INVENTORY

Introduction

The Virginia Department of Transportation's (VDOT) sign production facilities currently may not have the capacity to handle the demand produced by hurricane damage. The development of an inventory system for hurricane recovery equipment will allow VDOT to restore transportation systems to a functional state in a more timely manner.

This chapter deals primarily with the evaluation of alternatives for spares and reserves (i.e. inventory practices). One objective of the overall project is to assess the costs and risks of different inventory management systems for hurricane recovery equipment. This will allow VDOT to assess an inventory management system based upon cost, implementation time, and consequences. Several uncertainties can complicate the cost and risk assessment of inventory control alternatives. The location and time that a hurricane will hit or the degree of severity with which it will hit can not be predicted. The months at higher risk for hurricanes can be forecasted, but the probability of a hurricane hitting this year or next year or ten years from now cannot be predicted. In order to deal with this uncertainty, this project will not be concerned with the probability of a hurricane occurrence, but rather the consequences if one should occur.

Another uncertainty deals with the strength of a storm. Due to the unpredictability of hurricane movement and dissipation, Virginia will have little warning about the strength of a hurricane. The following Saffir-Simpson hurricane scale shown in Table 4.1 categorizes these storms based upon wind speeds and predicts the degree of damage.

Table 4.1. Saffir-Simpson Scale (VDOT, 1997a)

Category	Winds (mph)	Damage
1	74-95	Minimal
2	96-110	Moderate
3	111-130	Extensive
4	131-155	Extreme
5	>155	Catastrophic

As shown in the Table 4.1, different categories cause different levels of damage. Without a way of predicting the category of a storm, it is difficult to determine the extent of damage the storm can cause. In order to deal with this unpredictability the consequences of each category of storm must be determined. The consequences for each possible inventory alternative must be evaluated in terms of each possible hurricane scenario.

The final result is a recommendation for an inventory system that minimizes cost, implementation time, and risk. A spreadsheet will provide evidence of the accomplishment of these goals.

- The main objectives of this chapter are:
- Development of an inventory models for the Suffolk area.
- Development of a tool that will allow VDOT to assess different inventory policies based upon cost, time, and risk
- Presentation of the spreadsheet of policies and consequences to VDOT for alternative assessment.

The first section discusses the tasks that must be accomplished in order to carry out stated objectives for this portion of the project. This section gives the steps involved in the collection of data and the development of the methodologies that will be used to assess the inventory policies. second section will then describe how the cost and risk assessment will be delivered to VDOT. The section will give details about the spreadsheets that are being developed for VDOT for use as a tool in the assessment of inventory policies and will include a description of how each worksheet will be applied and definitions for each column in the worksheets. The last section, will then itemize the steps that must be taken from this point forward to complete the assessment tool for VDOT.

Statement of Activities

The accomplishment of the objectives for the assessment of spares and reserves involves the completion of the activities shown in Figure 4.1. Each activity will then be described in greater detail in the following subsections.

