

Final Report

Hurricane Preparedness and Recovery by a Transportation Agency

prepared by
Center for Risk Management of Engineering Systems and
Virginia Transportation Research Council
University of Virginia

(The opinions, findings, and conclusions expressed in this
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EXECUTIVE SUMMARY

Chapter 1. Introduction

The goal of the effort has been to improve hurricane preparedness and recovery of the Virginia Department of Transportation through the identification of planning and management options and the assessment and evaluation of the associated costs, benefits, and risks. There are seven related objectives: (1) A review of the literature and other agencies' experience; (2) Development of a software based platform for recovery priorities; (3) Identification of additional roads and critical facilities to be used in priority setting; (4) Decision support for resource allocation for hurricane recovery; (5) Time-to-recovery analysis; and (6) Analysis of schedule dependencies among agencies; and (7) Trade-off analysis performed on recovery/preparedness alternatives.

Chapters 2 and 3. Prioritization Modeling

The goal of these chapters is a methodology for setting recovery priorities following a large-scale disaster in the Virginia Department of Transportation's Hampton Roads district. The methodology will suggest which roads are the most important to restore immediately following the disaster and which roads can stand to wait for other roads with a greater need.

There are a number of criteria that can serve for the prioritization. Population, traffic, and road type and mileage are several important factors. But a distinguishing feature of this effort is the use of "critical" facilities, defined as any facility necessary for the well-being of a community.

The prioritization model uses a grid, and each grid cell receives a priority score. The user may choose any or all of critical facilities, population, road mileage, and user-defined data to drive the priority model to best address a current situation. Shading or colors are used to show high, medium, and low priority cells.

Figure ES.1 shows a sample of results of the prioritization model. On the left the output is displayed with numbers and colors that represent high (red), medium (yellow), and low (green) priority cells. The user can alter the percentile distribution of colors to create the most informative view. The right side displays the priority score (units are basically meaningless) laid over a map.

Alternately using several different choices of factors, the user can determine which cells are consistently the highest priority zones, which zones are consistently at the bottom of the chain, and how the priorities change in the short, medium, and long-term following the disaster. The model is primarily intended for supporting gross resource allocation decisions.

