Development of a Decision Support Tool for Assessing Vessel Traffic Management Requirements for U.S. Ports

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Abstract

Effective vessel traffic management is critical to the safety of maritime ports and waterways. The United States and other maritime nations have had difficulty in establishing justifiable criteria for selecting ports requiring vessel traffic systems and for determining the level of sophistication of the vessel traffic management system required. Recently, Congress directed the USCG to reexamine the Vessel Traffic Service (VTS) acquisition with a focus on meeting user needs. This paper 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 Vessel Traffic Management (VTM) 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 VTM intervention. The effectiveness of the tool was demonstrated in two groups consisting of experienced mariners. This paper outlines the technique used and the results of these sessions.

Introduction

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 (VTS) acquisition with a specific 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.

A George Washington University/Virginia Commonwealth University team was requested to develop a computer based set of tools that could be used by the USCG to assess the Vessel Traffic Management (VTM) requirement for each of the major Ports and Waterways in the United States. Two questions had to be answered in order to assess the requirement:

1. What are the environmental, safety and economic consequences of having or not having a VTM 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 were identified that would allow experts to:

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

The questions considered in determining the dominant risk factors were:

- What are the existing or likely future conditions in the port with respect to traffic density, traffic patterns, and complexity of 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 selected 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 relative risk in the ports or waterways around the United States. This involves identifying the major indicators of risk. This includes 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 was also developed to assess the relative benefits to a port or waterway of the various levels of VTM 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. Since risk can be defined as the probability of an unwanted event times its impacts or consequences, the criteria that make up the risk are the criteria that affect the accident probability and the criteria that affect the impacts or consequences.

Figure 1 shows the Port Risk model. The value to be assessed is shown in a box at the top of the tree. 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. 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 may be elicited from an expert group. These weights 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 may be used to validate and then calibrate the model.

Defining Best-Case and Worst-Case Ports

The minimum levels and maximum levels of each criterion correspond to a situation in a port or waterway around the United States. Example best-case ports were selected by the project team based on interviews with Coast Guard Marine Safety staff and historical data and used as the least-risk end points for all pairwise comparisons. Maximum levels of criteria correspond to a worst-case situation in a port or waterway around the United States. Example worst-case ports for criteria were also selected by the project team based on interviews with Coast Guard Marine Safety staff and historical data.

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, 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.

A Model for Assessing Risk Reduction due to VTM

The aim of the second model is to assess the relative effectiveness of various levels of VTM implementation. The VTM 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 2 shows the model. The experts were asked to compare the levels of implementation considering the associated changes to the system for each criterion. 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 shown in table 1.

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 Automated Information System--ship to shore to ship, ship to ship
VTIS	AIS-based Vessel Traffic Information System, no regulatory presence or authority
VTS	AIS-based Vessel Traffic System, 24-hr regulatory presence and authority

Table 1: Vessel Traffic Management Alternatives

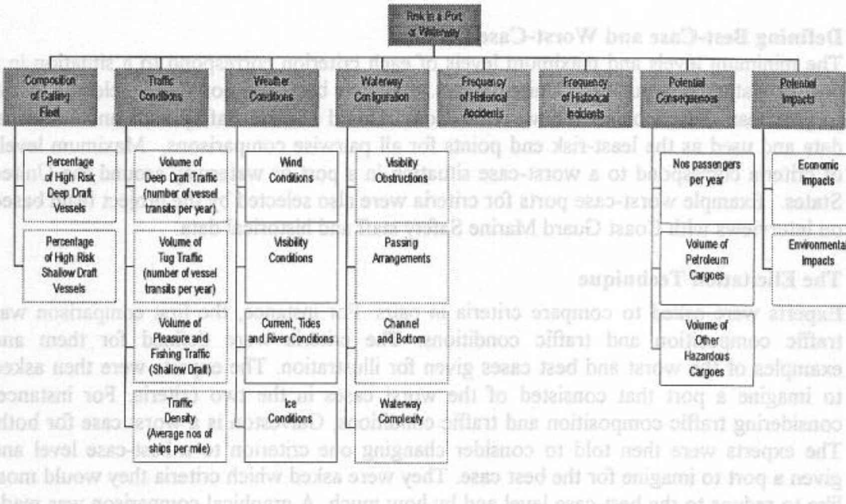

Figure 1. A hierarchical model of risk in a port or waterway.

