Executive Summary

The impacts of a hurricane on a coastal community can cripple a community's infrastructure for months or years. Once communications and power are re-established and roads have been cleared of debris, the recovery of traffic control equipment is required for the re-establishment of adequate public transportation. In the days immediately following the hurricane, temporary traffic control measurements are implemented. However, the permanent replacement and repair of this equipment is a costly and time-consuming process. The goal of this effort is to aid the Virginia Department of Transportation (VDOT) in improving the post-hurricane recovery of highway signs, lights, and signals through assessment of the risks, costs, and benefits of alternative plans. From a risk-based perspective, this project considers what is required to respond to another Hurricane Hugo in terms of the replacement and recovery of roadway signs, signals, and lights at what cost and over what period of time.

For this project, several needs have been identified to improve the ability of VDOT in such recovery management. Specifically, four approaches to the equipment recovery process have been improved upon through the application of systems engineering tools. The adoption and utilization of these tools, individually or as a whole, will result in a more efficient process of recovery.

The overall project can be represented graphically as follows:

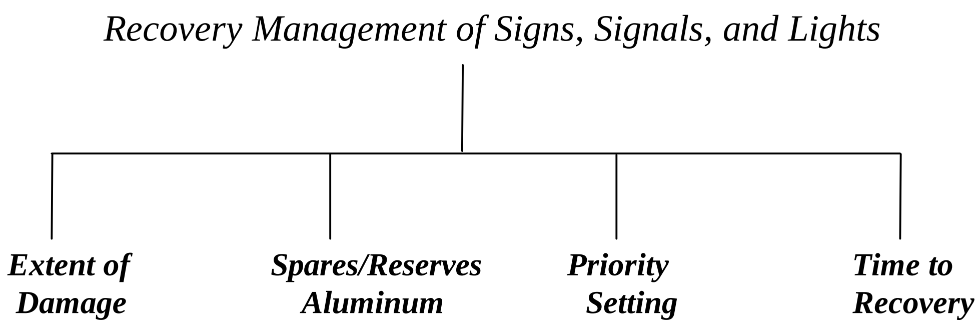

Figure ES.1: Project overview and integration.

The first approach examines the hurricane impacts to highway signs, signals and lights. A methodology is developed here to compare possible strengthening alternatives, including the reinforcement/retrofitting of damageable equipment against the threat of hurricane-force wind speeds. Comparison of costs versus hurricane damage aids in the evaluation of the various reinforcement plans. This tool will help VDOT determine whether such strengthening projects will be valuable and cost-effective. This study uses information gained from analysis of the impacts of different storm categories to highway signs and the characterization of damage for these scenarios.

A developed model compares the costs of various sign retrofits versus the expected damage from a given storm category. Each type of sign can be strengthened to varying degrees, resulting in positive and negative results - the positive result being less expected damage, and the negative result being a higher cost.

Figure ES.2 shows a depiction of the strengthening options for a given sign type. The diagonal lines show how overhead signs, retrofitted to 120% and 140% higher standards, might be expected to improve for each hurricane category. The expected damage for these scenarios can be compared to each other, as well as the 100%, or "do nothing," option. By comparing the different retrofitting options, one can decide as to whether the decrease in damage is worth the added increase in cost. When this model is used in practice, the percent damage would be calculated for all options and the costs of equipment strengthening would need to be accurately quantified.