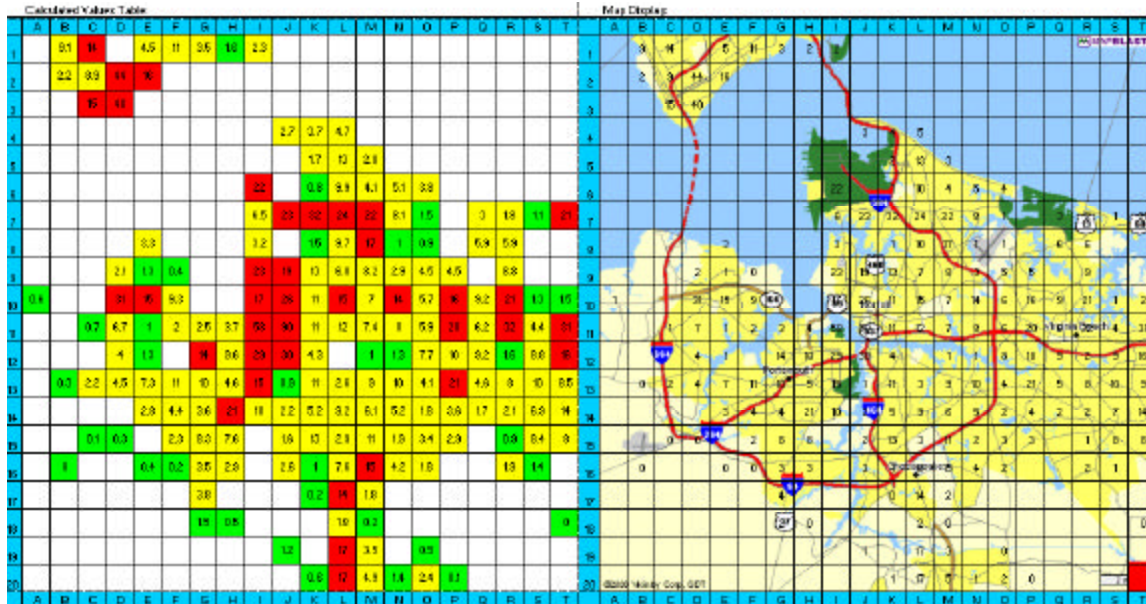


Figure ES.1 Outcome of the prioritization model

Chapter 4. Schedule Analysis of Time to Recovery

This chapter investigates the scheduling of the post-hurricane repair process to suggest improvements that could reduce the time to recovery following a natural disaster. A network model of the required activities and their relationships is used to determine the critical path and formulate an estimate of the overall completion time required by the repair process. A tradeoff analysis between time to recovery and pre-hurricane resource investments is performed to suggest how costly project delays can be avoided.

A schedule analysis of the post-hurricane repair process, which demonstrates the dependant relationships among repair activities, reveals the network diagram presented in Figure ES.2. Further analysis determines the activities that lie on the critical path of the process. Delays in the critical activities can cause a delay in the overall repair completion time. An examination of the critical path indicates that the length of time and level of resources required by the repair process are highly dependent on each individual activity being completed within the allotted time and budget. There is little slack in the repair schedule. Tradeoff analysis reveals that the length of time required to complete the activities lying on the critical path of the repair process can be reduced without a significant increase in cost.

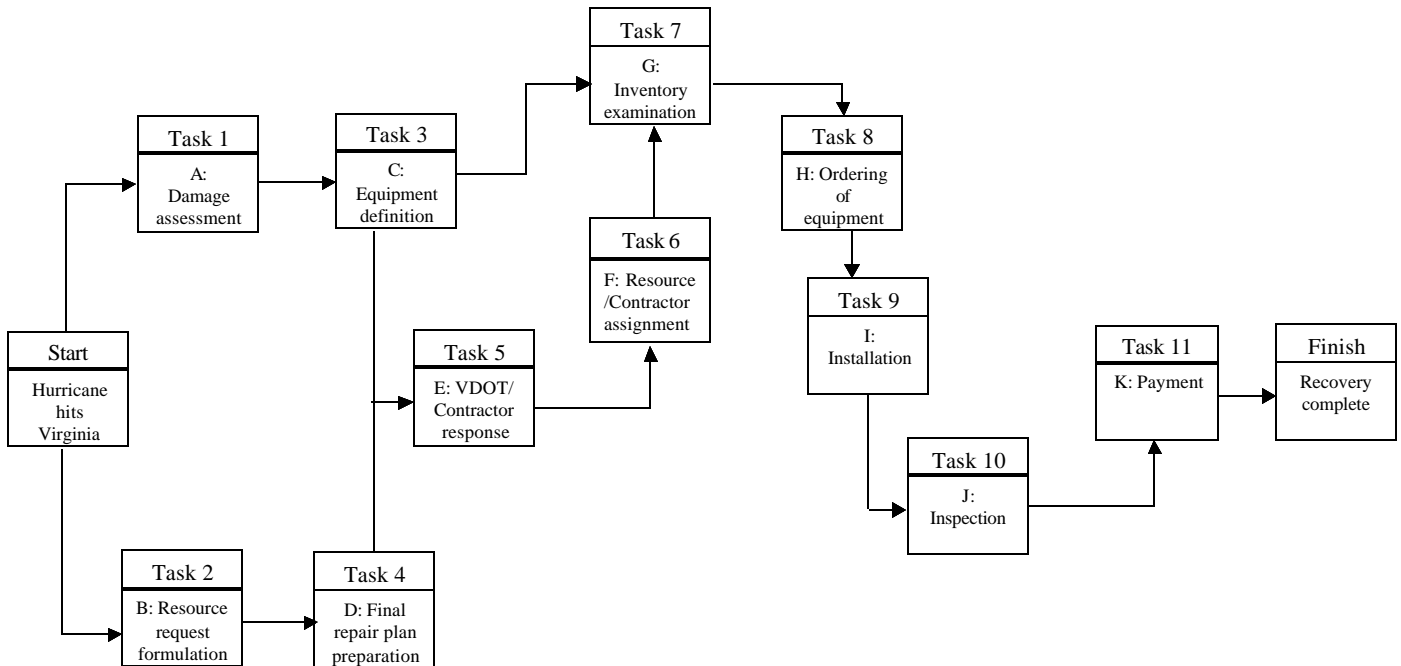


Figure ES.2 Network diagram of the post-hurricane repair process

The installation process, Activity I, is determined to be the most time consuming and variable activity based on data collected through interviews with VDOT personnel. A reduction in the length of time required by the installation process yields a shorter overall time to recovery. One way to shorten the installation process is to divide it into sub-tasks that can be performed simultaneously. In addition, pre-hurricane investments should be investigated in terms of the impact additional resources have on the time to completion of the installation process.

