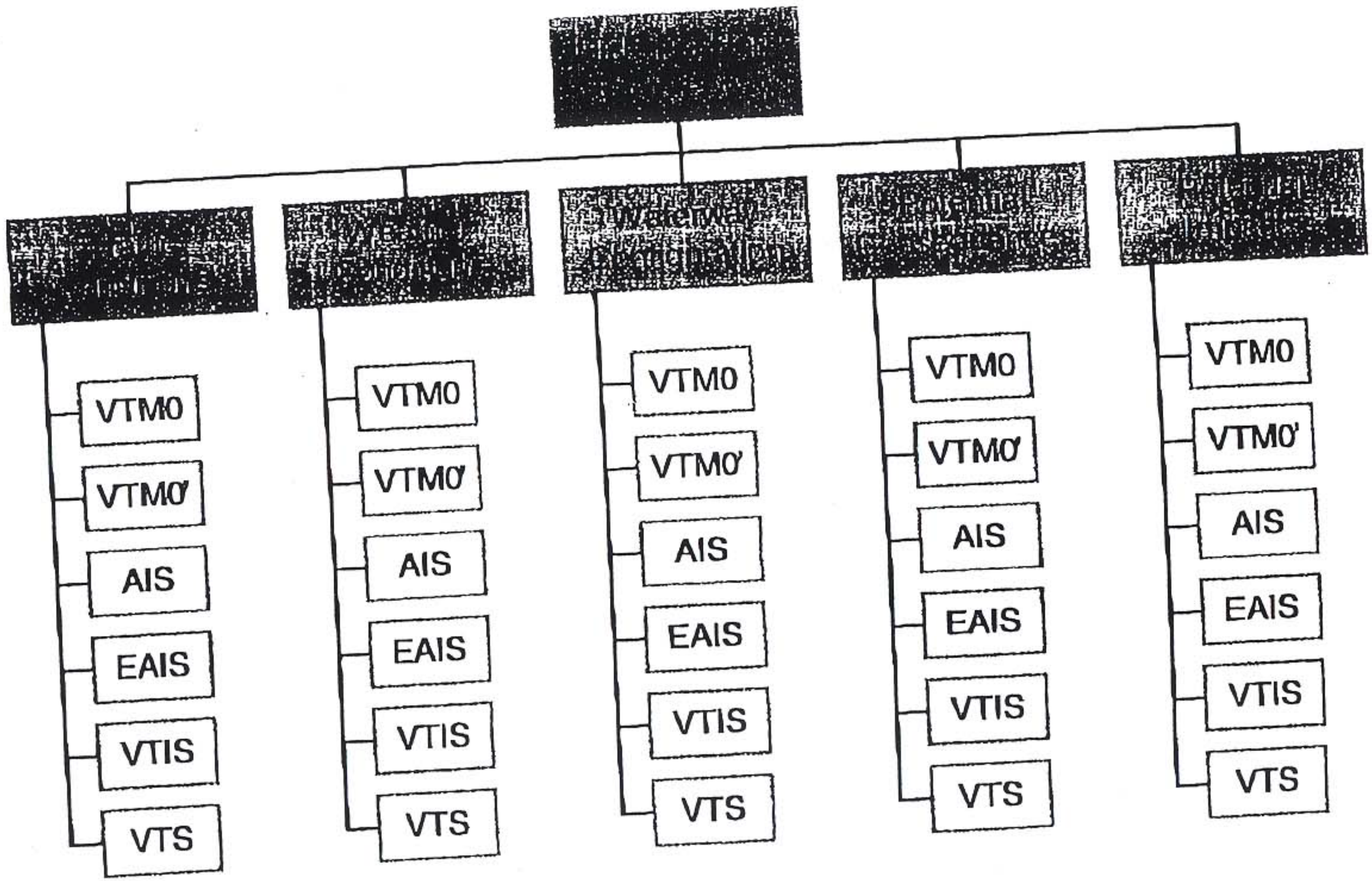

Figure 7. A hierarchical model of the change in risk due to various VTM implementation.

Thus the first comparison considers the changes caused to the composition of the fleet, then the changes caused to the traffic conditions are considered and so on.

