A NEW DECISION SUPPORT TOOL FOR PROACTIVE MANAGEMENT OF WATERWAY SAFETY

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Abstract

With safety defined as an acceptable level of risk, waterway managers seek to minimize risks in order to maximize safety. Failures in waterway operations result in events requiring emergency response. A proactive management approach identifies potential risks (adverse consequences and their likelihoods) associated with waterway operations, and identifies areas where improvements will yield reductions in those risks and the consequent incidents. This paper develops a high-level decision support tool that assesses waterway performance on two dimensions: realized risk outcomes and inferred risks. The assessment results, obtained using the Analytic Hierarchy Process, are represented as a performance map that can be used by waterway managers to compare the relative performance of different waterways. This tool can be useful in supporting resource justification and allocation decisions. In addition, the underlying hierarchy can be used to identify those specific areas requiring remedial attention or additional analyses to reduce risk and improve safety. This tool, called the Waterway Evaluation Tool, has been developed for the U.S. Coast Guard.

Introduction

The safe and efficient operation of U.S. waterways is a highly complex process that involves numerous stakeholders. The primary federal government stakeholders include the U.S. Coast Guard and the U.S. Army Corps of Engineers. However, there are numerous other governmental agencies that have a role in the operation of waterways. Brown, Corey, and Blythe (1995) identified 99 organizational elements that had 586 attributed waterways responsibilities.

The U.S. Coast Guard provides information and guidance, and applies controls to ensure that the "performance" of waterways is at an acceptable level with respect to particular goals. The Coast Guard's goals include maritime safety, maritime mobility, protection of natural resources, maritime security, and national defense. For three of these goals (maritime safety, protection of natural resources, and maritime security), there is a complementary prevention/response relationship. The Coast Guard undertakes numerous activities to *prevent* undesirable incidents (e.g., collisions, oil spills, terrorist attacks). If (when) those preventative measures fail, an emergency situation exists and emergency response actions are required. This paper focuses on the prevention aspect, and in particular, the development of a decision support tool that will enable a waterways manager to assess the health of a waterway and identify appropriate actions.

A number of decision support tools and approaches have been developed to provide information to assist Coast Guard waterway managers in analyzing U.S. waterways. The Volpe National Transportation Systems Center (1997) developed a value tree-based decision support tool named the Waterway Evaluation Tool (WET) Mark 1.1. This model focused on three Coast Guard goals including maritime safety, maritime mobility, and protection of natural resources. Harrald and Merrick (1999) used an Analytic Hierarchy Process approach to develop a decision support tool to evaluate overall hazard risk and assess alternative vessel traffic management alternatives for waterways. Nally (1998) developed an evaluative model that examined various risk factors in waterway operations and implemented a ranking procedure to prioritize areas for improvement. Kite-Powell, Jin, Lin, and Patrikalakis (1995) developed an analytic model for evaluating risk factors for groundings and collisions in waterways. Among these models, the Harrald and Merrick model has been implemented to focus on VTM evaluations and the Nally model has been used for local waterway assessments in Alaska. The WET 1.1 model provided great detail, but was found to be very difficult to implement. There is a need for a somewhat detailed model that is much easier to use and provides both overall and some detailed information about waterway operations. The remainder of this paper describes a portion of the revised WET (now 2.0) that accomplished these objectives The specific focus is on the application of WET 2.0 to the goal of Maritime Safety—"eliminate deaths, injuries, and property damage associated with marine transportation, fishing, and recreational boating." The maritime mobility and protection of natural resources goals modeled in WET 2.0 are not included in this paper.

Risk and Waterway Performance

Waterway performance should be measured directly with respect to the desired Coast Guard goal of maximizing maritime safety. In a given waterway, the waterway configuration, the vessel type and use, meteorological conditions, aids to navigation, vessel traffic management systems, cargoes carried, and a number of other factors may pose some "risk" to achieving that goal. These factors can be considered *risk drivers* that may have an adverse effect on achieving the goal or maximizing waterway performance with respect to maritime safety. In measuring waterway performance, it is preferred to measure the achievement of the goal directly (e.g., maximizing safety,). In practice, however, it is difficult to measure safety directly and an operational approach is typically used that seeks to minimize the risks to achieving the waterway goal (e.g., minimize casualties).