Chapter 5. Analysis of Schedule Dependencies in Hurricane Recovery

This chapter examines the issue of time to recovery discussed above on a macro level by considering various schedule dependencies that occur among involved agencies as opposed to a pseudo-schedule outlining the general tasks in the post-hurricane process. Schedule dependencies among the activities of the numerous federal, state, and local agencies and organizations that participate in the pre and post disaster processes frequently arise. In many cases, one agency's duties cannot be started until activities that other agencies are responsible for have been completed. The schedule dependencies can lengthen the time to recovery, and therefore increase the magnitude of the impacts of the disaster. An analysis of potential opportunities for advancing the schedule researched from the agencies involved can aid in VDOT's decision making.

A framework has been developed that measures and compares descriptive scenarios of potential opportunities for reducing delays. Critical inter- and intra-agency scenarios are identified that require future further investigation according to the extent of their overall significance to the time to recovery. The tool for measuring the magnitude of a delay takes into account its ‘Severity’ in regards to its time duration, the number of ‘Agencies Involved’, its ‘Likelihood’ of occurring in the future, the range of ‘Items Waited On’, its ‘Controllability’ for the future, the number of associated ‘Cascading Effects’, its ‘Maturity’, and the ‘Number of Similar Scenarios’.

A list of forty-eight delay scenarios has been gathered for analysis through interviews with state agencies from VA, FL, NC, and CA of the accounts they hold concerning their participation in the pre- and post-event processes of past natural disasters, especially in terms of the situations where they were waiting on their state DOT and vice versa. Ten of these scenarios have been collected from Virginia agencies, eighteen concern intra-agency delays identified within NCDOT, and the remaining twenty scenarios are various anecdotes from the other states.

Categorizing all of the descriptive scenarios into the common functions within the organizational structure of a state DOT identifies those functions that are involved with a significant number of scenarios. According to the sample of forty-eight delay scenarios collected, *Information Management* and *Operations* are associated with 31% and 23% of the scenarios respectively, which are primarily due to the unavailability of accurate real-time road status information. Additional analysis reveals the pairs of organizational functions that, when interacting, are the sources of many scenarios. Figure ES.3b displays the number of scenarios associated with each pair of organizational functions, and Figure ES.3a is a key defining the pairs of functions that lie on the horizontal axis of Figure ES.3b. Analysis of the descriptive scenarios indicates that the interaction of *Information Management* and *Operations* introduces 23% of the scenarios collected, and the interaction of *Operations* and *Structure and Bridge* introduces 19% of the scenarios, which suggests a lack of communication among these organizational functions.

