Final Report

Risk-Based Hurricane Recovery of Highway Signs, Signals and Lights

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 report are those of the authors and not necessarily those of the sponsoring agency)

Contract Research by
Virginia Transportation Research Council

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

Draft September 1999

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Introduction

Hurricanes along the East Coast of the United States are very destructive. A storm becomes a hurricane when it demonstrates a rotary circulation and reaches a constant wind speed of 74 miles per hour. The strength of its winds can cause considerable damage and they range in categories from I to V, with I being the weakest and V being the strongest. Each category of hurricane has the potential to cause different amounts of damage to the Suffolk District of Virginia. Hurricane force winds can result in damage to highways, which includes destruction of highway signs, lights and signals.

Impairment of traffic-control equipment reduces the ability to transport people, equipment, and resources needed for the restoration of infrastructure. Without signs to direct travelers and lights to illuminate roads, highways can be confusing and dangerous. Months or even years can pass before a locality can recover and return to its original state in terms of traffic control equipment. The faster the highway infrastructure can be recovered the sooner mobility in the Suffolk District can be restored. Furthermore, it can cost the state enormously to recover from a hurricane. Even though government provides federal aid through FEMA and FHWA for the recovery effort, these funds cannot be solicited until the state has documented efforts in disaster recovery planning. A systematic approach to repairing damaged roads after a hurricane must be established.

Potentially, after a hurricane hits the Suffolk District of Virginia, the road systems may be in complete disorder. There may be no systematic process to recover the signs, lights and signals on Virginia highways. The goal of this project is to improve the recovery of the road systems after a hurricane by assessing the risks, costs and benefits associated with upgrading equipment, managing spare equipment and priority setting for recovery efforts.

The report is divided into four main sections, each contributing to a hurricane recovery plan for the signs, lights and signals in the Suffolk District. The four sections are as shown in Figure ES-1:

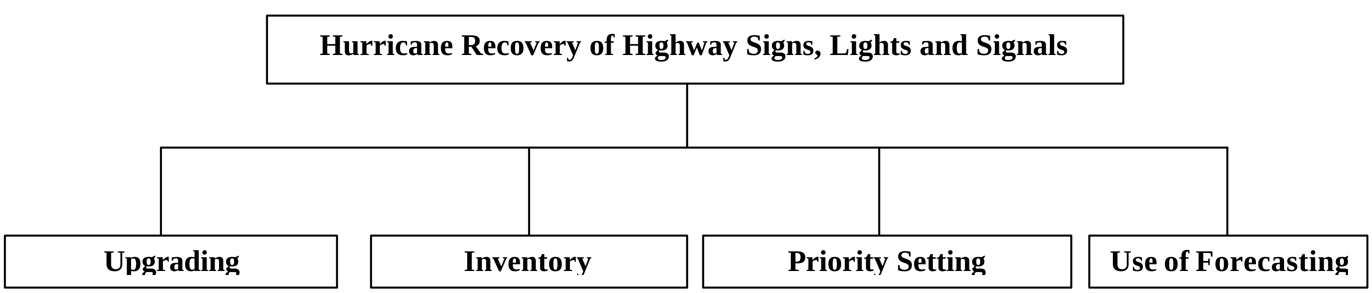

Figure ES-1 Main Sections of the Final Report

Part 1. Evaluation of Upgrading of Equipment

The first section involves consideration of strengthening alternatives. To characterize the impact of hurricanes to equipment, a straightforward linear model was developed to assess the percentage of signs that will be damaged in each category hurricane. As shown in Figure ES-2.

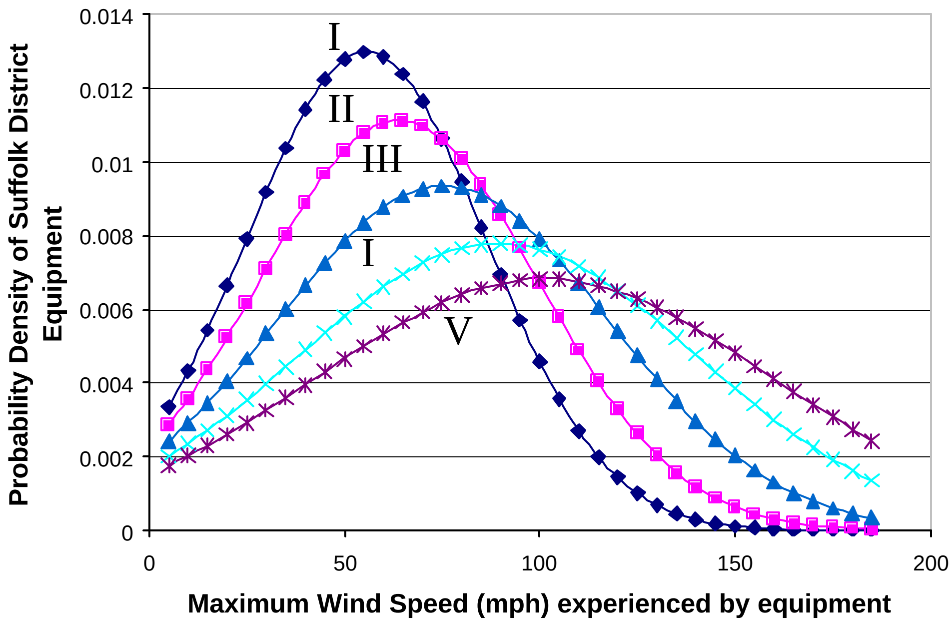

Figure ES-2. Normal Distributions of Damage

Since hurricanes of different categories (I, II, III, IV, and V) have different maximum sustained wind speeds, there are different normal density functions for hurricanes of each category. Each of these functions is defined by a mean and standard deviation. To calculate these two unknown parameters, the values for two percentiles are needed. The percentiles chosen were the 5th and 90th. The 5th percentile is the wind speed for which 5% of the installed equipment experiences less than that speed. According to the assumptions, the 90th percentile is the maximum sustained wind speed of a hurricane and the 5th percentile is five miles per hour.