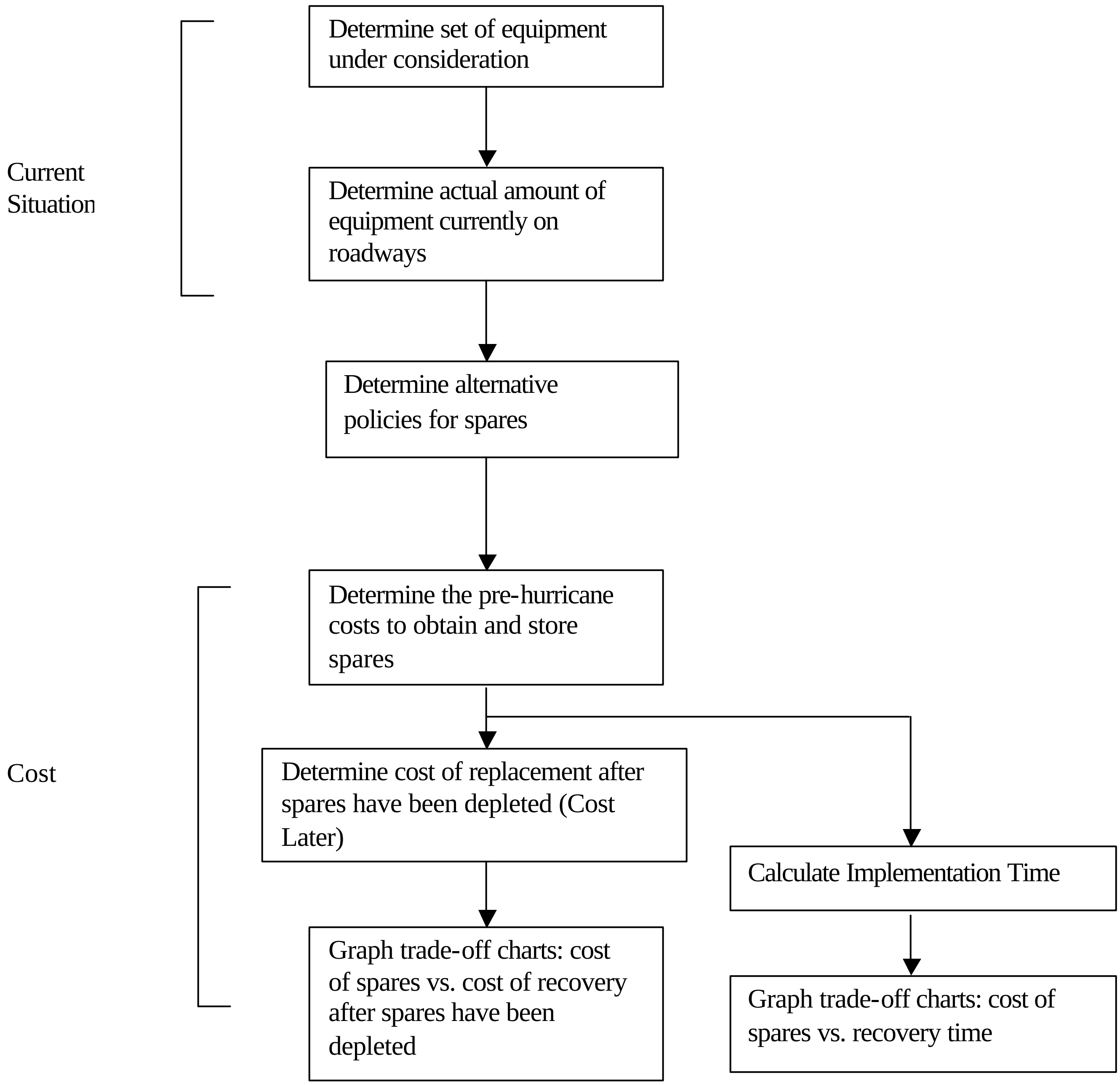


Figure 4.1. Activities for the Assessment of Inventory Policies

Determine Set of Equipment under Consideration

This step involves researching the equipment that VDOT currently stores for daily replacement. The Suffolk District inventory system report(VDOT, 1998a), a detailed list of hundreds of equipment types, such as. 30x30 yield signs, 30x30 left turn only signs, was used as a resource to view the equipment that VDOT currently keeps on hand. In order to assess possible inventory levels, the signs must be broadly categorized rather than listed in great detail. This is especially important when an at-a-glance understanding of the assessment is needed. In order to do this several assumptions were made:

- Exclude construction and maintenance signs. These signs are not the permanent signs that require replacement. Also, these signs may have drastically different sign strengths since most of these signs are meant for temporary use.
- Sort by sign size. Prices should be similar for each sign size.
- Exclude sign sizes that only encompassed one sign type. However, sign sizes that have more than 10 signs on stock even if it is only represented by one sign type are included. This assumption reduces the number of sign categories, making modeling more feasible.
- By making these assumptions, the signs were grouped by size and displayed similar costs from which average costs were taken. The equipment is grouped then by category. The categories under consideration are shown in Table 4.2.