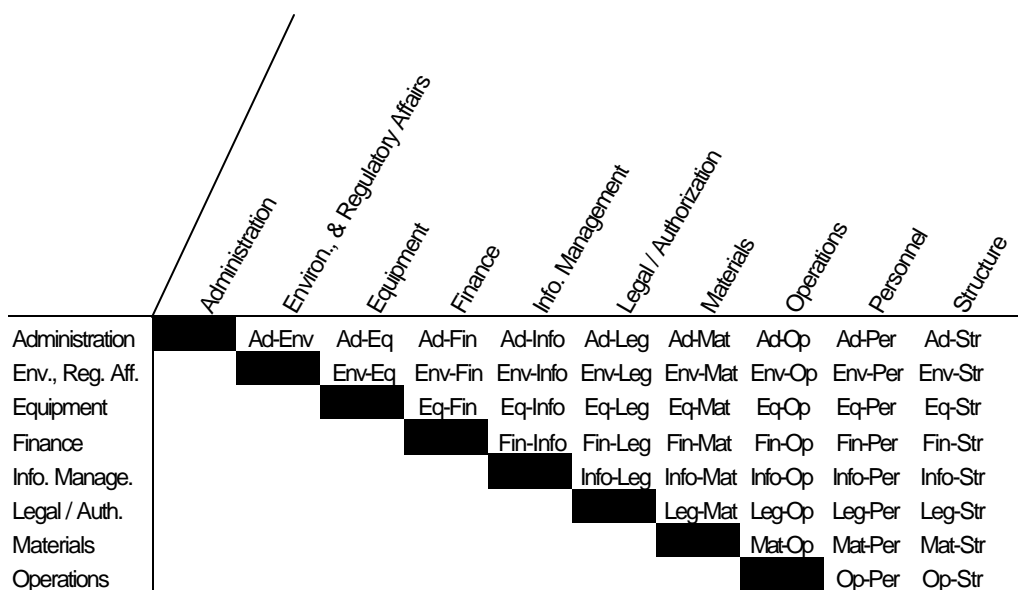


Figure ES.3a Key for denoting pairs of organizational functions within the state DOT

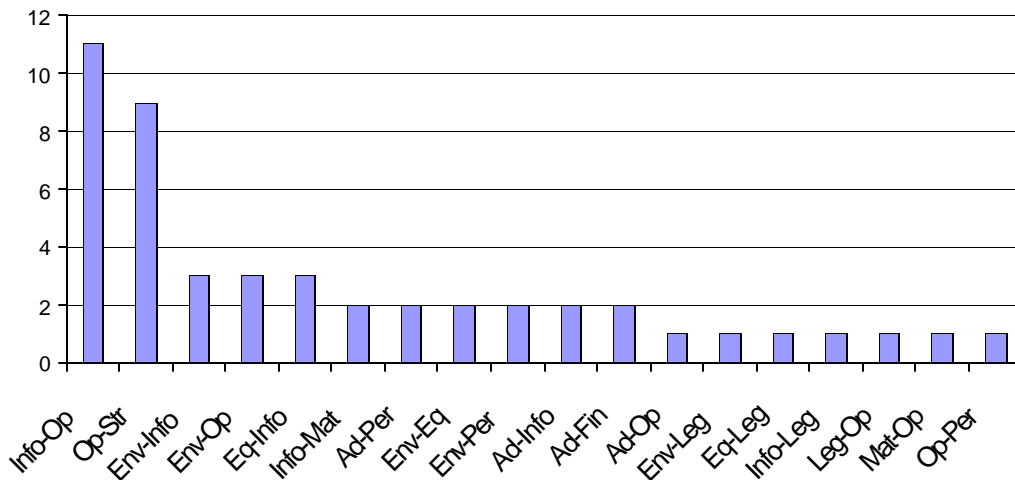


Figure ES.3b Number of scenarios collected that are associated with pairs of organizational functions within the state DOT

Various recommendations regarding an enhancement of VDOT’s current computer-based information system, VOIS, and an increased level of communication encouraging more shared information among involved agencies could decrease the likelihood of many delays in the future by supporting a higher level of agency coordination during pre and post disaster processes. Other recommendations are proposed regarding evacuation processes, equipment standardization, and a statewide radio communication system.

Chapter 6. Decision Support for Resource Allocation for Hurricane Preparedness

This chapter addresses decision support for resource allocation in order to aid managers in the Virginia Department of Transportation in the event that a hurricane affects the Tidewater region of Virginia. Examples of recovery activities include clearing debris from an interstate, repairing slope failure on a primary road, or repairing damage to a bridge on a secondary route. In September of 1999, Hurricane Floyd sent heavy rains into the Tidewater region of Virginia. These storms resulted in extensive flooding and many instances of severe damage to local interstate, primary, and secondary roads. The Virginia Department of Transportation Emergency Operations Center received over 100,000 phone calls as a result of Hurricane Floyd, a category I hurricane. Equipped with a generic method for classifying and prioritizing these calls, volunteers were challenged in organizing recovery efforts.