The levels of VTM implementations are defined as follows:

Name	Description of Vessel Traffic Management Alternative
VTM0	Existing risk management system (ATON, Pilotage, RNA, VTS, VTIS, etc)
VTM0'	Existing system enhanced by non VTM improvements
AIS	Ship to ship automatic identification system
EAIS	Enhanced AIS - ship to shore to ship, ship to ship
VTIS	AIS based VTIS, no 24 hr CG presence or COT authority
VTS	AIS base VTS , 24 hr CG presence, COTOP authority

THE PRELIMINARY TESTING OF THE MODEL

The model was described to the expert group and the levels of VTS implementation defined. The experts were asked to consider a port for which they had a high level of familiarity. Some experts worked in pairs others alone. After the elicitation for the first model, the experts were familiar with making both pairwise and group comparisons and were allowed to choose the method with which they felt the most comfortable. Approximately one hour was allocated for the experts to work on the model considering their chosen port.

The aim of this procedure was not to achieve final results for any given port. Such results will be obtained using larger groups of experts with a high familiarity with the port in question. The procedure was performed to allow problems with the model to be ironed out. The format of the model was acceptable to the experts and they found the comparisons possible to make. However, there was confusion about the levels of VTM implementation. The definitions used were generic and vague enough to allow any port to be considered. However, to make the comparisons the experts needed exact definitions for the specific port. One of the main confusions was the interpretation of VTM0 and VTM0', for instance what were the improvements that should be considered for VTM0'. Some experts considered ports that already had a full VTS in place and thus they questioned the interpretation of VTS or VTIS.

It was concluded that the levels of VTM implementation to be considered should be defined specifically for the particular port or waterway and the definitions should be detailed. Given these specific definitions the experts were, however, able to use the model to assess the risk reduction due to VTM improvements.

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March 9, 1998

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Table of Contents

I. PROBLEM DESCRIPTION

The Ports and Waterways Safety Act of 1972 directed the U.S. Coast Guard to maintain an "acceptable level of safety" in the ports and waterways of the U.S. The law established an explicit, but subjective, goal for the Coast Guard's historic waterway management function. The realization of this goal implies the ability to measure and to quantify both the level of risk in any waterway and the risk reduction value of safety interventions such as aids to navigation systems, pilotage, and vessel traffic systems. In particular, it has been difficult to establish justifiable criteria for selecting ports requiring vessel traffic systems and for determining the level of sophistication of the vessel traffic management system required. In September 1996, Congress directed the USCG to reexamine the Vessel Traffic Service acquisition with focus on meeting user needs. The USCG sponsored a National Dialogue Group on VTS that developed factors for consideration, but did not establish measurable criteria.

This proposal outlines a process for developing a port evaluation tool to be used as the basis for a systematic approach for identifying ports in need of new VTS technology and for establishing the level of technology required. The tool is based on the technologies of eliciting and structuring the judgment of experts representing port users, and combining this knowledge base with available quantitative data to estimate the current level of safety in a port and the potential reduction in risk achievable through a VTS intervention.

The level of investment for a VTS should be determined by the possible risk reduction resulting from that investment. A potential decision matrix is shown in Figure 1.

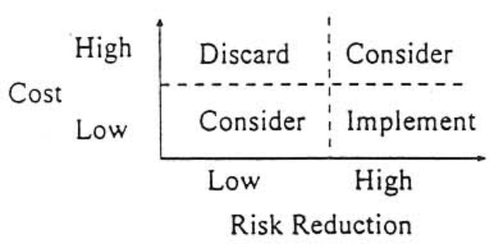

Figure 1. The trade-off between cost and risk reduction.

To rate the safety improvement of a VTS implementation accurately would require a full risk assessment. This would be costly to perform for each port or waterway under consideration. The alternative is a small timeframe, low cost approach that gives rough estimates of the safety improvement.

Various questions must be considered by the modeling approach:

- Who are the stakeholders in the port?
- What are the dominant hazards in the waterway as seen by all stakeholders?
- What are the possible causes of these dominant hazards?
- What are the probabilities of occurrence and the consequence of each dominant hazard?
- What are the dominant organizational and situational factors that drive the risk in the system?
- What interventions can be implemented to reduce the occurrence of these major hazards and their causal factors?
- Are there any adverse side effects of these interventions?
- Where does the VTS program fit within a ranking of the possible risk reduction interventions?