Results of expert panel one

The first expert panel consisted of 15 experienced mariners: 8 licensed merchant mariners and 7 Coast Guard officers; all with experience in a wide range of U.S. ports and vessel types. The weights elicited for the top-level criteria are shown in table 2.

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

Table 2. 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 3 shows the criteria ranked by their elicited risk. The weights elicited for the sub-level criteria are shown and ordered in figure 4. The contribution to the probability of an accident waterway characteristics (complexity, obstructions, channel configuration) and traffic density were highly weighted by the experts. The experts also ranked the threat to passengers and potential health impacts as the most important accident consequences.

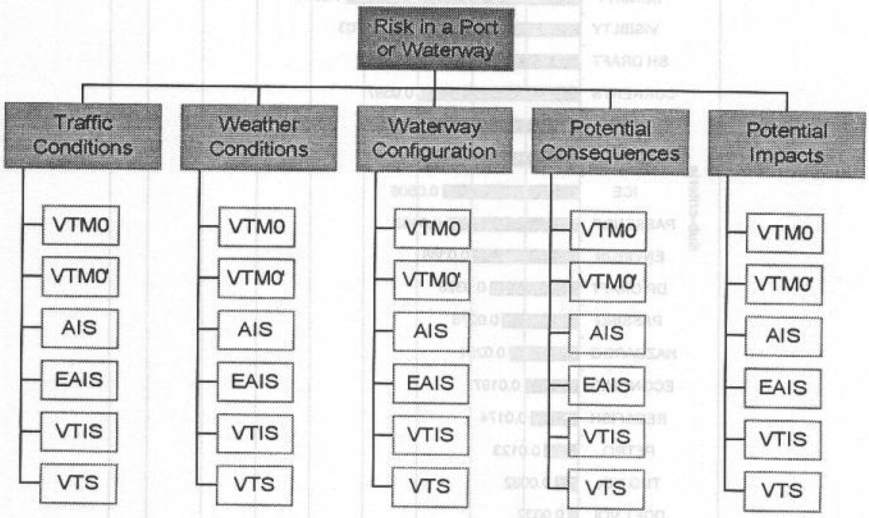

Figure 2. A hierarchical model of the change in risk due to various VTM implementation.

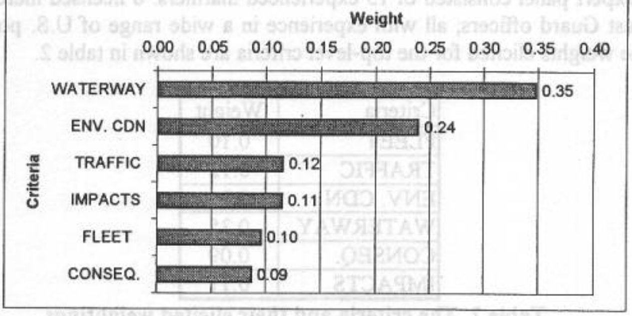

Figure 3. The criteria ordered by the elicited weights

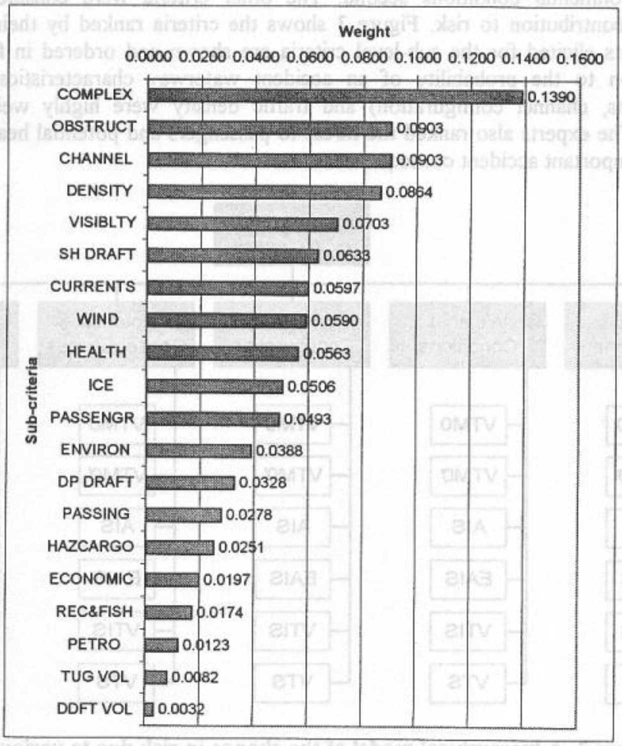

Figure 4. The sub-criteria ordered by the elicited weights.