Table 4.2. Categorization of Damageable Equipment Under Consideration

Small Ground Signs	6"x48"
	9"x24"
	12"x24"
	12"x36"
	15"x21"
	18"x24"
	18"x30"
	18"x36"
	24"x24"
	24"x30"
	24"x36"
	30"x30"
	36"x36"
	36"x45"
	36"x48"
	48"x48"
	48"x60"
Sign Poles	4"x4"x16'
	6"x6"x18'
Overhead Panel	120"x212" Sign Head
Overhead Mounts	2 Pole Span (1 way travel, 2-3 lanes)
	Cantilever
	Bridge Mount
Traffic Signals	Mast Arm or Spans
	Cabinet
	Signal Heads
Lighting	Pole and Luminaire
	High Mast Lighting Structures

These categories may be condensed to facilitate understanding. More general categories may be necessary for VDOT management to make at-a-glance assessments of the inventory policies. However, the categories must allow enough detail in order to assess the costs and benefits of storing different types of equipment.

Approximate Quantities of Equipment on Roadways

To determine consequences of policies, the amount of equipment that has the potential to be damaged must be determined. To calculate the damage, the amount of each equipment type has already been installed on the roadways in the Suffolk District must be estimated. Since it is infeasible to count the number of equipment on every roadway in the Suffolk district, densities of different types of equipment have been used. To do this, two pieces of data were needed: the density of each type of equipment on the roadways in Suffolk district, the total miles of highway road in Suffolk, and the number of interchanges in the Suffolk District. A calculation of the amount of equipment found on the roadways in the Suffolk District is then performed. The calculation was explained in detail in the Upgrading section. By fitting a distribution to the wind speed, the fraction of highway equipment that will actually experience certain wind speeds can be determined as well as the percentage of equipment that will be destroyed. A more detailed description of this process is described in the Upgrading section of this document.

Define a List of Possible Inventory Policies

Different inventory policies will be followed based on the percentage of equipment currently on the roadways. For example, one policy might dictate the storing of 10% of cantilevers, 15% of 36x36 signs, and 20% mounting equipment. A set of feasible alternatives has been determined based upon budget, minimum need, etc. A set of preliminary policies has been entered into the spreadsheet. The workbook is meant to allow VDOT to assess its own policies. Therefore, the spreadsheet allows VDOT representatives to change the percentages in the alternatives in order to assess a range of different policies. The Alternatives subsection in the Spreadsheet portion of this chapter describes the alternatives interface in more detail.

Determine Cost of Spares

When considering the storage of spares and reserves, cost will be of primary concern to VDOT decision-makers. To make an educated decision, they must be able evaluate possible cost savings that may result in any investment that they choose to make. A greater initial investment into spares and reserves may mean cost savings after a hurricane by avoiding premium prices generally charged by equipment contractors under heightened demand. When it comes to highway equipment, the investments can reach millions of dollars. Therefore, a cost assessment is of extreme importance. The evaluation tool is designed to handle such a cost analysis by allowing VDOT representatives to compare the different alternatives based upon a trade-off analysis between the pre-hurricane investment and post-hurricane recovery cost.

To determine the cost of keeping the spares in each alternative, the first step is to calculate the cost of bringing the current level of inventory to the level of the proposed policy. The pre-hurricane investment is fairly easy to calculate and requires the following data:

C_L = cost per unit to purchase under low demand
C_S = cost of storage (this is assumed to be a fixed cost)
P_i = percent of installed roadway equipment proposed for storage for policy i, where i = 1, 2, 3, …
E = number of equipment installed currently on roads in Suffolk District
S = number of equipment currently in storage

Storage of equipment involves two costs. The first is the cost to procure the equipment by way of either purchase or in-house production. This cost procurement cost is a fixed capital cost. For this segment of the task, two assumptions are made. The first assumption is that all sign heads will be produced in house by VDOT, since VDOT sign shops provide the signs at cost and would be much cheaper than purchasing the equipment from a contractor. The second assumption is that the other equipment (cantilevers, span mounts, signals, and lights) will be purchased from contractors or vendors, since VDOT is not equipped to manufacture such items. The warehousing cost will also be considered. To calculate the warehousing costs the following assumptions were made:

- Cost of storage is the additional storage cost born by VDOT beyond the purchase cost.
- Cost of storage for signs is $5,000 for the storage facility. This is a fixed cost for any amount of signs up to 100,000 square feet of sign panels. Beyond 100,000 square ft, another facility is needed. (Assumption based upon information gathered by Capstone 1997)
- Cost of storage for all other equipment besides sign blanks is free. Sylvia Taylor, a contractor, suggested that the equipment would be stored at no additional charge to the contractor if the contractor is used to produce and manufacture the equipment. Since we are already assuming that all other equipment besides sign panels will be contracted, we will also assume that the contractor bears the cost of storage. Of course, storage will not really be free, but rather, absorbed in the purchase price of the equipment. Storage costs here will be nonexistent since no additional cost beyond the purchase price will have to be paid by VDOT for storage.

However, the warehousing costs, unlike the procurement costs, are annual. In order to represent both the fixed warehousing costs and yearly warehousing costs the pre-hurricane cost calculations, the procurement costs were annualized. To annualize cost, the following assumptions were made:

- There is some interest rate (5%) for which VDOT will pay yearly on the capital fixed cost of purchasing the signs. This assumption is made as if VDOT were to borrow money from itself and pay the interest on the loan rather paying back the enitire principle at once. So each year, VDOT only pays 5% of the total cost of purchasing the equipment. This assumption is reasonable since the VDOT would not be purchasing the equipment all at once.
- Added to the yearly interest that VDOT pays cost of spares and reserves is the yearly cost of the facilities (storage costs).

For each alternative, the cost of spares will be calculated for each alternative using Equation 4.1:

Cost to keep additional spares = $i * [(P_i * E - S)C_L] + C_S$ Eq.4.1

For each policy, the cost to keep spares is then summed over the different equipment types to produce a total cost for spares.

The data in Table 4.3 is entered into the spreadsheet. The Data was Obtained from Comments by David Williams, BLC Construction, Inc. (1999):

Table 4.3. Purchase Cost of Cantilevers, Span Mounts, Signals, and Roadway Lighting.

	Equipment Type	Unit Cost	Delivery Time
Overeads Signs	Cantilever	$8-10,000	16 weeks
	Span Mount	$15-75,000	16 weeks
Traffic Signals	Mast Arm	$2,500	16 weeks
	Cabinet	$6,500	8 weeks
	Signal Head	$120	on stock
Roadway Lighting	Pole	$900-1,000	6 weeks
	Luminaire	$400	6 weeks
	High Mast Lighting Structure	$20,000	16 weeks

The data provided in the Upgrading chapter, Table 3.14 provides a combined cost of purchase and installation. In order to calculate cost of storing spares and reserves, the purchase cost alone is obtained. The data in table 4.3 represents the purchase cost of equipment from manufacturers.

Table 4.4. Purchase Cost of Signs from a VDOT Sign Shop. The Data was Obtained from the Purchasing and Inventory Management Report, (VDOT, 1998)

Description	Size (Inches)	Balance on Hand	Unit Cost
R1-1 STOP HI	30X30	25	43.009
R1-1 STOP HI	48X48	8	106.358
R1-2 YIELD HI	36	13	29.685
R1-2 YIELD HI	48	12	49.196
R2-1 SPEED LIMIT 25 HI	24X30	0	35.856
R2-1 SPEED LIMIT 35 HI	24X30	5	37.033
R2-1 SPEED LIMIT 45 HI	24X30	2	35.218
R2-1 SPEED LIMIT 55 HI	24X30	7	35.035
R2-1 SPEED W/O NO. HI	24X30	0	35.7298
R2-1 SPEED W/O NO. HI	48X60	0	132.127
R2-5A REDUCED SPEED AHEAD	24X30	8	35.301
R2-5A REDUCED SPEED AHEAD	48X60	10	138.447

Table 4.4 shows the unit cost of signs ordered from VDOT sign shops. These shops provide Virginia with signs at cost.