Risk has two facets: likelihood and consequences (Armacost & Pet-Edwards, 1999; Haimes, 1998) that must be addressed when assessing waterway performance and describing outcomes. Risk drivers affect risk outcomes. Functionally, the risk outcomes are dependent variables, and the risk drivers are independent variables. In a waterway, primary risk drivers are associated with the physical waterway system, the vessels operating in the waterway, the behavior of the personnel involved in waterway activities, the waterway activity levels, any waterway or operating interventions, and the meteorological conditions. These primary risk drivers affect both likelihood and adverse consequences. It is important to note that some of the risk drivers are controllable, while others are beyond the direct control of waterway managers or others.

Theoretically, for a given waterway, there is a functional relationship between the risk drivers and the risk outcomes. Practically, because this functional relationship has not been identified, it is necessary to use another means of estimating the effects of the risk drivers. Waterway performance in WET 2.0 is assessed based on the *concept* of the relationship between risk drivers and risk outcomes. In some cases, particular outcomes may be measured directly (e.g., reported casualties). These measured outcomes represent ***realized*** risk outcomes. In other cases, risk outcomes may be ***inferred*** because of the values of various risk drivers (e.g., collisions will increase because of increased vessel traffic). Although it is not possible to infer exact outcomes, it is possible to characterize the general direction and scope of the risk outcomes based on experienced judgment—an indirect measurement. These two approaches, direct measurement (realized risk outcomes) and indirect measurement (inferred risks) provide the two dimensions on which the performance indicators are developed. In "balanced scorecard" terminology (Kaplan & Norton, 1996), the inferred measures would be considered *leading* indicators and the realized measures would be considered *lagging* indicators.

Risk-Based Value Trees

Risk-based value trees are used to estimate a realized risk outcomes score and a inferred risks score for the maritime safety goal. The weights associated with the various activity levels in the tree are determined using the Analytic Hierarchy Process (AHP) with absolute measurement (ratings method). A value tree (objectives tree, hierarchy) is a hierarchical representation of a decision maker's objectives and attributes that support a particular goal (see Clemen, 1991; Mollaghasemi and Pet-Edwards, 1997; Saaty, 1994a, 1994b; Zahedi, 1986). A major use of a value tree is to assist a decision maker in deciding among a set of alternatives in order to select the one that best satisfies multiple attributes.

A value tree is constructed by first identifying the relevant attributes. In the case of WET 2.0, these attributes represent the risk drivers that may have an adverse effect on achieving the maritime safety goal. When the attributes are identified, they are next organized in a hierarchy. In a top down approach, a goal is specified, and below that, there are criteria or attributes that characterize how well or how poorly that goal is being met. The attributes can be refined into subattributes. In the top down approach, proceeding down the tree answers the question "how?" the goal is achieved. In a bottom up approach, various attributes are grouped to form clusters that may also be grouped in higher levels. The "bottom up" approach answers the question "why?" the attribute/goal above it is needed. In the development of a tree, both approaches are used and in every tree, the how and why questions serve to check the tree structure.

A WET 2.0 value tree has the general structure shown in Figure 1. The realized risk outcomes trees generally have the goal, attributes, and rating categories (levels of adverse effect.) The inferred risks trees have an additional level of subattributes between the attributes and the rating categories. The realized risk outcomes trees contain four rating categories for each attribute and the inferred risks trees include three rating categories for each subattribute to ensure adequate discrimination among waterways within the model.

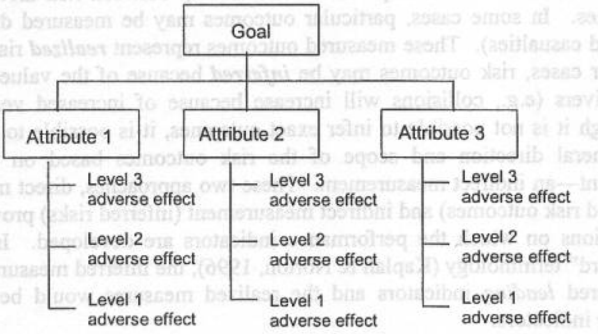

Figure 1: General WET 2.0 Value Tree

The focus of the realized maritime safety risk outcomes tree is to identify those realized risks or outcomes that can be directly measured that reflect an ***adverse effect*** on vessel and personnel safety while in the waterway. The specific attributes involve the levels of damages, fatalities and injuries associated with commercial and recreational vessel casualties, as well as *unexpected* near incidents for commercial vessels. Vessel casualties include collisions, allisions, and groundings. The resulting tree is illustrated in Figure 2.