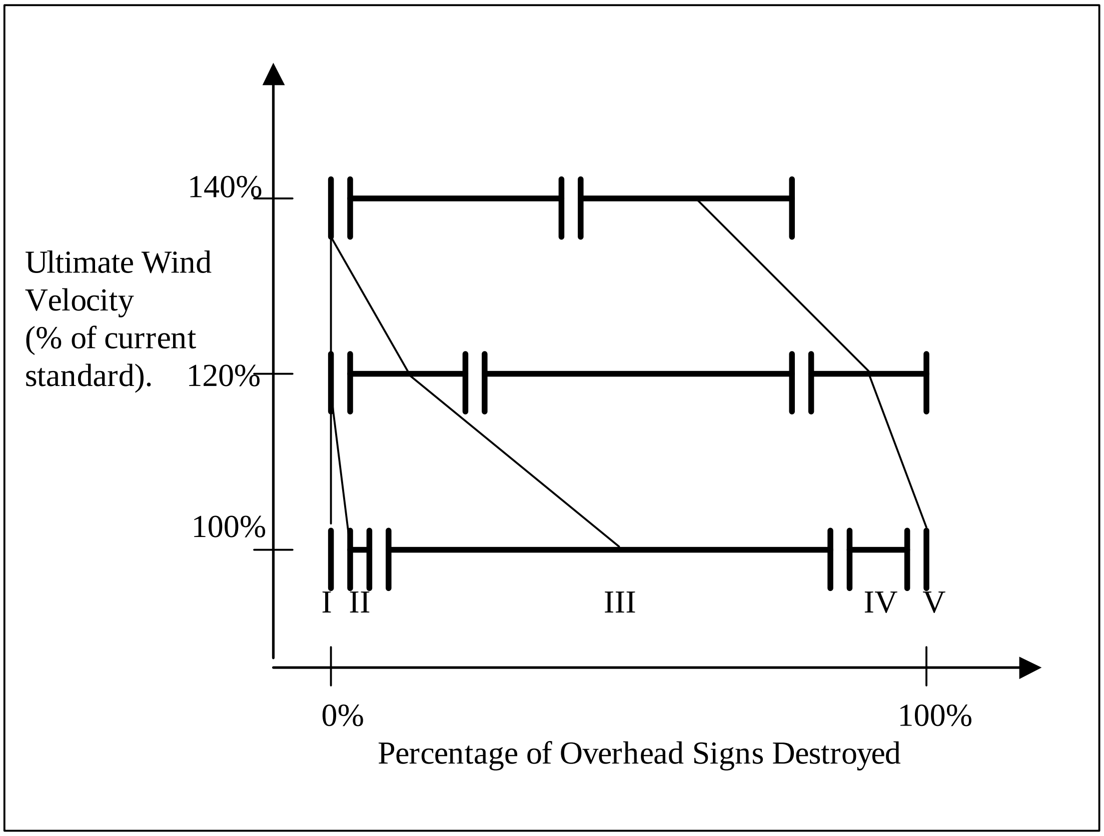

Figure ES.2: Retrofitting Overhead Signs

The characterization of hurricane damage is a valuable component of hurricane preparedness and recovery. The aspects of hurricane characterization that are most in need of further analysis are: the representation of ultimate wind velocity for damageable equipment, the characterization of total equipment damage, and the criteria involved in possible strengthening alternatives. The alternatives for sign strengthening can be depicted through two different comparison models presented in this document. By analyzing and comparing these alternatives, VDOT will be able to determine the option that is the most cost-effective in the long run.

The second approach examines existing, large inventory management systems already in place, such as those for auto-makers and other industrial manufacturers. By studying how these inventories manage extreme stresses placed upon them, an inventory system for raw material used to produce signs is formulated. This methodology is compared to the cost of contracting out all the production of signs. Production rates, storage costs, and contractor costs are considered to give VDOT a realistic look at the benefits of producing signs by itself after a major disaster such as a hurricane. The cost to contract out all sign production exceeds the cost for VDOT to produce all the material itself.

The result of this approach is a model with which VDOT can decide how prepared for a hurricane the region needs to be based on economic standards and community requirements. If VDOT has allocated a specific amount of money to hurricane recovery, then it is shown how much aluminum can feasibly be replaced with that investment. If VDOT decides that in order to have an efficient recovery for the community it must be prepared for a category 2 hurricane, then the results will show how much money and resources it will take to be completely prepared for a hurricane of this strength. The benefit of this model is that VDOT has the power to make a decision from any standpoint and still obtain valuable information and improved efficiency. Figure ES.3 shows graphically the information provided to VDOT. Each line represents a different hurricane and from this you can infer the percentage of signs made by VDOT and the cost incurred during production and storage.