Determine the Cost of Replacing Equipment after Spares have been Depleted

Calculating the costs of replacing equipment after spares have been depleted has an added level of complexity, since the costs will differ depending on the severity of the hurricane. Each hurricane category creates different consequences. For example, if VDOT decides to store minimal equipment, no extra equipment may be needed in the event of a Category 1 Hurricane. However, if a Category 4 hits, VDOT may have to spend millions of dollars as well as several more months or years after the hurricane strike to replace equipment. Therefore, this task involves determining what the implications of each policy are in the event that different categories of hurricanes occur. The cost of replacing the spares later must be considered for each hurricane category. The cost assessment of replacement after a hurricane strikes follows the structure shown in Figure 4.2.

The first level in Figure 4.2 shows the alternatives that will be considered. For each alternative, a different damage caused by hurricane scenario results in a different amount of equipment that needs to be replaced. The third level shows how different equipment costs would be charged for hurricane scenarios due to changes in equipment demand. The end result is a separate cost for each alternative and hurricane scenario.

The post-hurricane cost assessment requires the following data:

C_m – Cost to purchase equipment under moderate demand
C_h – Cost to purchase equipment under high demand
P_i – percentage of roadway equipment proposed for policy i
θ_j – percent of roadway equipment damaged in a category j hurricane
E – number of damageable equipment installed on roads in the Suffolk District

The model accounts for the possibility of a premium price charged by the manufacturers or contractors when the need for equipment is higher than normal as it would be in the aftermath of a hurricane. Consider the possibility of other districts or states outside of Suffolk District that may have felt the destruction of the hurricane as well. The need for extra equipment may further boost the demand for highway equipment. For this reason, the model differentiates the purchase price of equipment to account for changes due to moderate and high demands. In order to move forward, the following assumptions about equipment demand were made:

- Low demand prices are charged during the pre-disaster period.
- Moderate demand prices are charged after a hurricane of Category 1, 2, or 3.
- High demand prices are charged after a hurricane of Category 4 or 5.
- Price of equipment would double in the event of a moderate demand (e.g. Category 1, 2, or 3) and increase by a factor of three in the event of a high demand (e.g. Category 4 or 5).
- Signs maintain the same price under low and moderate demand, since they are produced in-house. Only under extreme demand would it be necessary to contract the work.

Equations 4.2 and 4.3 represent the cost to replace equipment after a hurricane has hit:
For hurricane Categories 1, 2, or 3:

$$\text{Post-hurricane cost} = (\theta_j E - P_i E)\, C_m \qquad \text{Eq. 4.2}$$

For hurricane categories IV or V:

$$\text{Post-hurricane cost} = (\theta_j E - P_i E)\, C_h \qquad \text{Eq. 4.3}$$

For each policy, the post-hurricane costs are then summed over the different equipment types to produce a total post-hurricane cost for that policy.

Conduct a Trade-off Analysis

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. This can be represented graphically for clarity as shown in Figure 4.3.