Figure ES-3 shows the step in modeling and developing a tool for deciding among upgrading options. This process includes graphical comparisons of options or alternatives. The first two steps in Figure ES-3 develop a model for characterizing the extent of damage to highway equipment for each category of hurricane. The amount of damage is greater in a more severe hurricane, and it is necessary to develop a way to calculate the damage expected in a hurricane. Each type of equipment has a different strength. There needs to be a model that predicts equipment damage in a hurricane of a particular category given the strength and the amount of each equipment type.

Steps three through six develop a way to evaluate different upgrading alternatives. The results of these steps help management to see clearly what the costs and expected reduction in damage are for each alternative, and choose an alternative that suits its needs and objectives.

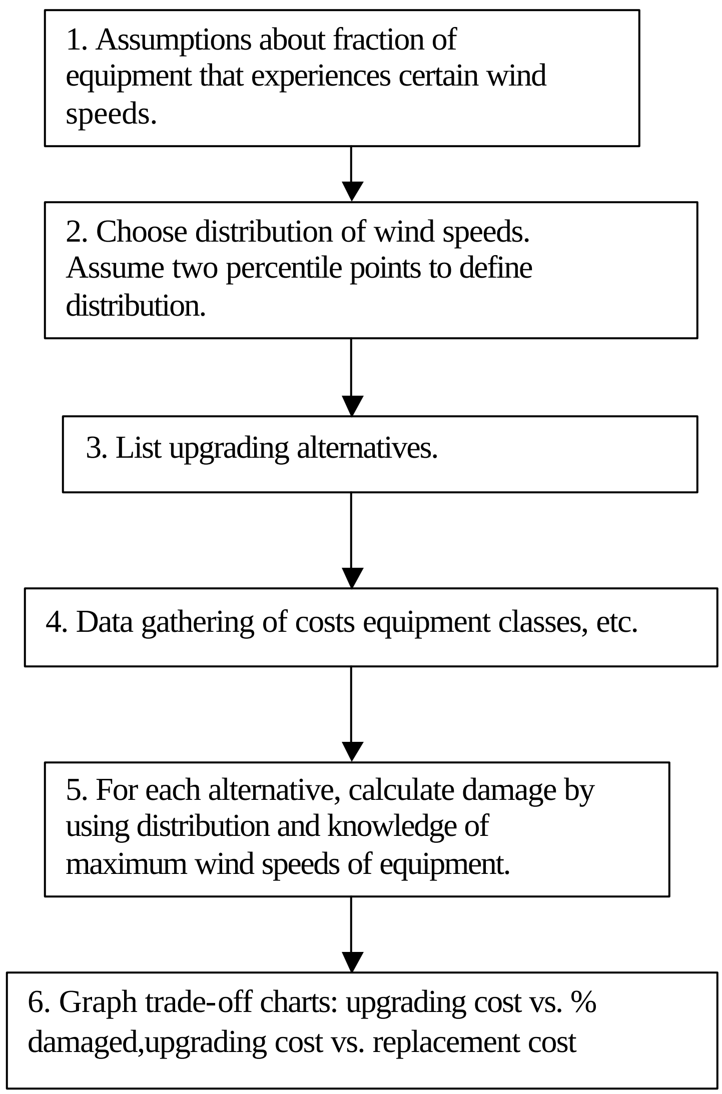

Figure ES-3. Process for Modeling and Deciding among Upgrading Alternatives for Lights, Signs, and Signals

The first section of this report also suggests factors that need to be considered and data that can be gathered to model the costs of preparedness and recovery, including the cost of upgrading, degree of upgrade, lifetime of equipment, cost of maintenance, wind speed, and hurricane frequencies. Lastly, the section suggests a graphical representation of sign upgrading alternatives that compares the cost of various sign upgrades to the expected damage from a given category storm.