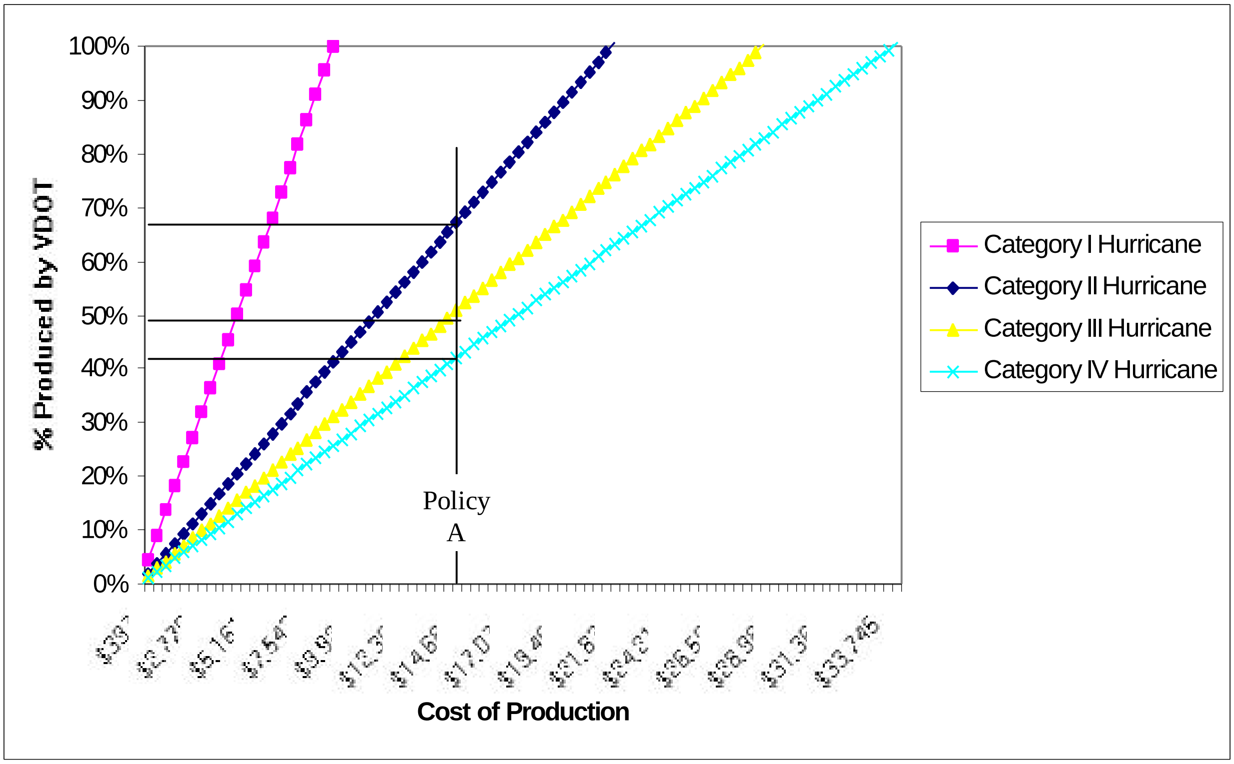

Figure ES.3: Example policy with fixed expenditure by VDOT

The third approach utilizes network analysis mathematics and node-weighting techniques to assess the relative gains from recovering individual road segments. These assessments provide a basis for prioritization of road-segment equipment recovery, i.e. a long-term road recovery schedule. The goal of this analysis is to provide a methodology for establishing priorities needed to determine the optimal orders of the long-term recovery of road segments in the Suffolk District. An improvement in the effectiveness of the road recovery schedule will lead to benefits for all Suffolk District residents.

Figure ES.4 shows the step-by-step connectivity comparison of the first 66 road segment re-establishments for three methods of road recovery explored in this document.