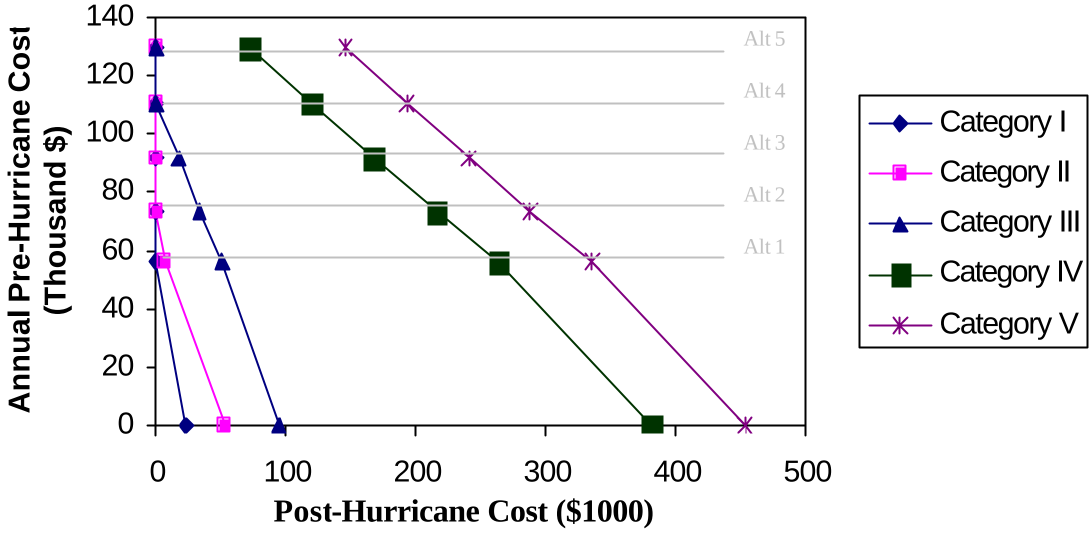


Figure 4.3. Pre-Hurricane Costs vs. Post-Hurricane Costs

Each horizontal line in the graph represents an inventory alternative. Each policy will have the same pre-hurricane cost, but its post hurricane costs will differ according to the hurricane category. The 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. This graphical analysis is meant to allow VDOT decision-makers to make at-a-glance comparisons of the cost benefits of the different policies.

Consider Opportunity Loss

Keeping spares and reserves in storage may require a considerable investment to cover the costs manufacturing, purchasing, and storing. It is impossible to tell when a hurricane might hit the Suffolk district. When considering the level of storage that should be maintained, VDOT must consider the opportunity loss involved in tying the money up in an inventory for highway equipment. This money could potentially be invested elsewhere for some other type of profit or benefit. For example, the Culpeper sign shop currently maintains approximately $1.4 million worth of signs and raw materials on hand. If this money were put in the bank, it would generate some type of monetary interest. The money could also be spent on a project that would benefit the community. These types of benefits would be potentially lost from the spares sitting unused in storage.

Calculate the Recovery time

When a hurricane strikes, it could take a community months or even years to recover. This time is attributed to the time it takes to manufacture, deliver and install the needed equipment. Equipment orders could take several weeks or even months to fill. Having spares and reserves for highway equipment on hand could reduce the time it takes to replace the damaged equipment, thereby reducing the amount of time for the community to recover. To calculate the recovery time, the time needed to manufacture, deliver, and install each type of equipment must be determined. This was accomplished by contacting manufacturers.

Table 4.5a. Time to Manufacture and Deliver Equipment. Data was Taken from Comments by David Williams, BCL Construction, Inc. (1999)

Equipment Type (20 pcs.)	Delivery Time
Cantilever	16 weeks
Span Mount	16 weeks
Mast Arm	16 weeks
Cabinet	8 weeks
Signal Head	on stock
Pole	6 weeks
Luminaire	6 weeks
High Mast Lighting Structure	16 weeks

The data in Table 4.5a shows the amount of time it takes to manufacture and deliver the equipment. The equipment requires the indicated amount of time for every 20 pieces of equipment. Notice that a 20-piece order could take up to 16 weeks to manufacture and deliver. In the event of a disaster like a hurricane, massive amounts of equipment may be ordered. With a 16-week turnaround for 20-piece orders, it is not difficult to imagine how larger orders for hurricane recovery could result in months or even years to manufacture enough equipment.

Table 4.5b. Time to Install Equipment. Data was Taken from Comments by Sylvia Taylor, President, Baldwin Line Constr. Of MD, Inc. (1999)

Equipment	Installation cost ($)	Installation Time (man hrs)
Ground		
Pole and	132	4
Overhead		
Pane	132	10
2 Pole Span (1 way travel, 2-3 lanes) (span	600	12
Cantileve	600	40
Bridge	675	15
Traffic		
Mast Arm or Spans (4 pole) including signal		18hr/1000 ft wire to replace
Cabine	220	40
Signal Heads	154	3.5
Mast Arm	700	16 (8 to set pole, 8 to set mast
Roadway		
Pole and Luminaire (Roadway Lighting)	90	2.5
High Mast Lighting	2,20	50

Another consideration is the time it takes to install the equipment. The data in Table 4.5b represents the amount of time it takes to install the equipment. Installation time can take up to 50 man-hours for large structures and can add a significant amount time to the total recovery time as well.