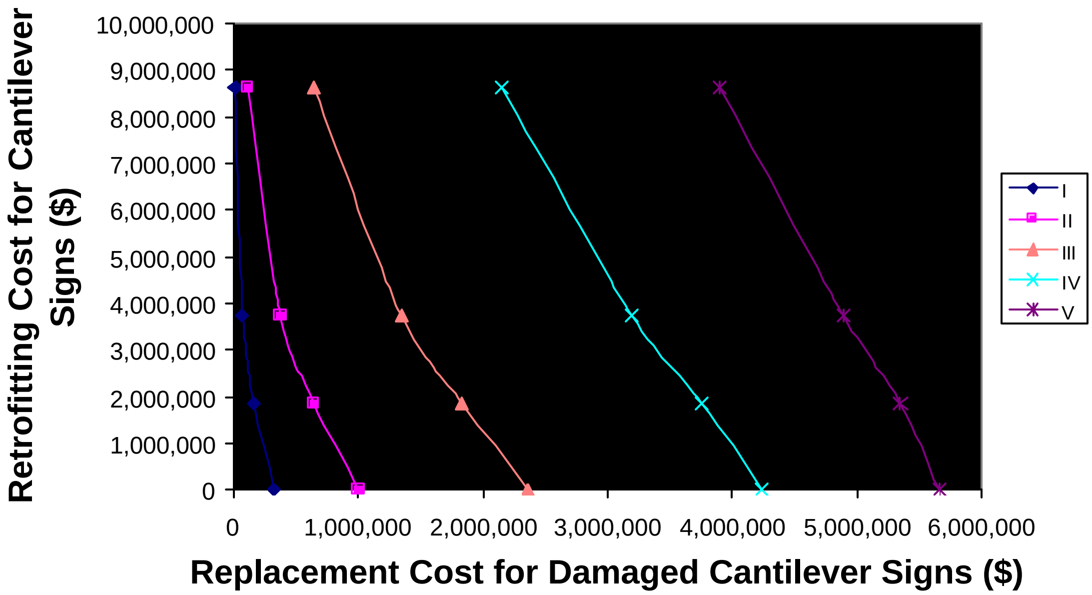

Figure ES-4. Trade-offs between Upgrading Cost and Replacement Cost for Cantilever Signs

Figure ES-4 demonstrates the trade between an up-front annual investment in upgrading the wind-speed standard of a given equipment and the potential replacement cost of damaged equipment following a storm event. The up-front investment can be likened to an insurance premium, while the cost in the aftermath depends on the level of storm that occurs (I to V). The four policies represented in the figure are the no-upgrade, increase current standards by 10, 20, and 40mph respectively, for cantilever signs. In the case considered in Figure ES-4, additional investment has little impact for the aftermath of the type I storm. It has relatively more impact for the occurrence of the type V storm (savings of about $2 million) when comparing 40mph upgrade with no upgrade (however at an annual cost of $8,000,000). On cost alone the investment is probably not justified; however, the upgrading of some smaller set of critical cantilever signs could nevertheless be justified for selected routes in the road network, if for example, the selected routes are needed for immediate repair, recovery, return of evacuated populations.

Part 2. Inventory

The second section develops a system of acquiring inventory needed for roadway equipment by assessing the cost and potential benefits of alternatives for spares of damageable equipment. The alternatives include using contractors to make and deliver signs or producing the signs in-house. The factors needed to compare these alternatives are the level of sign-material inventory, level of new signs inventory, VDOT costs (to make signs and keep in storage), contractor costs, implementation time, and external demands for sign materials. An initial step is to estimate the number of signs that are currently on the roads by counting the number of each sign type on two sample roadways. Using the extent of damage analysis developed in the first section, the number of signs damaged in each hurricane type is calculated. Using estimates for the cost of production per square foot of aluminum, the cost of aluminum lost in each category of storm is calculated. A fixed warehousing cost is incorporated with the model for a total cost of aluminum sign-material lost. Using a contractor's estimate of the cost per square foot of signs purchased, the cost of contracting the replacement of the amount lost in each category of storm is also calculated. It is suggested to compare different inventory level policies based upon the costs of preparedness and the costs and the time to recovery in the aftermath.

The accomplishment of the objectives for the evaluation of policies for spares and reserves involves the completion of the activities shown in Figure ES-5.