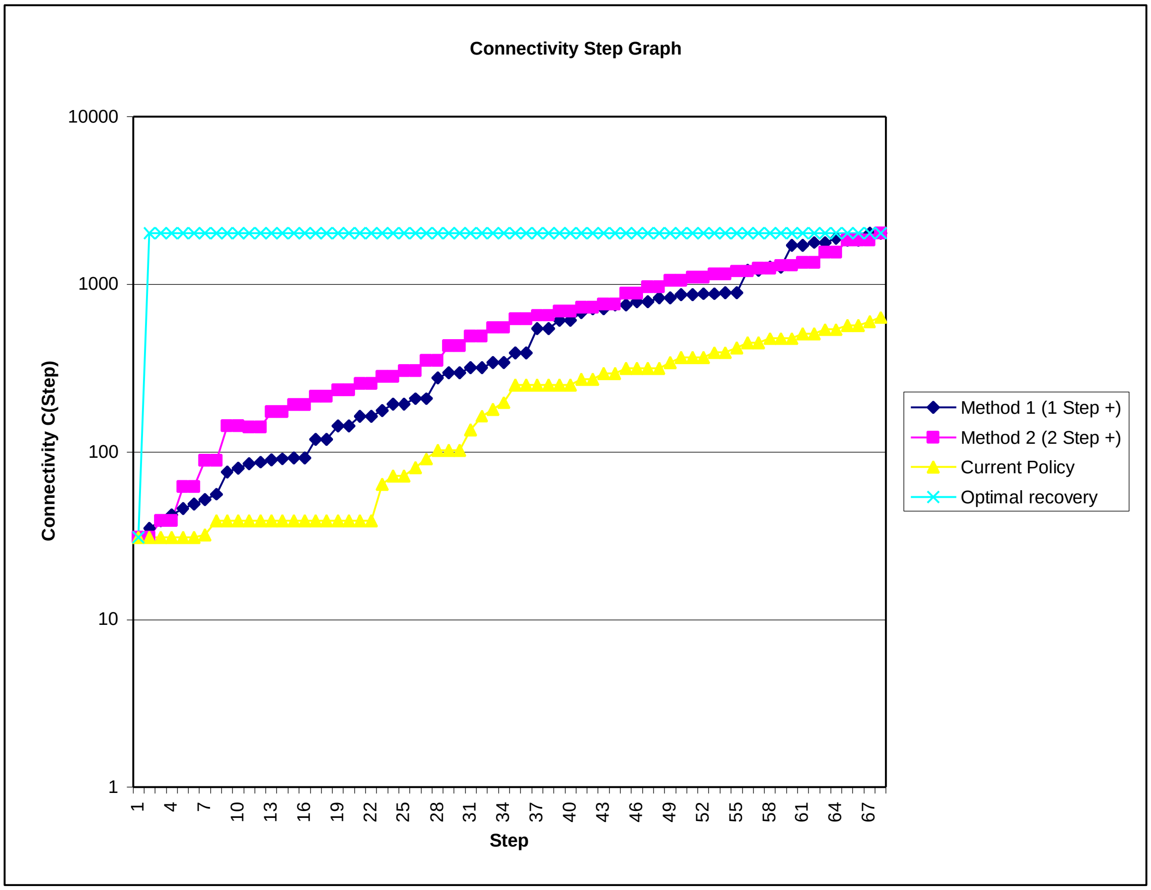

Figure ES.4: Connectivity graph comparing all three methods

This graph shows the connectivity of critical facilities through systematic road segment recovery. Using tools such as this, VDOT can consider the various road recovery orders available to them, and compare these orders to each other for long-term effectiveness.

There is opportunity for improvement in the order of road recovery. Using a weighted measurement technique that assesses the effectiveness associated with each road segment recovery, VDOT recovery facilitators can increase recovery efficiency in the administration of road re-establishment efforts. This can help a community affected by a hurricane regain its civic well being through a quick return to standard traffic conditions. A recovery prioritization model such as the one developed for this criticality analysis can be applied to any community where a major disaster has resulted in the crippling of the transportation network. In addition, the criticality analysis allows for variation in the weighting used to assess the relative importance of the network nodes. Thus, this adaptive model can provide support to traffic engineers in improving the effectiveness and efficiency of road re-establishment by suggesting a better sequence of recovery.

The fourth approach looks at the overall recovery project to determine what activities take place and how these activities relate to the timing of hurricane recovery. By identifying flows of tasks using networking techniques, a critical path of events is identified that helps to determine where problem areas and bottlenecks in scheduling could occur. By collecting additional data and employing this methodology, improvements in efficiency and speed of recovery of damageable equipment can be achieved.

This analysis, when performed on the VDOT hurricane recovery process, reveals a network such as that presented in Figure ES.5.