The Recovery time spreadsheet evaluates the approximate time it would take to recover from the point that the hurricane strikes to the point that the equipment is replaced. The comparison of the alternatives involves the time it takes to manufacture and deliver the equipment and the time it takes to install the equipment. As with the post-hurricane costs of replacement, implementation time also depends upon the hurricane category. For example, a Category 5 Hurricane causes more damage and therefore require a greater length of time to acquire and repair highway equipment than a Category 1 Hurricane.

To calculate the recovery time, several assumptions were made. The first assumption is that the different categories of equipment are contracted to different companies. That is, all signs are manufactured by one company, all overhead mounts (cantilevers, span mounts, etc.) are ordered from another company, and all signal equipment (signal heads, mast arms, cabinets) are manufactured by yet another company. This assumption is justifiable, since the equipment in the different categories are currently manufactured by separate companies. For example, VDOT manufactures all sign panels, NAPA manufactures all sign poles, and signals and lights are contracted to Richardson Whaler, a private contractor (Bridewell, 1999). Since separate companies manufacture the different categories of equipment, orders for signs, signals, and lighting can be filled simultaneously by the different companies. The second assumption is that the equipment in storage can be installed while the additional equipment needed is being manufactured. Since manufacturing and delivering additional equipment could take weeks, the work crews will be able to install the equipment that is in storage while they are waiting for the additional orders to be filled. This assumption is what allows spares and reserves to be beneficial in terms of implementation time, since some equipment can be installed immediately. However, if the time it takes to install the equipment in storage exceeds the time it takes to manufacture and deliver the additional equipment, then the time it takes to manufacture and deliver the equipment is negligible and does not reduce the recovery time. This assumption results in the existence of an optimal point at which recovery time cannot be further improved, and keeping additional spares and reserves on hand would not be beneficial.

The following data are needed to make the calculation:

D = time it takes to manufacture and deliver each unit of equipment
I = time it takes to install each unit of equipment
S = amount of equipment in storage
N = amount of equipment not in storage
T_d = time it takes a contractor to fill an entire order of the equipment category it was assigned (i.e. time it takes ABC Contracting, Inc. to fill the entire lighting order – pole, luminaire, high mast lighting)
T_s = time it takes to install equipment in storage

T_n = time it takes to install equipment not in storage
T_R = total time to recover equipment for a particular category (signs, signals, lights)

The installation and manufacture times are calculated using the following equations:

$T_d = \Sigma D*N$
$T_s = \Sigma I*S$
$T_n = \Sigma I*N$

Since work crews can install the equipment in storage while contractors are manufacturing the additional equipment needed, the recovery time is affected by whichever activity takes the longest. Therefore, the maximum between the time to install the equipment in storage and the time to manufacture additional equipment is used. The time to install the additional equipment from the contractors is then added for a total recovery time as shown in Equation 4.4.

$$T_R = \max(T_d, T_s) + T_n \qquad \text{Eq. 4.4}$$

This calculation is made for each equipment category (ground signs, sign poles, traffic signals, etc.)

A trade-off analysis is then graphed in terms of investment versus the time it takes to recover. This graphical representation of the trade-off between investment that would be made before the hurricane and the time it would take to recover after the hurricane for the different alternatives is shown in Figure 4.4.