The chapter has developed a method to systematically prioritize recovery activities in order to effectively aid in decisions concerning resource allocation for VDOT in the event of a natural disaster. In order to achieve this, a tool was developed that utilized multi-objective decision

analysis in order to prioritize recovery activities based on available data. Data was collected through contacts in the VDOT and CDOT (Caltrans), and was used to conduct two case studies. The first case study analyzed recovery activities resulting from the September 1999 Hurricane Floyd strike on Virginia, and the second case study analyzed the effectiveness of recovery activities from the 1998 El Nino Storms in California. The data provided for both studies had to also be used to determine the performance indices/objectives to use to prioritize and evaluate the effectiveness of the recovery activities. These objectives were to fall under the three categories of risk reduction, performance gain, and resources used. The indices that are used include average daily traffic (ADT), population density, and total estimated cost. The decision to include these indices meant that those activities located in highly populated areas on a route with heavy traffic flows would receive high priority. The third factor to consider in resource allocation decisions would be cost.

From the data provided multi-objective charts developed from this study have been created as shown in Figure ES.4.

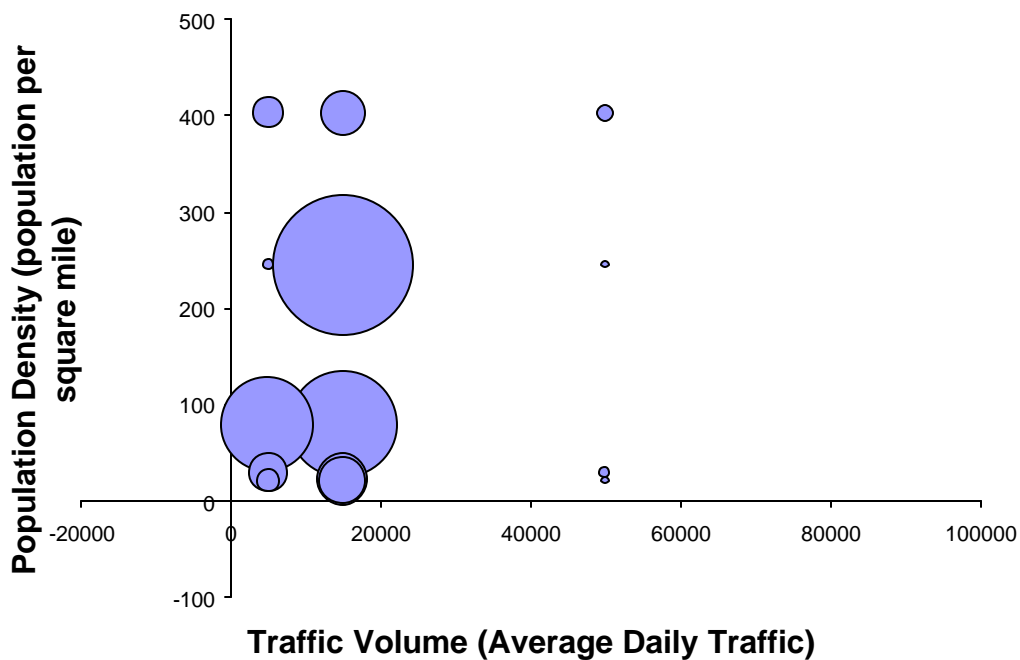


Figure ES.4 Recovery activities plotted for counties in Hampton Roads (icon area is proportional to activity cost)

The use of this tool should result in better overall management and allocation of resources. Resources go where they are most needed and where they will contribute the most to the recovery efforts. The developed charts should also result in improved communication between VDOT and other state agencies; help VDOT managers show other state agencies where the resources are going and why. Finally, the new technology will provide better prioritization of

preparedness and recovery activities in the short, medium, and long term and show what recovery activities need to be completed before other recovery activities can begin.

Chapter 7. Characterizing Preparedness and Recovery Alternatives

Chapter 7 describes a methodology for developing and characterizing hurricane preparedness and recovery alternatives for a highway agency in both the pre- and post-event phases of a hurricane. The study includes two major parts: 1) A characterizing template and 2) A variety of case studies consisting of hurricane preparedness and recovery alternatives. When creating post-event plans and decisions, a highway agency considers the possibility of adverse events that damage road systems. Events such as storm surges, high wind speeds and heavy traffic wear are possible in a hurricane.