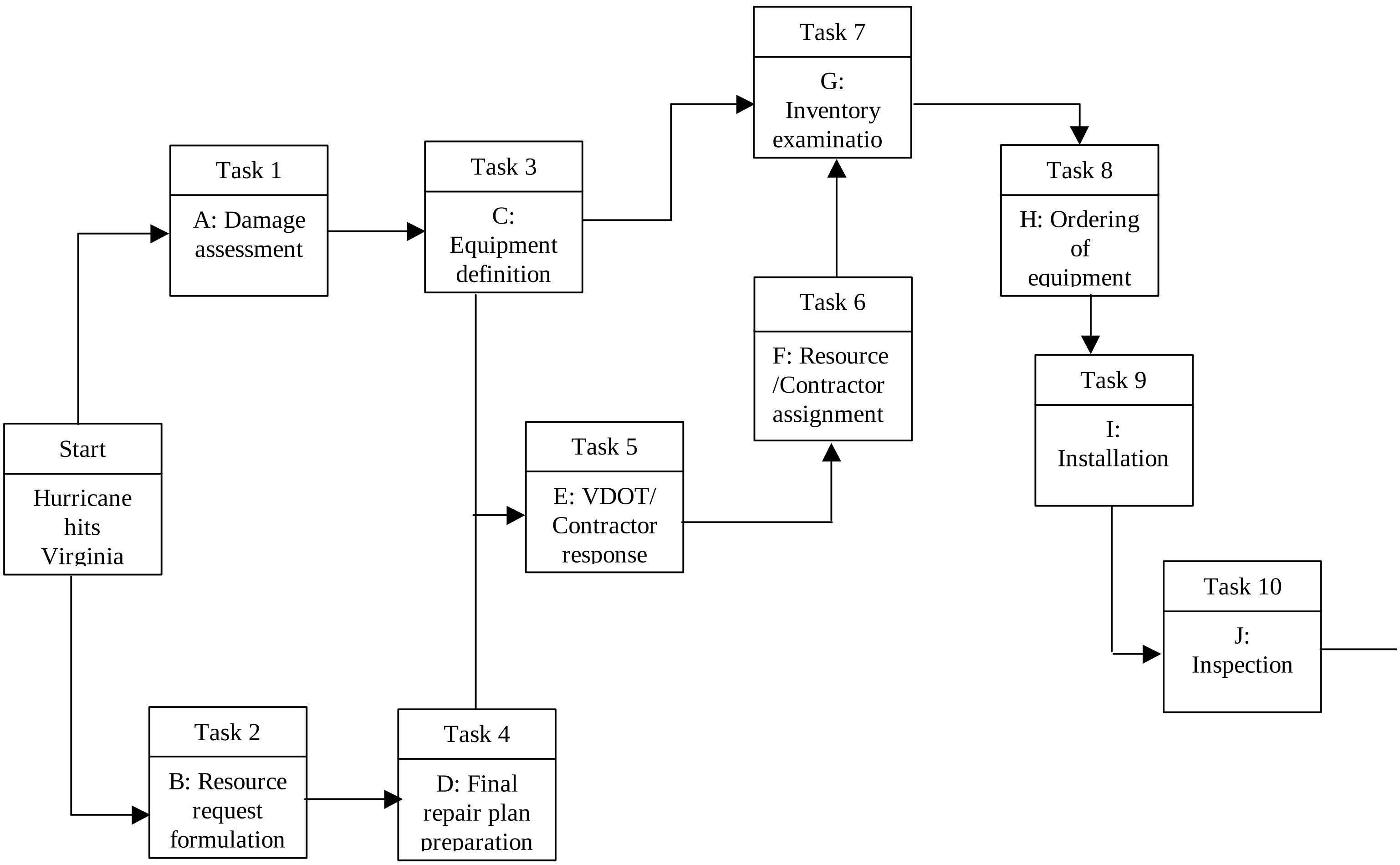

Figure ES.5: Network diagram for project activities showing the relationship between various tasks necessary for p

Figure ES.5 shows the layout of potential hurricane recovery activities as they occur. This layout shows how each recovery activity is related to every other recovery activity, thus establishing relationship and precedence patterns that reveal the importance of each task. Further, such network representation of the recovery process allows accurate estimation of the time-to-complete-recovery following a hurricane.