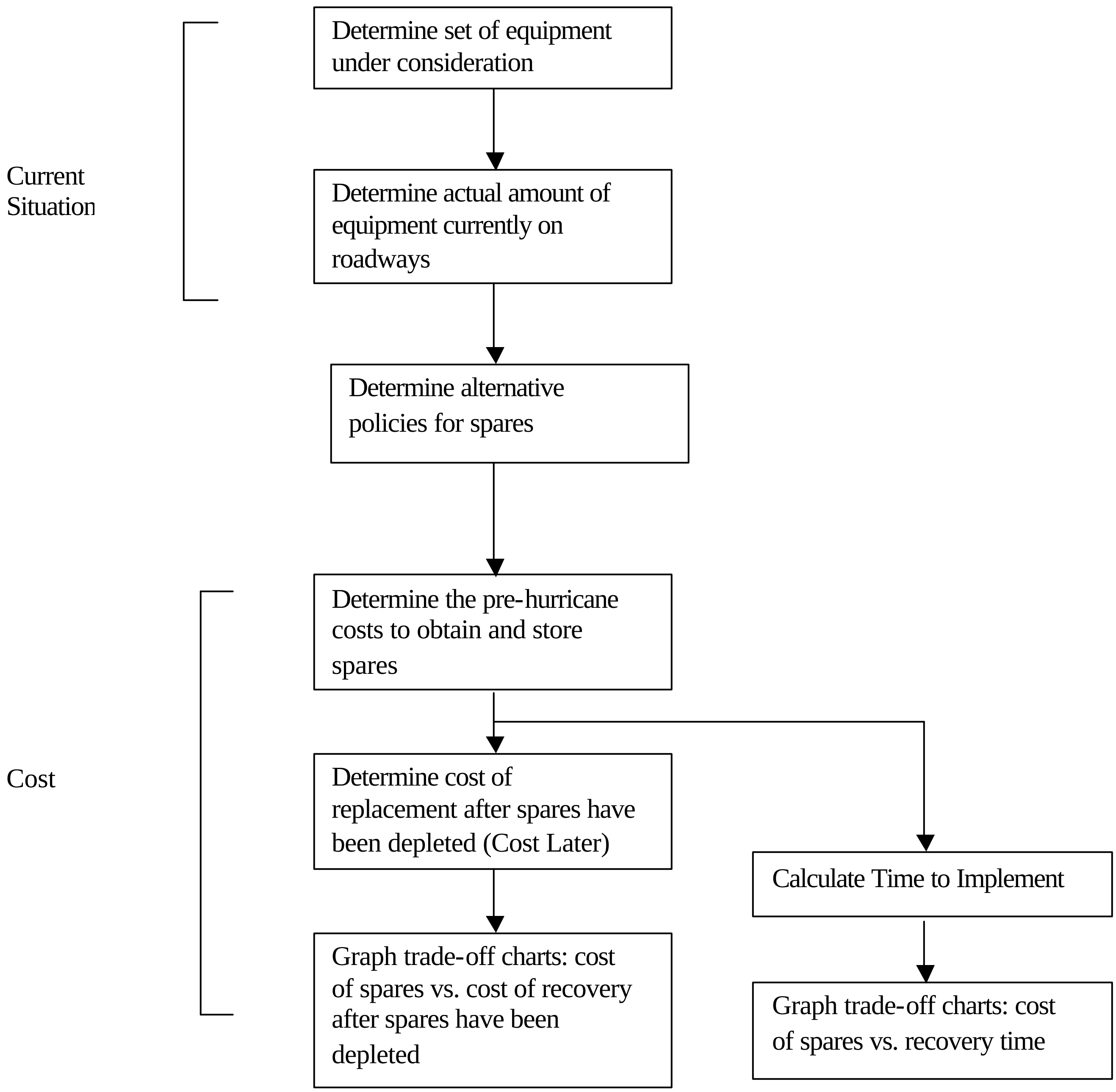

Figure ES-5 Activities for the Assessment of Inventory Policies

When the pre-hurricane cost of spares and the post-hurricane cost of recovery are calculated, the two can be compared for each alternative and hurricane type. The associated trade-offs can be graphically represented as shown in Figure ES-6.

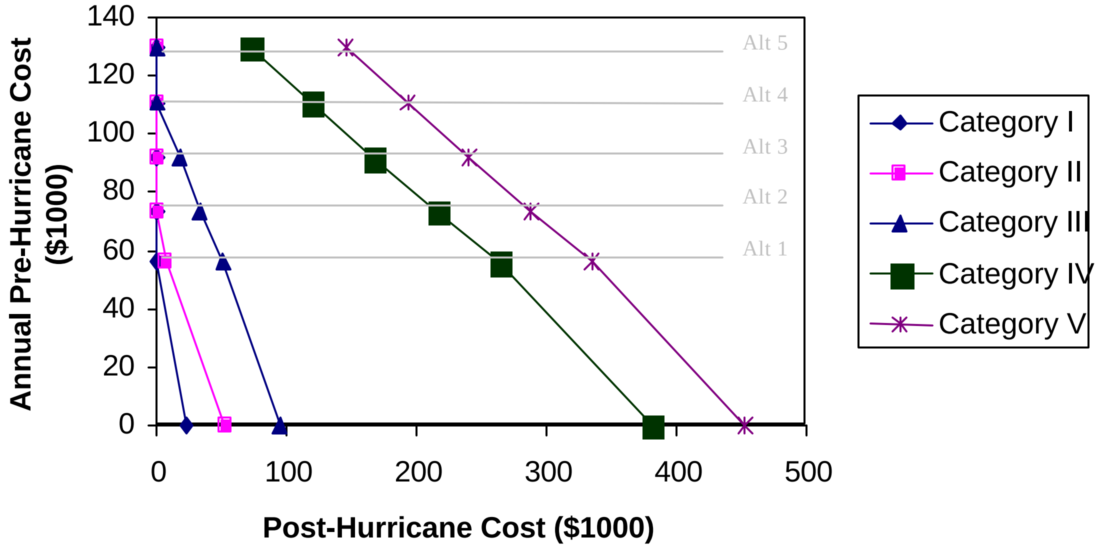

Figure ES-6. Pre-Hurricane Costs vs. Post-Hurricane Costs for Spares and Alternatives

Each horizontal line in Figure ES-6 represents an inventory alternative. Each policy will have the same pre-hurricane costs, but its post-hurricane costs will differ according to the hurricane category. The five curves on the graph represent the different hurricane categories. The graph shows how much it may cost later for the possible hurricane types if VDOT were to invest a certain amount of money into storing spares now. The graphical analysis is meant to allow the agency decision-makers to make at-a-glance comparisons of the costs and benefits of the available policies.

Part 3. Priority Setting

The third section develops a methodology for establishing priorities for the order of full recovery of road segments. The model that was developed in this section is based upon the accessibility of critical facilities from a partially recovered road network. The model establishes a ranking of the road segments for recovery that allows the quickest re-connection of critical facilities. The number of critical facilities that are accessed through that intersection determines the importance of an intersection (highway interchange). First a network of intersections and roads connecting the intersections under consideration is defined.

Figure ES-7 is a map of the Suffolk District. The hurricane recovery plan is currently applied to the Suffolk District of Virginia but can be adapted to the rest of the state.