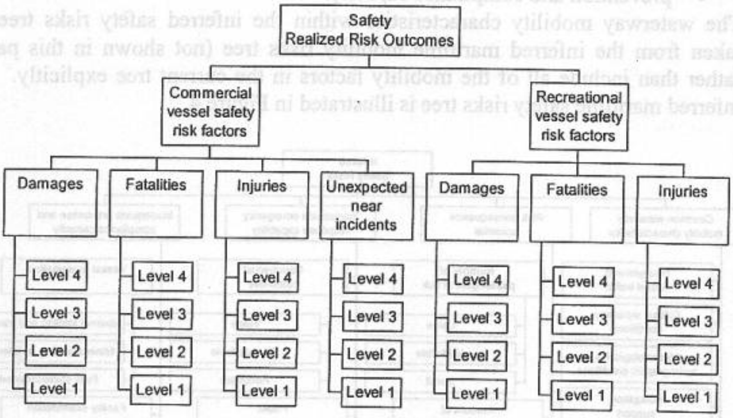

Figure 2: Realized Maritime Safety Risk Outcomes Value Tree

The realized risk outcomes are generally measured on two dimensions representing the likelihood of the adverse effect and the consequences (e.g., frequency of incidents and number of incidents). Figure 3 illustrates the four levels associated with damages associated with commercial vessel casualties.

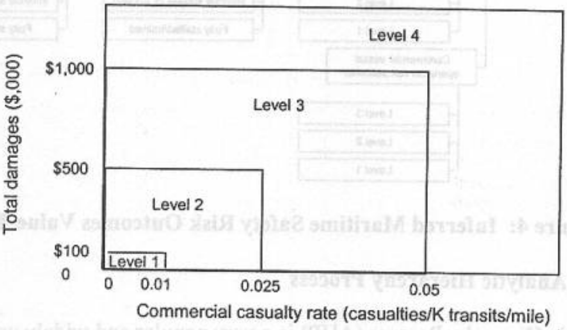

Figure 3: Commercial Vessel Damages Rating Categories

The focus of the inferred maritime safety risks tree is to identify activities, structures and other risk drivers that are expected to ***adversely affect*** commercial and recreational vessel safety and personnel safety while in the waterway. The relevant attributes include the

- common waterway mobility characteristics,

- risk potential associated with the consequences of adverse events,
- emergency response capability, and
- prevention and compliance capacity.

The waterway mobility characteristics within the inferred safety risks tree are taken from the inferred maritime mobility risks tree (not shown in this paper) rather than include all of the mobility factors in the current tree explicitly. The inferred maritime safety risks tree is illustrated in Figure 4.

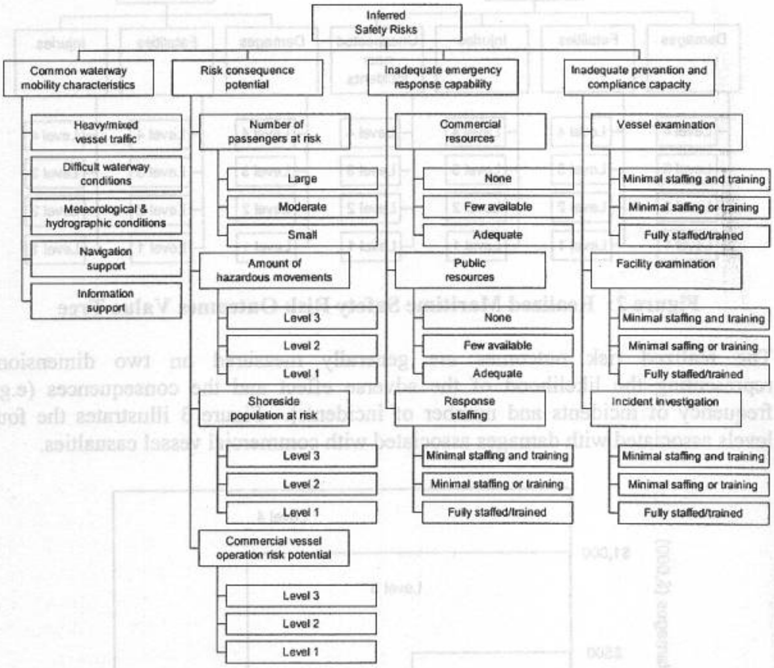

Figure 4: Inferred Maritime Safety Risk Outcomes Value Tree

Use of the Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a very popular and widely used multiple attribute decision tool. Mollaghasemi and Pet-Edwards (1997), Saaty (1994a, 1994b), and Zahedi (1986) provide easy to understand introductions to AHP and describe numerous examples of its use. AHP is currently being used in the PAWSA port risk assessment model (Harrald & Merrick, 1999). For the WET 2.0 model, the absolute measurement (ratings method) approach in AHP is used to evaluate waterway performance. This approach permits a meaningful comparison of a large number of ports. Specifically, AHP is used to determine the weights of the various attributes in the value trees, and the relative weights of the rating categories for each attribute at the bottom level of the value tree. The waterway is "scored" by utilizing the global weights associated with the appropriate performance level in each rating category and summing over all rating categories.