This time-to-recovery evaluation of the hurricane project has revealed that the current set-up of tasks may be improved, and that the completion time of highway recovery and its cost are highly dependent on each task being completed within the allotted time and budget. There is little leeway for delay built in to the recovery procedure. Specifically, the actual act of installation of emergency equipment is the most expensive and most variable task. The installation process determines to a large degree how soon recovery can be completed. Therefore, this activity must be split up into similar tasks that can be performed simultaneously. The project improvement analysis reveals that time to recovery can be lessened by several weeks without excessively increasing the recovery costs. Therefore, it would be in VDOT's interest to invest more capital and resources in the case of severe hurricane damage for quick recovery. VDOT is encouraged to examine the various configurations of tasks that take place following a hurricane, and in doing so to decrease the number of activities that slow down the recovery process.

To summarize, table ES.1 presents a summary of the project approaches as presented above.

Table ES.1: Summary of VDOT project approaches used to improve highway recovery

Issue	**Extent of Damage**	**Spares/Reserves Aluminum**	**Priority Setting**	**Time to Recovery**
Goals	Characterize comparison of sign strengthening	Provide information to improve inventory of spares/reserves	Improve effectiveness of road recovery order	Project management and reduction in time to recover
Alternatives or Decision Variables	Varying degree of retrofit/ strengthening	Producing signs vs. contracting out sign production	Varying road recovery orders	Varying task lengths and costs, and schedule configurations
Evaluation Criteria	Cost, sign damage	Production rates, storage costs, contractor costs	Criticality of road segments	Time to complete recovery, cost
Analysis Tool	Storm impacts under uncertainty	Inventory modeling and cost analysis	Network modeling and analysis	Project management techniques
Sources of Data	VDOT wind design standards	PIMS report, VDOT sign shops, independent contractors	Road maps, critical facility locations,	Work rates and cost data for light installation

This table mentions the four approaches developed in the project including their goals, the alternatives, the evaluation criteria, the analysis tools, and the sources of data that were employed to create the individual analyses.

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Chapter 1

Introduction

1.1 Background

Hurricanes can be one of the most destructive natural disasters to a society. On a large scale, a hurricane can damage the most vital and fundamental public infrastructures of a community. The free movement of people, goods, and services is abruptly stopped, threatening human health, safety, and well being. The economic stability of individuals, the community, the region, and the state is affected through the disruption of commerce. The restoration of the highway and street systems depends on the extraordinary efforts of those that routinely build, operate, and maintain it. A planned, organized, and swift response is essential to restoring highway and street operations so that problems are minimized.

This study develops a framework to improve hurricane recovery management of signs, lights, and signals for the Virginia Department of Transportation. To do so, the project team has identified four major needs of VDOT, and has developed corresponding methodologies to address each of them. The four methodologies are inter-related and as such, they may be implemented independently or simultaneously, depending on the interests of VDOT management. The needs and approaches are described as the following:

1.2 Alternatives for Reinforcement of Highway Sign Structures

A methodology is developed here to compare possible strengthening alternatives, including the reinforcement/retrofitting of damageable equipment against the threat of hurricane-force wind speeds. Comparison of costs versus hurricane damage aids in the evaluation of the various reinforcement plans. This model will help VDOT to determine whether such strengthening projects will be valuable and cost-effective. This approach uses information gained from analysis of the impacts of different storm categories to highway signs and the characterization of damage for these scenarios. The strengthening of damageable highway equipment might save VDOT money in the long run.

1.3 Alternatives for Spares/Reserves Inventory of Aluminum for Signs

This section examines existing, large inventory management systems already in place, such as those for automakers and other industrial manufacturers. By studying how these inventories manage extreme stresses placed upon them, an inventory system for raw material used to produce signs is formulated. This methodology is compared to the cost of contracting out all the production of signs. Production rates, storage costs, and contractor costs are considered in order, giving VDOT a realistic look at the benefits of producing signs by themselves after a major disaster such as a hurricane.

1.4 Critical Replacement of Damaged Equipment

This approach to recovery improvement utilizes network analysis mathematics and node-weighting techniques to assess the value of individual road segments. These assessments provide a basis for prioritization of road segment equipment recovery, i.e. a long-term road recovery schedule. The goal of this analysis is to provide a methodology for establishing priorities needed to determine the optimal orders of the long-term recovery of road segments in the Suffolk District. An improvement in the effectiveness of the road recovery schedule will lead to benefits for all Suffolk District residents.