Figure 2 shows a taxonomy of the events that lead to a maritime accident. The effect of the organizational and situational factors is also shown. The assessment tool should take the role of these factors into account.

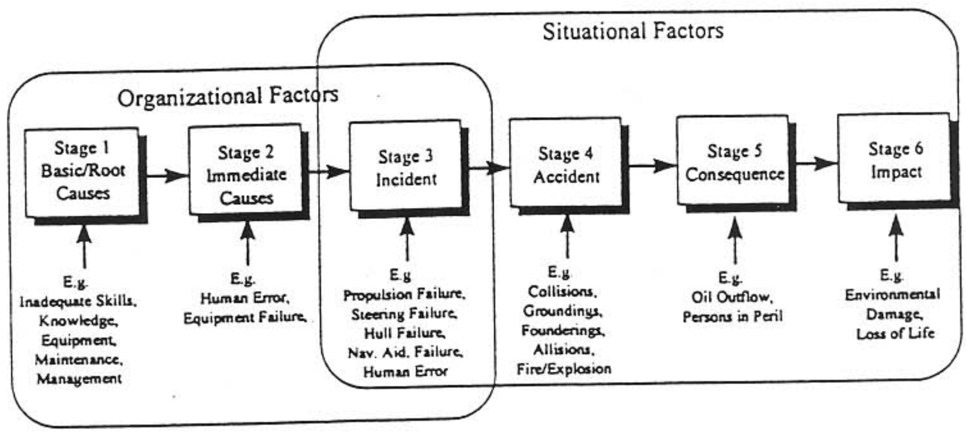

Figure 2. A taxonomy of the accident event chain.

The safety improvement can then be estimated by considering the effect of the VTS implementation on the accident event chain, as shown in figure3.

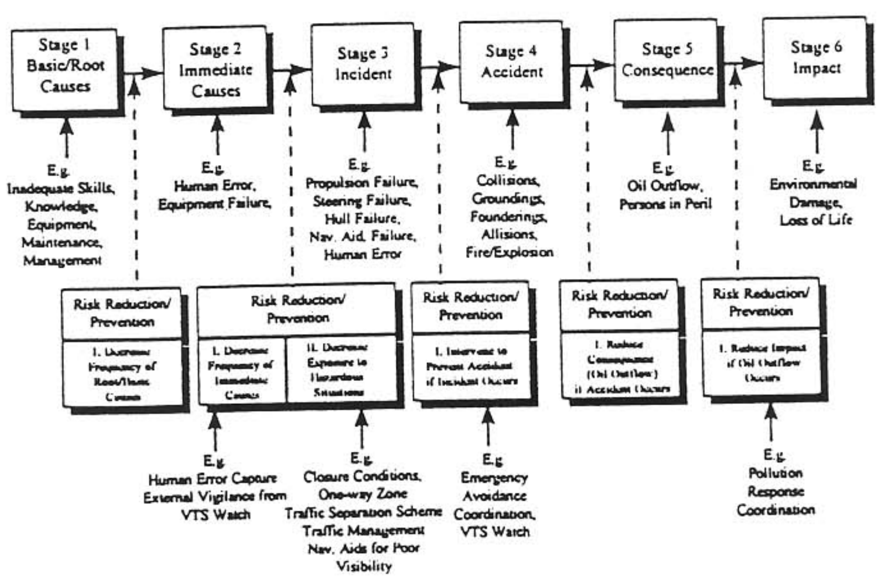

Figure 3. The role of a VTS in improving system safety.

II. OBJECTIVES

The purpose of the proposed work is to develop a tool by which the USCG can assess the VTS requirement for each of the Ports and Waterways. Two questions must be considered to assess the requirement:

1. What are the environmental, safety and economic consequences of having or not having a VTS within the port given the existing safety systems?
2. What is the level of investment that can be justified by the improvement in the system safety?

To this end a methodology will be developed that can

- identify the dominant risk factors and subjectively evaluate both the probability of each risk factor occurring and the consequence if it does occur; and
- identify and subjectively evaluate the current risk reduction interventions.