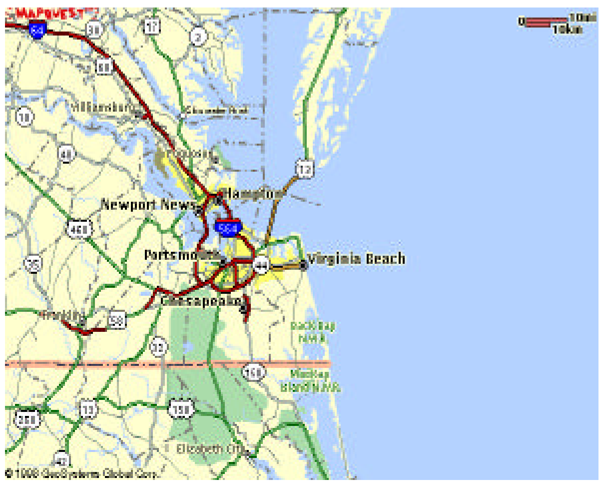

Figure ES-7. Sample Map of the Suffolk District

The major critical facilities considered in the Suffolk District (only military bases, hospitals, fire/rescue stations, and others) are identified and added to the map in order to determine the number of critical facilities accessible by each intersection. A sample of the map of the critical facilities is shown in Figure ES-8.

A connectivity measurement is then calculated using a combinatorial formula. The ordering of intersections is determined by two methods that maximize the connectivity of critical facilities. Thus producing a method for priority setting when restoring road segments in the Suffolk District.

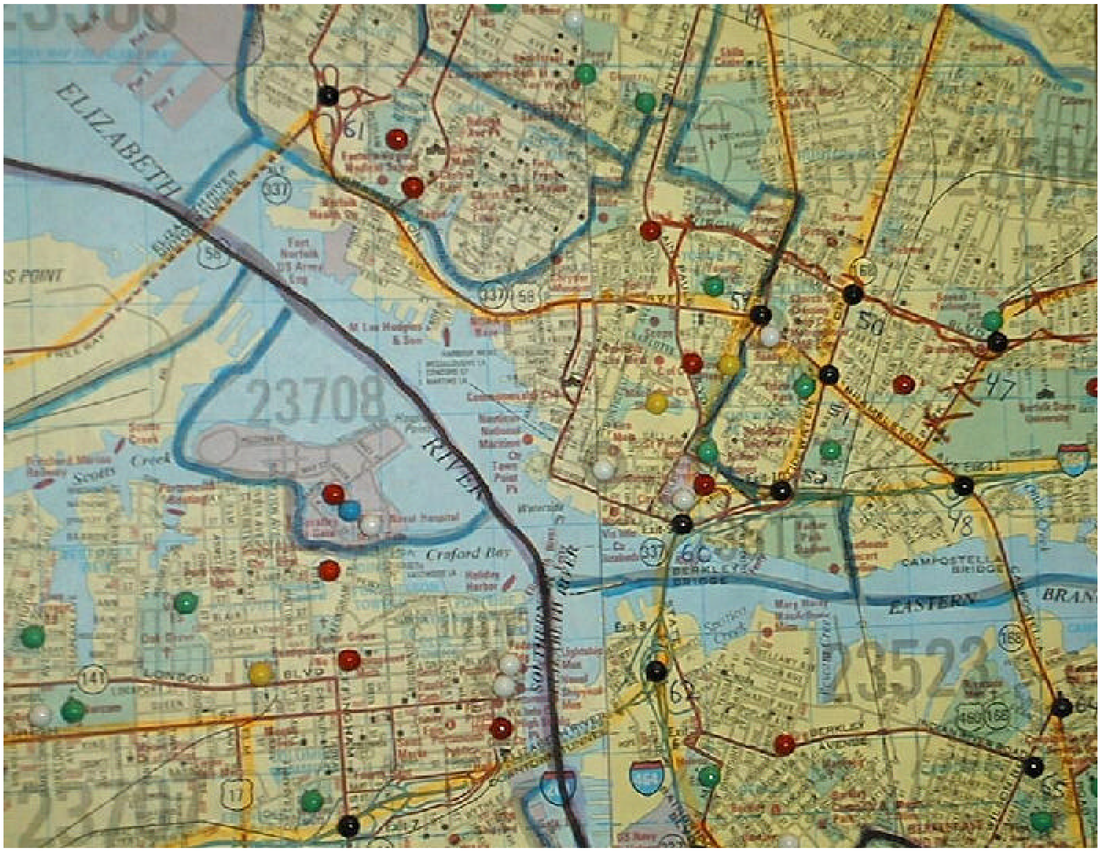

Figure ES-8. Critical Facilities Map

There are many clients (critical facilities) that are involved in priority-setting. Figure ES-9 shows how clients are divided into six different categories: Health, Safety, Education, Food, Alternative Transportation, and Government Operations.