1.5 Alternatives to Reduce Time-to-recovery of Signs, Signals, and Lights for a Hurricane-Damaged Highway System

The goal of this methodology is to gain insights into the time to completion and the costs involved with hurricane recovery procedures. Here, the overall recovery sequence is examined to determine what activities take place and how these activities relate to hurricane recovery. By identifying flows of tasks using networking techniques, a critical path of events is identified that helps to determine where problem areas and bottlenecks in scheduling could occur. Although no definite task management plan exists (Cogburn, 1998), by collecting data and employing this methodology, improvements in efficiency and speed of recovery of damageable equipment can be achieved.

For all four methodologies the road system under consideration is the Hampton Roads/Suffolk district, as shown in Figure 1.1:

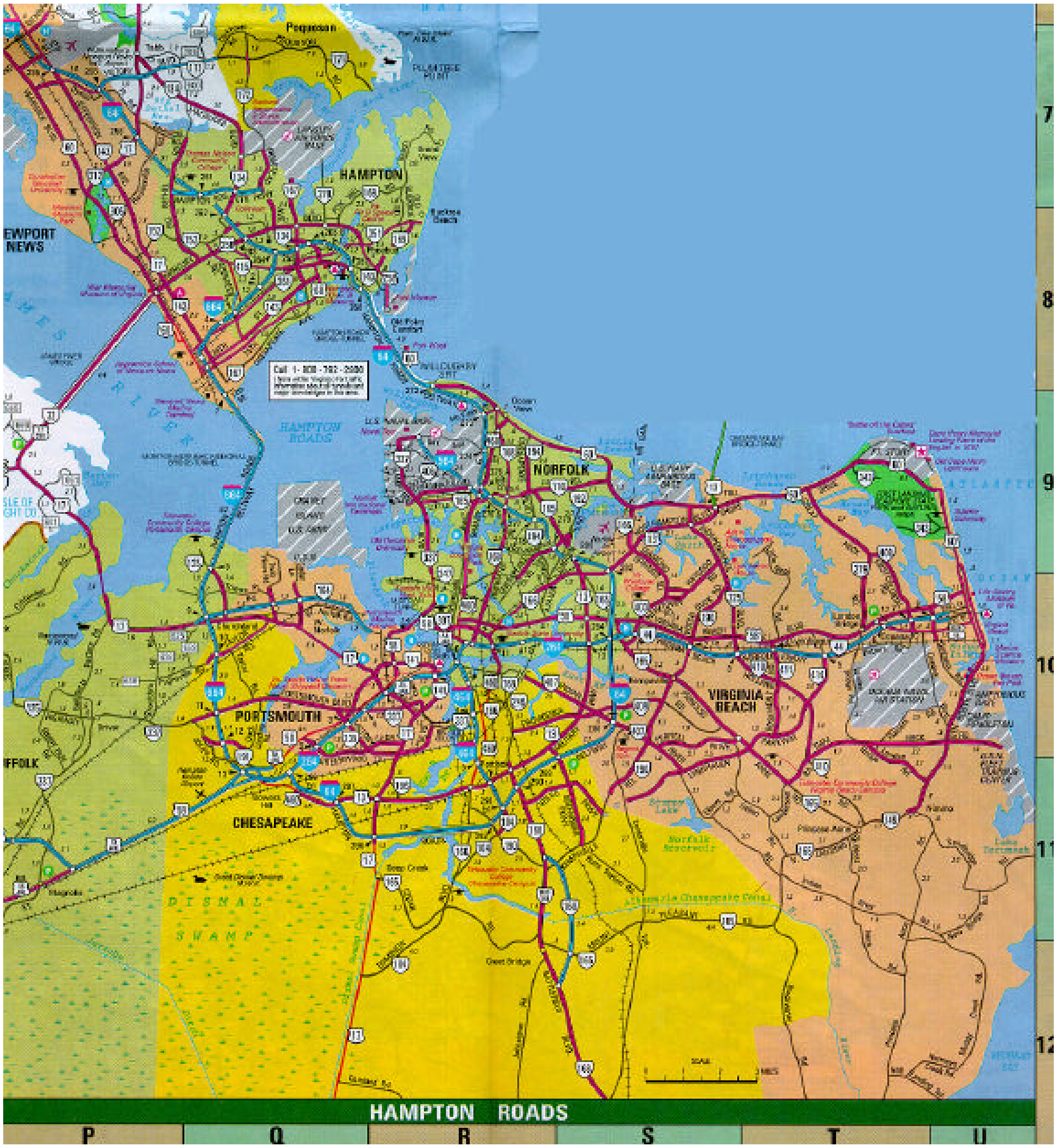

Figure 1.1 Map of Suffolk district showing major roads under consideration for this study