The questions to be considered in determining the dominant risk factors include:

- What are the existing or likely future conditions in the port with respect to traffic density, traffic patterns and complexity or traffic or vessel movements?
- What are the sizes, types and numbers of vessels operating in the port area?
- What is the history (including the causes) of accidents, casualties, pollution incidents and other vessel safety problems within the port area?
- What are the physical limitations of the port?
- What types and amounts of hazardous or environmentally sensitive cargoes are transported within the port?
- What are the prevailing conditions and extremes of weather and oceanography in the port?

The method proposed uses the Analytic Hierarchy Process (AHP) approach and will be implemented using the *Expert Choice* software package. The contract team will facilitate two workshops. One to build the basic structure of the AHP-based tool and elicit the weights of the factors included in the model. The second workshop will be a specific assessment of a chosen port or waterway.

A report will be written after each of the workshops to allow feedback on the model and further explanation of how the approach can be applied. Thus the development will be an iterative process to ensure the quality of the final product.

III. PROJECT TASKS, SCHEDULE AND DELIVERABLES

The stages of the development of the VTS requirement assessment tool will be as follows:

1. Preliminary model development by the GWU team using *Expert Choice*.

   - Applying Coast Guard furnished materials.
   - Including the expertise of the project team from prior maritime risk assessment projects.
   - Expert interviews.

2. USCG Workshop, facilitated by GWU, to develop the basic structure of the assessment tool.

   - This will be a group workshop performed in the Management Decision Center located at the George Washington University's Virginia Campus. This lab is set up for interactive facilitation sessions using Expert Choice.

- The group should consist of 12-15 subject experts. The expertise required will be in managing risk in a port or waterway and experience in several such environments. The project team proposes that this expertise can be found the USCG.
- The objective of this workshop will be to confirm the structure of the AHP model and obtain preliminary weights for the factors included.
- An example implementation of the tool will be performed considering a port or waterway that is well known to both the project team and the group of experts. This will allow a better understanding of the structure of the model and the weights elicited.

3. **Deliverable** – a report on the model obtained from the workshop will be delivered.

   - This will allow feedback on the structure of the model and the results of the test application.
   - Based on the feedback obtained the model can be modified at this point.

4. A test implementation of the tool will be performed in a workshop setting for a specified port or waterway.

   - A test port will be chosen and the assessment tool used to assess the requirements for VTS improvement.
   - This workshop will again be based upon an interactive facilitation session using *Expert Choice*.
   - The group should consist of 12-15 subject experts. The expertise required will be in the port or waterway under consideration. The group should consist of representatives of the major stakeholders in the system.
   - The proposed budget is based on limited travel expenses.

5. **Deliverable** – a report on the model obtained from the workshop will be delivered.

   - This will allow feedback on the results of the test application.
   - Based on the feedback obtained the model can be modified at this point.

6. **Deliverable** – the Port Assessment Tool developed will be delivered in the form of an *Expert Choice* file.

IV. STATEMENT OF CAPABILITIES

The George Washington University

The George Washington University is in the process of establishing an Aviation Safety Institute that will link faculty experts in the Institute for Crisis, Disaster and Risk Management, The Institute for Travel and Tourism, The Transportation Research Institute, and the Joint Institute for Advancement of Flight Sciences. The Aviation Safety Institute formalizes the collaboration of this group of experts that resulted in the successful 1997 International Conference on Aviation Safety and Security (Sponsored by GWU and the Gore commission) and the GWU Certificate Program in Aviation Safety and Security that was initiated in October, 1997.

The George Washington University Institute for Crisis, Disaster, and Risk Management will lead the proposed research. The ICDRM was established in August 1994, as an interdisciplinary academic center. The Institute integrates the existing diverse expertise and research related to crisis, disaster, and risk management at The George Washington University and is unique in its interdisciplinary focus and structure.

The GWU Institute for Crisis, Disaster and Risk Management developed its risk assessment methodology combining dynamic simulation and expert judgment in a series of transportation related risk assessment projects. The most recent projects were an assessment of the risk of passenger vessel traffic on the Lower