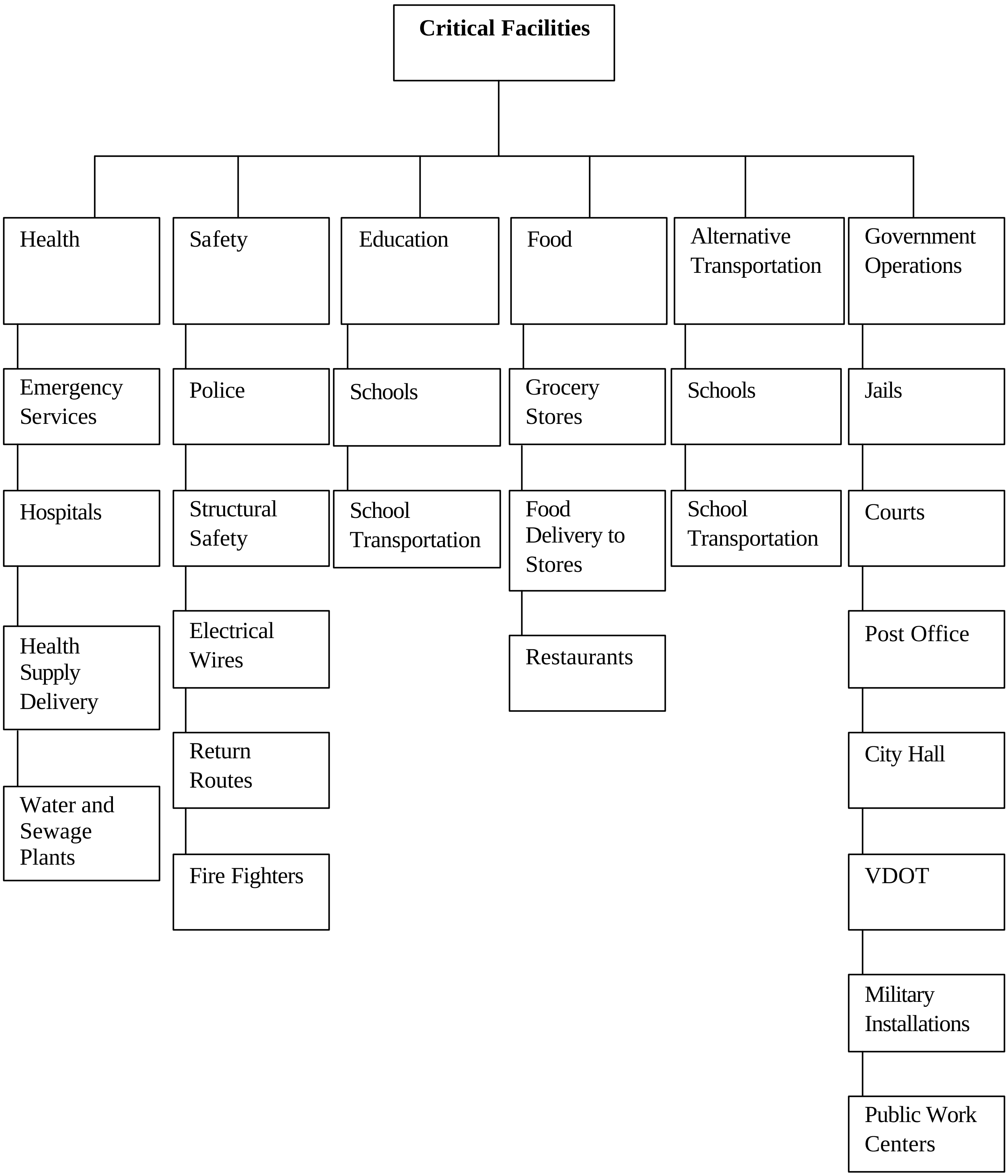

Figure ES-9. Classification of Critical Facilities to Aid in Setting Recovery Priority

The tasks shown in Figure ES-10 are completed in order to implement the priority setting.

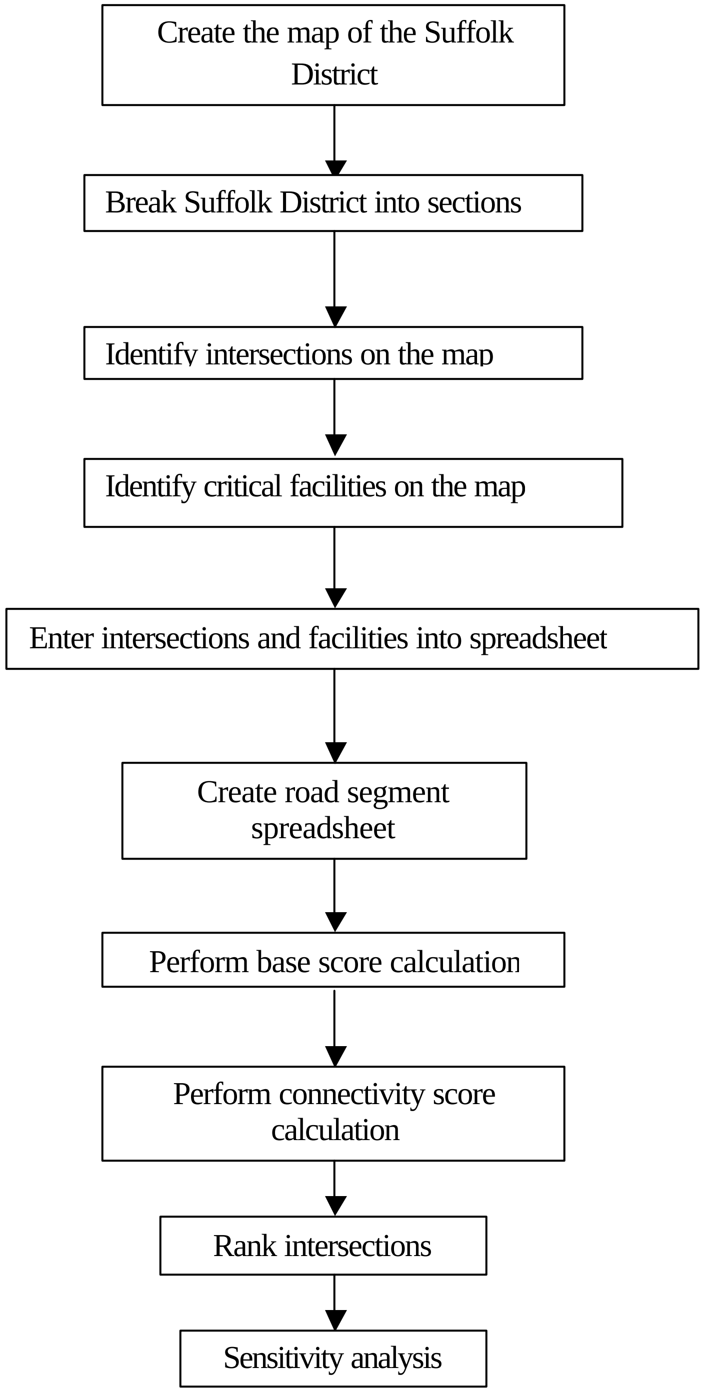

Figure ES-10. Flow Chart of Activities Needed to Complete Priority-Setting Alternatives.