In the case studies part of the project, thirty-four different alternatives were analyzed. Each alternative looked at trying to improve the resilience, robustness, and redundancy of different road systems. Furthermore, each alternative was looked at to show whether the alternative needed action in the pre-event (before the hurricane) or post-event (after the hurricane). The pre-events and post-events were broken down further into short, medium, and long term events. Short-term events were the hours to days before the hurricane hit. Medium-term is weeks to months or basically, during the hurricane season. Long-term is the preparation years in advance or basically general advancements in the building of the systems to be better prepared. The same time frames apply for post-events except they are the recovery efforts after the hurricane.

In addition to looking at the time frames for each alternative, the case studies also looked at what the impacts of each alternative would be and whether they aid in evacuation. The impacts of each alternative are based on goals of highway agencies that are aimed at protecting life, property, and the environment. So the impacts that the case studies look at are cost, recovery time saved, human lives and the safety of the public, economic impact to the community, property saved, and protection of the environment. After looking at the possible impacts, the case study looks at how each alternative can be improved or enhanced and the ways are to prevent against stronger winds, prevent against higher storm surges, or to handle greater traffic flows. Finally, the last part of the case study shows whether or not each alternative helps in the aid to evacuate the area.

Table ES.1. A case study characterizing the enhancement of systems to mitigate flooding

Alternatives:	Redundancy	Resilience	Robustness	Short term	Medium term	Long term	Short term	Medium term	Long term	Time savings	Cost savings	Lives saved	Economic impact	Environmental impact	Private property	Wind velocity	Storm surge	Traffic flow	Aids in evacuation
10. Store extra sandbags		●			●				●	◐		●		●					●
11. Strengthen flood gates	●			●					◐	●		●		●					●
12. Install more gates	●		●		●	●			◐	◐		●		●					●
13. Install more pumps		●			●				●	◐		●		●					●
14. Increase pump strength	●			●					●	◐		●		●					●
15. Raise tunnel entrances	●		●		●	●			◐			●		●					●
16. Raise bridge entrances		●			●				◐			●		●					●

Table ES.1 shows one of the four case studies performed. The case study looks at trying to mitigate flood damage in the table above. The case study has seven alternatives to try and prevent or at least minimize the damage from flooding. To fill out a case study, the user fills in solid circles where each area has an impact on the alternative. If the alternative enhances the system through robustness, then robustness would get a solid circle. Likewise, if an alternative saves the highway agency time and money, then solid circles would be placed in the columns as well. If there is only a minor impact, say in the area of economic impact, then a half filled in circle demonstrates a minor impact to the area because of the alternative. Finally, depending on whether the alternative would be receptive to wind damage, storm surge damage, or say another destructive force, then the user-defined force would be replaced in the column.

Recommendations for future work characterizing preparedness and recovery alternatives include:

- ☞ Generate more alternatives using the methodology given
- ☞ Perform more case studies for different types of destructive forces
- ☞ Extend to different types of disasters like earthquakes, flooding, snowstorms, etc.

Chapter 8. Cost-risk-benefit Analysis Decision Framework

Chapter 8 develops a cost, risk and benefit decision framework for VDOT for their pre and post-event phases in a hurricane. The study involves two major parts, of which the first explains the enhancement capabilities of road systems and the second describes the spreadsheet tool for cost, risk and benefit tradeoff analyses.

The enhancement of road systems through increasing their robustness, redundancy and or resilience can minimize the impacts of the adverse events as well as improve the highway infrastructure in a hurricane (As explained in the previous section). The main methodology, here, is to develop hurricane tradeoff analyses that compare different enhancement alternatives.

Each alternative has the ability to enhance a variety of road systems to different levels. While one alternative might have enhanced bridges more than smart highway systems, due to a flood prone environment, another alternative might have enhanced only signs, signals and lights in an attempt to minimize fallen debris on highways. Either way, the alternatives allow a highway agency to understand how to enhance a wide variety of road systems that are affected by hurricanes. With this knowledge and the tool provided by the effort, a highway agency can make educated decisions about which alternatives are more cost and risk efficient. The following describes the tool as well as the associated tradeoff graphs.