Results of Expert Panel Two

A second expert panel convened at Marine Safety Office Hampton Roads consisted of twelve persons with knowledge of the maritime operations of the Port of Hampton Roads. The weights selected for the top criteria by the two panels are shown in table 3.

Criteria	Weight Panel 1	Weight Panel 2
FLEET	0.17	0.10
TRAFFIC	0.14	0.12
ENV. CDN	0.16	0.24
WATERWAY	0.21	0.35
CONSEQ.	0.17	0.09
IMPACTS	0.15	0.11

Table 3. The criteria and their elicited weightings.

The weights elicited for the sub-level criteria are shown and ordered in figure 5. The experts in this port ranked the presence of deep draft petroleum tankers as a major risk contributor. As a consistent result, they were much more concerned with the potential threat of environmental impacts. The national panel had not reflected this concern.

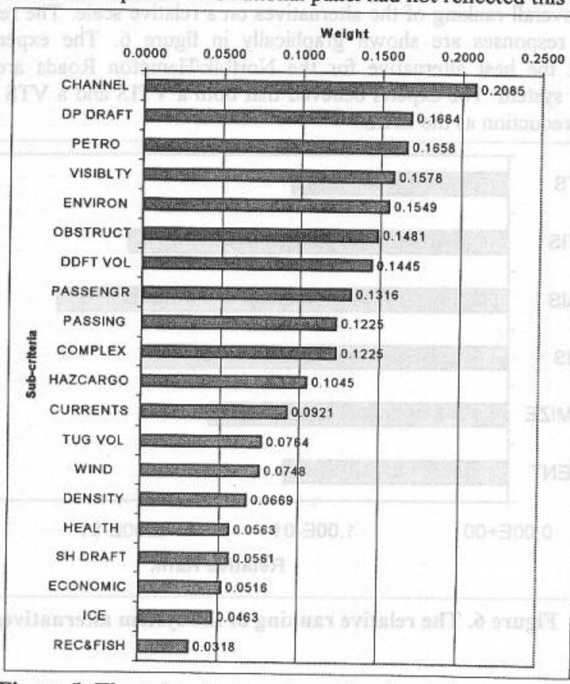

Figure 5. The sub-criteria ordered by the elicited weights.

A Comparison of the Results of the Two Panel Sessions

The results of the two panel sessions were not identical. The purpose of the sessions was to test the concept and feasibility of the model. There was no effort to ensure that all participants were, in fact, experts, and that the composition of the two groups was similar. In addition, the test showed that clarification of definitions for some terms would be required prior to implementing the model as a decision support system.

The results of neither panel session should be considered for use as the final model. The aforementioned problems should all be addressed and a large, comprehensive panel convened to complete finalized questionnaires. This panel must be given a full education on the process and precise definitions of all terms used. To achieve full participation by such a panel, the results must be fed back to them during the process, not processed after the session. This would imply an on-line approach, in which the experts responses are fed straight into the calculation mechanism.

Preliminary Testing of VTM Intervention Model

The VTM Intervention model is based on the results of the first model. The upper-level criteria weights from the first model are entered and the risk reduction alternatives are compared, considering only one of the upper-level criteria at a time. The result of the model is the overall ranking of the alternatives on a relative scale. The results of the first expert panel responses are shown graphically in figure 6. The expert panel session indicated that the best alternative for the Norfolk/Hampton Roads area would be an extended AIS system. The experts believed that both a VTIS and a VTS would not offer the same risk reduction as the EAIS.

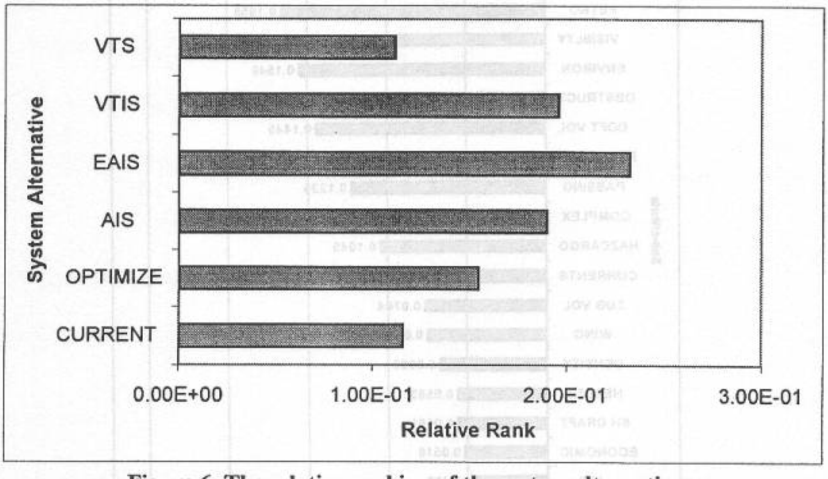

Figure 6. The relative ranking of the system alternatives.