Part 4. Use of Forecasting

The fourth section, planning for operation using forecasts uses historical data to determine the potential impact of hurricanes on a given year. The historical data of land-falling hurricanes provided by the National Hurricane Center (NHC) provides key information on strike probabilities for a region. The model incorporates the probability that a given type of storm will be the worst to strike a region in either a high or low forecast season. The decision-maker is able to compare investment in reserves of the equipment with the potential times of recovery following a storm in a multi-objective framework.

To improve decisions for managing reserves, the agency should have the forecast and cost information. Long-term and short-term decision-making with regard to reserves involves considering numerous models and criteria. To what extent should the agency maintain its spares? What are appropriate production and storage capacities? There are various trade-offs that have to be considered. VDOT has to determine whether it should pay now (preparation cost) or pay later (cost to recover). Another trade-off that can be assessed in the decision model is the preparation cost versus the recovery time.

A decision tree gives ideas on how to plan for the long-term and the short-term, capturing the sequence of decisions. The sequential forecast model utilizes historical data to evaluate different policies by incorporating the probabilities of a type of storm (I, II, III, IV, or V) being the worst storm to strike a region given a high or low hurricane season. The model described in this section is called 'planning for operation.' 'Planning for operation' decisions are made on the basis of long climatological records.

Figure ES-11 illustrates the "Planning for Operation" decision model.

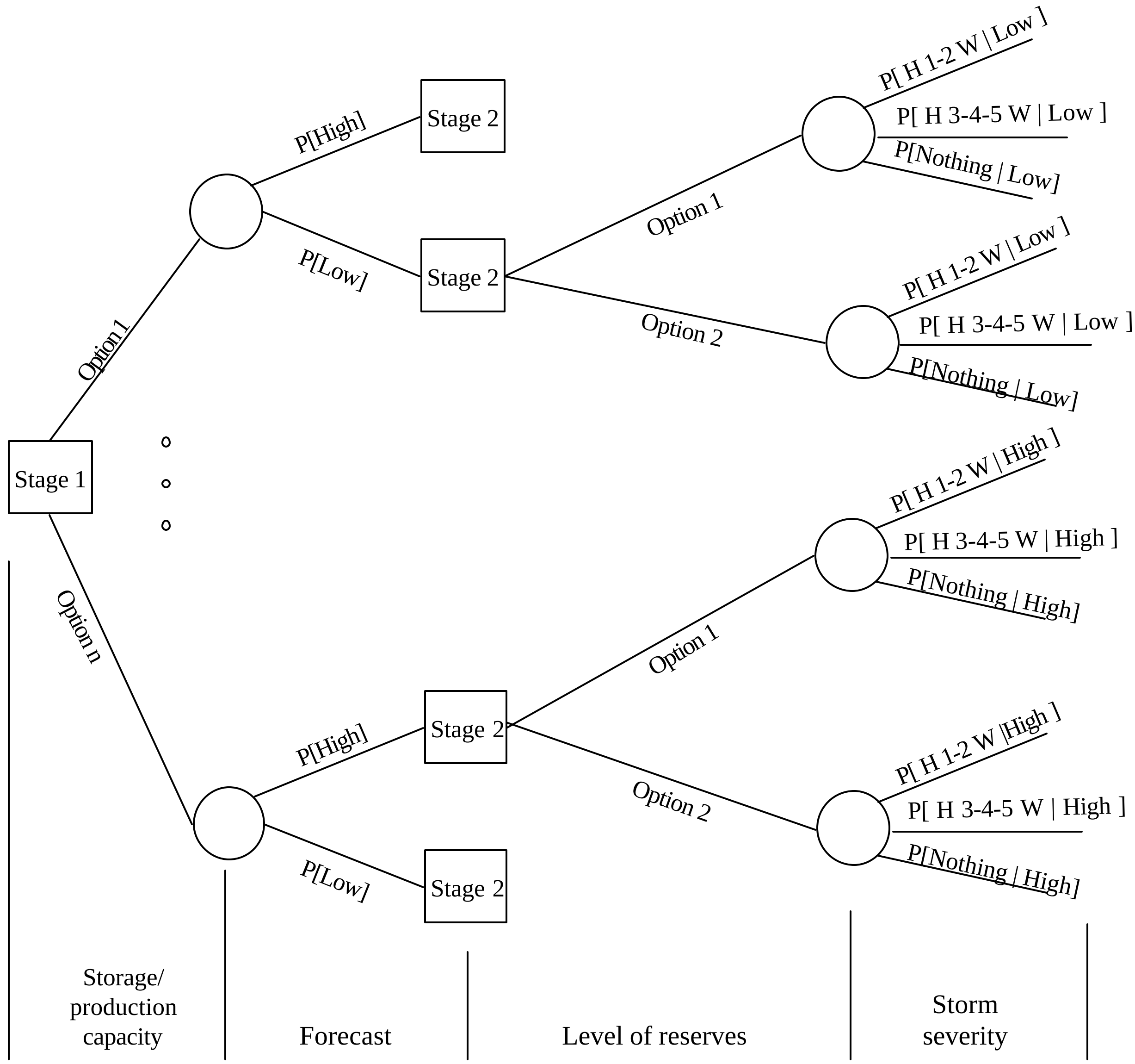

Figure ES-11: Sequential Decision-Making Model, “Planning for Operation”

Figure ES-12 illustrates a trade-off comparison of the preparation costs versus. the post-hurricane costs of recovery. The results shown in Figure ES-12 were attained from the production and installation rates, potential damage, seasonal forecasts and the historical information provided for Virginia.