When all of the elements (attributes, subattributes, rating categories) of the trees are defined, the weight for each of the elements that reflects that element's relative contribution to the total evaluation is estimated. In AHP, users make pairwise comparisons of the elements (n elements means that n(n-1)/2 pairwise comparisons are required) at each level of a tree to estimate the relative importance of the two elements in each pair. Pairwise comparisons start at the bottom of the tree with the rating categories. Then, a computation to estimate the weights of the different elements (called **local priorities/local weights** in AHP terminology) is performed. The basis for the pairwise comparisons is typically "how much more does attribute 1 adversely affect the goal as compared to attribute 2?" After all of the local weights are computed, the weights are multiplied across all levels to compute the **global weights** for the various rating categories. These global weights are used to compute the waterway score when a particular rating category is selected for a given waterway by summing the global weights of the selected rating levels.

Performance Measurement and Performance Maps

In order to assess the performance ("health") of a waterway with respect to maritime safety, aggregate performance is estimated with respect to two dimensions: realized risk outcomes and inferred risks. In order to develop an aggregate measure, the various realized risk outcomes are combined to form an overall realized risk outcomes score using the results of the AHP value trees. Similar to realized risk outcomes, the risk drivers in the waterway are evaluated and an inferred risk score is computed to provide another indicator of performance. The realized risk outcomes value tree score and the inferred risks value tree score when translated into performance scores now provide a means of describing waterway performance and for comparing different waterways.

For each AHP value tree, the weights of the attributes and ratings categories are determined for the given waterway category and the waterway is rated on each attribute at the bottom level of the tree. The ratings result in a computed score for the given waterway. At the same time, the realized or inferred risk score is computed for the "worst" condition ratings, and for the "best" condition ratings. The worst score is converted to a realized or inferred performance score equal to zero, the best score is converted to a performance score of 100, and the waterway value tree score is converted to an appropriate performance score on the zero to100 scale. Evaluation of another comparable waterway can be used to provide a meaningful comparison of the two waterways. When a waterway is evaluated on the realized performance dimension and the inferred performance dimension, the waterway performance scores can be represented as a point in a performance map, providing a visual image to facilitate the comparison (see Figure 5).

Figure 5: Performance Map

The best and worst cases assume that they are in fact achievable. From a practical perspective, there may be a practical best or a practical worst case that is different from the 100 and 0 performance score values. Those practical performance scores will likely be different for different waterways. The practical limits give a good measure of the performance "gap" for each of the waterways and will be useful for program decision making.

The performance scores and performance maps provide a quick indicator of the "health" of the waterway. When consistent weights (e.g., national standards) for the value trees and the rating anchors are used, comparisons among waterways using performance scores are meaningful, provided the waterways are "comparable" (i.e., they must have the same general level of activity.) Comparing waterways of different sizes or of very different types of users is not meaningful.

There are numerous decision support uses for the WET 2.0 Model and associated data. The performance maps can be used to

- compare waterway performance against the best possible performance for a given goal
- compare waterway performance against the "practical" best possible performance for a given goal and develop a performance gap concept for decision making
- compare waterway performance against other waterways' performance for a given goal
- compare waterway performance gap against other waterways' performance gaps for a given goal
- compare waterway performance against the best possible performance for all goals
- compare waterway performance against other waterways' performance for all goals
- compare waterway performance for a given goal over time (trends)

- evaluate expected waterway performance associated with particular changes in operations

These types of comparisons are helpful for examining the overall performance of a waterway in comparison to other waterways or the potential for a given waterway. In order to determine "why" there are differences or to determine where improvements should be made, it is necessary to look deeper (*drill down*) in the AHP value trees. One could compare the ratings in particular parts of the tree, compare ratings with other waterways to ascertain the reasons for the differences, and do the same thing using the global weights associated with those ratings.

Summary

The WET 2.0 Model and associated AHP value trees provide a concise way of characterizing the health of a waterway by examining the various components and creating a composite view that is based on the program manager's description of what is important. The resulting output as well as the associated input data can yield important decision insights through a follow on analysis. The WET 2.0 model is in prototype evaluation by the Coast Guard. The method used in WET 2.0 has broad applicability as a risk-based performance assessment decision support tool.

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