The spreadsheet tool exhibits how to apply a methodology to analyze the post-event phases of the events. The methodology can be applied to other events similarly. The tradeoffs among enhanced alternatives are in terms of the risk metrics: damage, repair cost, time to recover, and the cost to the industry and or stakeholders. The metrics measure the degree of a storm surge or wind speed-related impact. Different road systems have different values for the risk metrics. Therefore, by plotting the values, a decision maker can see the tradeoffs between different alternatives. Figure ES.5 shows the tradeoff graph that plots the cost of alternative versus the ratio of repair cost to reconstruction cost, or damage. The different curves refer to the different wind speed impact scenarios that may occur.

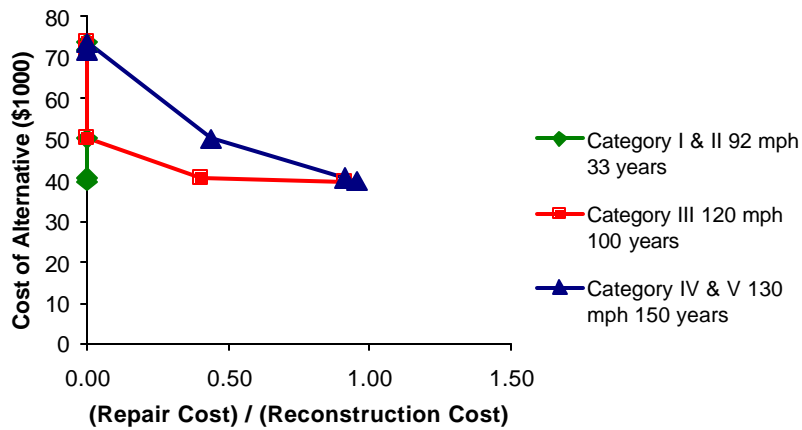


Figure ES.5. Tradeoff graph between different designs of cantilever signs in cost of alternative and ratio of repair cost to reconstruction cost after various wind speed impacts