The roads in this area are encompassed in the Suffolk District of VDOT are:

- State Roads 460, 13, 58, 168, 464

- Interstate 64, 264, 464, 564, 664, 164
- Routes 44, 10, 17, 258

Equipment that can be damaged in a hurricane includes:

- Traffic control systems on important arteries and collector roads
- Barricades
- Emergency lighting systems
- Hazard signs
- Directional signs

The classes of equipment under consideration in this study are signs, signals, and lights. However, the analyses performed for the recovery of this equipment can be applied to the other types of equipment listed above. Additionally, the results of this report can be further put to use in regions of Virginia other than the Suffolk district. Since the nature of the following report is to develop methodologies for the improvement of recovery, the results from this report can be put to use in developing more focussed recovery plans in those states susceptible to natural disasters such as hurricanes.

Using the methods described above to increase the efficiency and effectiveness of recovery management, this report can help VDOT implement a process that is beneficial to the community and economical to the state. This project helps VDOT understand the entire process of recovery management including hurricane impacts, aluminum production and supply, recovery priorities, and the repair process.

One of the various implications of this project concerns VDOT's dealings with the Federal Emergency Management Administration (FEMA). FEMA is the government agency that provides funding to states after a crisis, such as a hurricane. When a hurricane strikes a given state, that state's department of transportation has the difficult task of estimating the monetary value of all damage repairs. These damage estimates are made by both FEMA and VDOT officials immediately following a hurricane strike. Often there are differences between these estimates, and the value of this study to VDOT is to minimize these discrepancies. This project could eventually serve as a solid basis for any claim made by VDOT in these critical estimation periods. This study in hurricane preparedness and recovery will give both agencies a common ground to work on, and provide a blueprint for success.

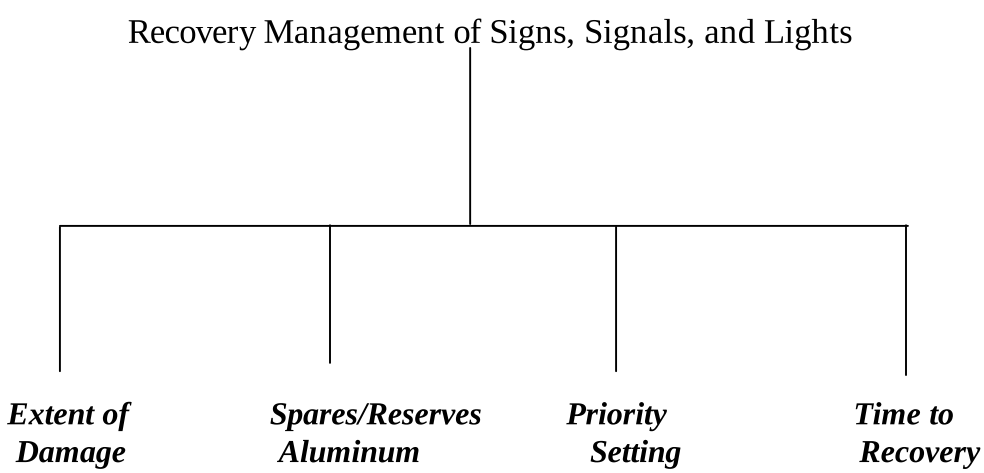

Figure 1.2: Project Overview and Integration.

The overall project is represented graphically as shown in Figure 1.2. All four methodologies work to combine and create an overall improvement in highway recovery.

Table 1.1: Summary of VDOT project methodologies used to improve highway recovery

Issue	**Extent of Damage**	**Spares/Reserves Aluminum**	**Priority Setting**	**Time to Recovery**
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Table 1.1 presents a summary of the four approaches developed in the project including the goals, the alternatives, the evaluation criteria, the analysis tools, and the sources of data.