Selecting VTM Investments--Model Limitations

Suppose we have a list of 5 ports: A, B, C, D and E. Attaining a final set of weights for model 1 and obtaining scores for each port in each sub-criterion would allow the development of a ranking of the 5 ports by risk. For example, we might find that port D is the most at risk, then A, then E, then B, with C the least. It should be noted that the model does not allow us to make a statement like "port A is twice as much at risk as port B". The conclusion of this analysis is that port D should be our first priority for risk reduction. Port D should thus be studied to find what risk reduction measures would reduce the risk to a more acceptable level.

At this point, model 2 must be used. Using the upper-level weights from model 1 and an expert panel with local knowledge of port E, comparisons of the various VTM alternatives can be made under each criterion. This gives a ranking of the effectiveness of the alternatives. For instance, in the pilot study, EAIS was ranked as the most effective alternative for the port of Hampton Roads, VTIS and AIS were next, then an optimized system with VTS and the current alternative ranked as the least effective alternatives.

The multiple application of this procedure will provide a ranked list of port-alternative intervention combinations, as shown in table 4. This list will be, however, an ordinal list--the intervals between each port-alternative entry (the relative risk reduction differential) cannot be estimated without a re-computation of model 1 (the Port Risk Model) under the assumption that the alternative has been implemented.

Table 4: Prioritized Ordinal Listing of Port-VTM interventions

Priority	PORT NAME	VTM INTERVENTION
1.	Port D	VTIS
2.	Port A	VTS
3.	Port E	EAIS
4.	Port B	EAIS
5.	Port C	VTIS

However, it is entirely possible that VTM is not the best measure for a high-scoring port. It is possible that a port with a lower score would benefit much more from VTM measures than the high-ranking port. However, it must be realized that the current approach does not allow the comparison of risk reduction alternatives amongst ports, only within a given port.

The final decision required from this process is a portfolio of measures to be used nationwide within a fixed budget. Thus, it is desirable to add the scores for the ports (not currently possible) and achieve a nationwide total score. The aim would then be to change this score by putting a VTS in port A, an AIS in port B, etc., and find the maximum reduction in risk within a fixed budget. This more complex problem would require small extensions of the current model.

Conclusions

The intent of this project was to demonstrate the feasibility of a low-cost decision support tool for the selection of Vessel Traffic Management risk reduction interventions in U.S. ports. The tool was developed based on the results of the VTS Dialogue Group and using the commercially available software package Expert Choice (EC), was accepted, and was understood by the maritime experts in the two expert panels. The EC software, the two EC models, and the results of the two expert panels are submitted with this report.

The two expert panels were limited in participation level and in time, but the results from the session provided ample evidence that the tool could order ports as to the need for VTM intervention and could assess the relative value of VTM alternatives. The calibration of the results (converting relative to absolute measures) using CG accident, incident, traffic, and cargo data is possible but not completed under this contract.

The results of the Port Risk Model (model 1), once the model is populated with the expert judgment of an appropriate panel of experts and calibrated with actual data, will provide an interval scale list of ports, prioritized by risk, for vessel traffic management interventions. The results of the VTM intervention model (model 2) will provide for each port an ordinal listing of VTM interventions appropriate for the port. The combination of the lists will provide a ranked listing of national VTM interventions. In order to provide an actual estimate of the benefits of risk reduction interventions, however, the actual relative risk reduction resulting from the intervention would have to be estimated. This could be done by re-populating the Port Risk Model (model 1) based on the revised assumption that the intervention had been implemented.

The results may be used in one of two ways. If a fixed capital budget amount is available for investment in Vessel Traffic Management interventions, the investment strategy should be to implement VTM interventions in the order they appear on the priority list, and implement as many as funding permits. If, however, the investment strategy is to implement only those interventions that exceed some cost-effectiveness threshold, the Port Risk Model should be re-calibrated for each alternative selected and the relative risk reduction estimated.