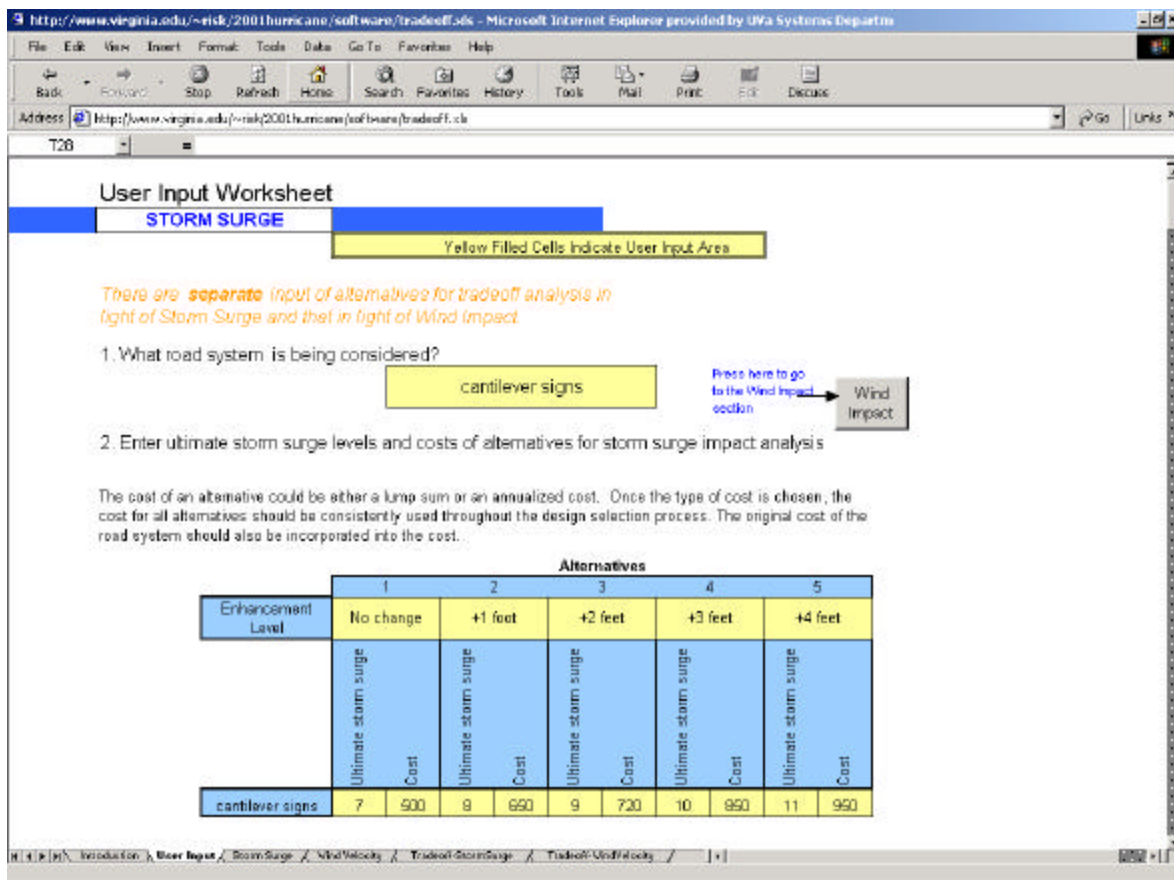


Figure ES.6 Tradeoff graph between different designs in cost of alternative and ratio of repair cost to reconstruction cost after various wind speed impacts for cantilever signs

Summary of Recommendations

The following is a compilation of recommendations identified from this effort.

Chapters 2 and 3. Prioritization Modeling

- ~~///~~ Consider a systematic approach to priority-setting for recovery
- ~~///~~ Adopt the grids for priority-setting
- ~~///~~ Use various grid-size resolutions (District, Residency, smaller)
- ~~///~~ Adopt the demonstrated metrics (populations, mileages, stakeholder facilities, etc.)
- ~~///~~ Consider adding a metric to represent the degree of recovery
- ~~///~~ Use the developed software downloads and demonstrate with GIS divisions

Chapter 4. Schedule Analysis of Time-to-Recovery

- ~~///~~ Apply the methodology to additional data and post-hurricane processes
- ~~///~~ Consider dividing activities up into sub-tasks that can be performed simultaneously
- ~~///~~ Examine the impacts of assigning more resources to the installation process
- ~~///~~ Examine various schedule configurations of activities and potential sub-activities
- ~~///~~ Investigate opportunities for further time and cost savings in the post-hurricane process

Chapter 5. Analysis of Schedule Dependencies in Hurricane Recovery

- ~~///~~ Perform a more extensive data collection to minimize bias in analysis, possibly with an online surveying tool
- ~~///~~ Analyze individual scenarios collected using PERT, an activity network modeling tool, to identify potential opportunities for advancing the schedule in the post-hurricane process
- ~~///~~ Investigate the costs and benefits of pre-hurricane resource investments on the alternatives identified from the PERT models

Chapter 6. Decision Support for Resource Allocation for Hurricane Preparedness

- ~~///~~ Consider a systematic approach to resource allocation for recovery
- ~~///~~ Represent the variety of recovery projects across regions
- ~~///~~ Discover the balance among all project impacts and costs
- ~~///~~ Use the approach to improve the allocation of resources to diverse projects
- ~~///~~ Project from past storms to the needs arising from future storms

Chapter 7. Characterizing Hurricane Preparedness and Recovery Alternatives

- ~~///~~ Generate more alternatives using the methodology given
- ~~///~~ Perform more case studies for different types of destructive forces
- ~~///~~ Extend to different types of disasters like earthquakes, flooding, snowstorms, etc.

Chapter 8. Cost-risk-benefit Analysis Decision Framework Alternatives

- ~~✍~~ Expand upon the methodologies presented in this report by collecting data that will focus the approach analysis used.
- ~~✍~~ Consider a systematic approach to cost-benefit analysis of recovery and preparedness.
- ~~✍~~ Expand the functionality of the tool to evaluate additional natural disasters such as earthquakes, tornadoes, snowstorms, floods due to rainfall, and any such event where the impacts can be lessened through mitigation.
- ~~✍~~ Expand the functionality of the tool to incorporate additional enhancement alternatives in addition to wind speed, storm surge, and traffic flow.
- ~~✍~~ Utilizing the flexibility of the framework will maximize VDOT's understanding of their preparedness efforts.