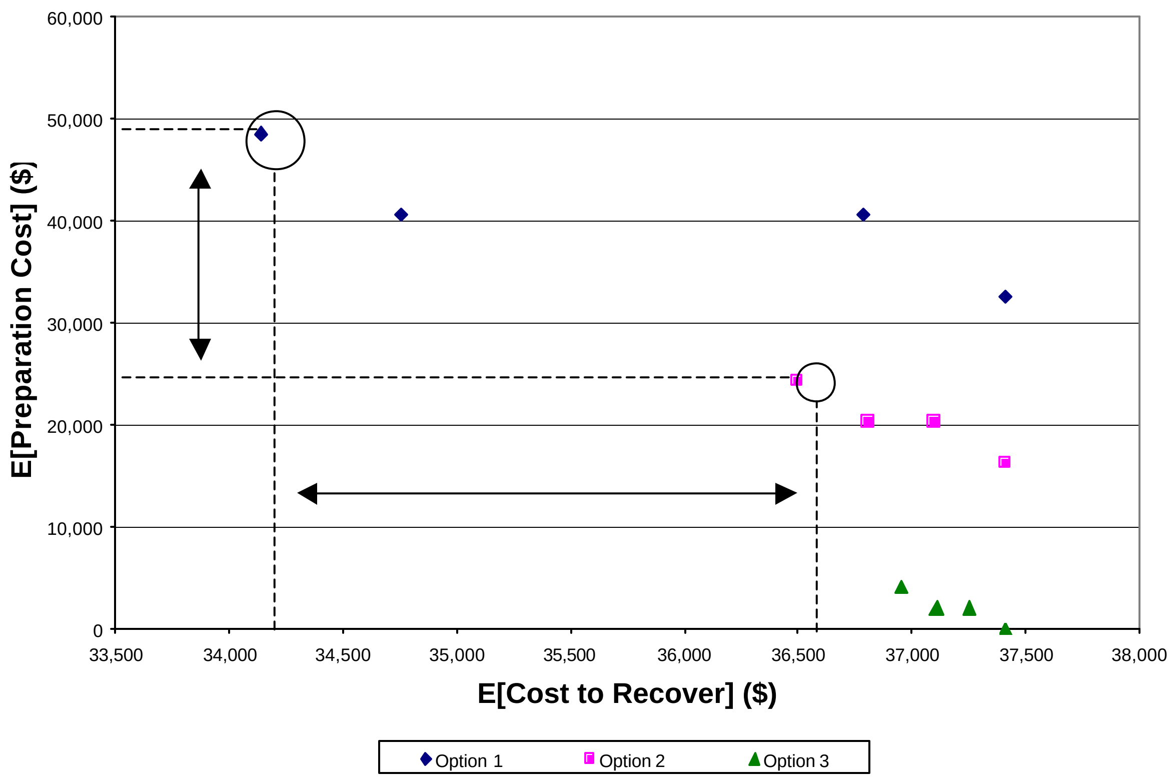

Figure ES-12. Pre-Hurricane Preparation Cost ($) Versus Cost to Recover ($) for Virginia

Trade-offs can be examined to establish the preferred policies. A comparison can be made of investing almost $50,000 in pre-hurricane preparation costs, and $34,200 in post-hurricane costs versus investing $25,000 in pre-hurricane costs and $36,000 in post-hurricane costs. The highway agency can determine whether to invest more initially, rather than spending more funds to recover later. Therefore, changes in production or installation capabilities such as the increasing the number of crews would decrease the time to recover which in turn would change the results attained in Figures ES-12.

Recommendations

The following are the main recommendations to the highway agency:

- Notice the problem: Hurricanes can cause region-wide damage to traffic equipment
- Consider four remedies:
  1. upgrading equipment
  2. keeping an inventory of spares and reserves of highway equipment on hand,
  3. priority setting of roads for recovery
  4. use of seasonal forecasts to determine the levels of reserve equipment
- Distinguish between short and long-term recovery efforts. Short-term efforts involve temporary replacements while long-term efforts have permanent replacements.
- Evaluate different upgrading or spares policies by assessing the cost before a hurricane strikes and the damage, cost, and recovery time after a hurricane.
- Adapt spares and reserves to hurricane-center and other seasonal forecasts.
- Perform impact analysis using the various storm categories
- Consider the trade-offs between investing in spares and/or upgrading, and the times and costs of recovery
- Adopt the models for estimating the costs and effectiveness of upgrading and spares policies
- Consider upgrading only of routes critical to a community's well-being in a hurricane
- Use probability distributions of wind speeds for different categories of storms to model hurricane impact on equipment
- Consider critical facilities throughout the road network in setting priorities for recovery, using accessibility to the critical facilities as a measurement of the importance of restoring a damaged road
- Consider the following categories of critical facilities: health, safety, education, food, alternative transportation, and governmental operations
- Maintain a web site for support of recovery of signs, signals, and lights. This web site may be adapted in the future to evaluate and prepare for the damage caused by other disasters.