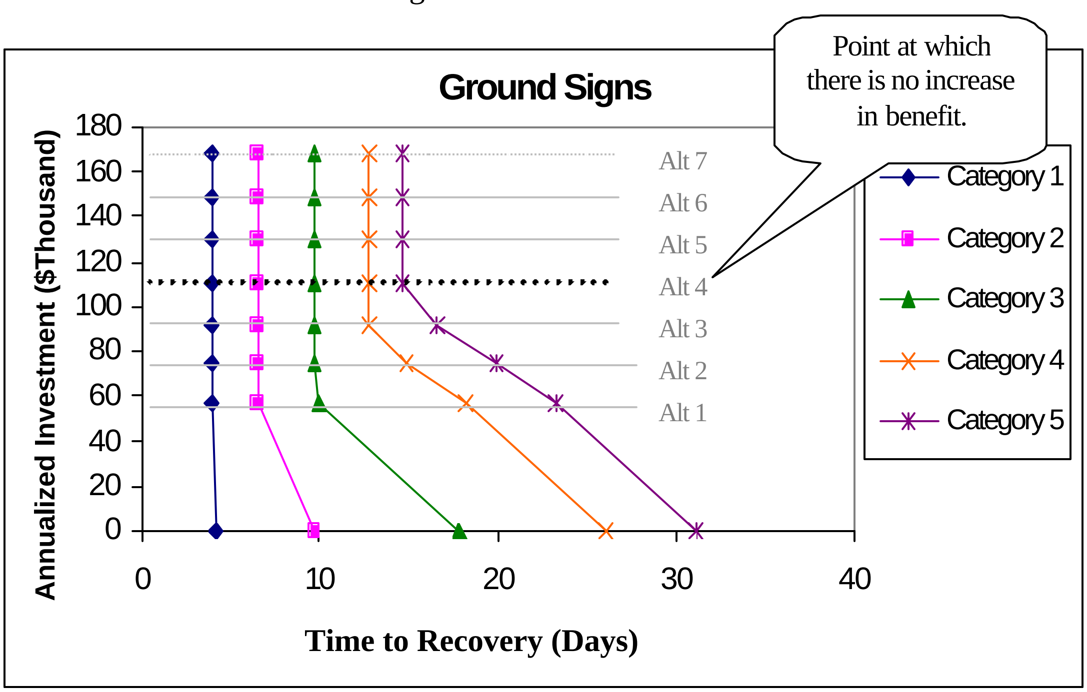


Figure 4.4. Investment vs. Recovery time

Each policy will require the same investment as indicated by the horizontal lines, but its recovery time will differ according to the hurricane category. Each curve in the graph represents a different hurricane category. The graph shows how long recovery will take later for different hurricane types if VDOT were to invest a certain amount of money into storing spares now.

Using the graph of the trade-off analysis, VDOT representatives can visually compare the recovery time benefits that each policy offers to better evaluate the utility of investing more money in spares and reserves. VDOT can also use the graph to determine the point at which investing more money into spares and reserves would no longer add benefit in terms of recovery time. For example, Figure 4.4 shows that investing $110,000 into Alternative 4 would offer the greatest reduction in recovery time, since at this point, the curves become vertical. Beyond this point, storing more spares would be a waste of money since the recovery time would not be further improved.

Design of Automated Spreadsheet

The calculations will be delivered to the Virginia Department of Transportation in the form of a Microsoft Excel Workbook. The worksheets are separated to allow users to view different aspects of the data, like the alternatives chosen, the extent of damage, the pre-hurricane cost of spares, and the post-hurricane cost of recovery. Trade-off analyses for each alternative and hurricane category have also been added and are represented graphically as in Figure 4.4a in the Conduct a Trade-off Analysis Section. Two spreadsheets allow the VDOT representative to enter data into the workbook like costs and policies. Assumptions that were made can easily be changed through these updateable spreadsheets. However, the other spreadsheets holding the calculations are protected to prevent accidental changes and to uphold the integrity of the calculations. Calculations are dynamically linked to the data in the updateable spreadsheets, so any changes made to the worksheet will be reflected in the calculations.

"Data" Worksheet

The Data Worksheet is the interface through which raw data is entered. The worksheet is updateable to allow users to change the data as costs change over time and more accurate data is obtained. Changes made through this worksheet will be carried throughout the workbook in the calculations. As shown in the Figure 4.5, data can be entered for each type of equipment.

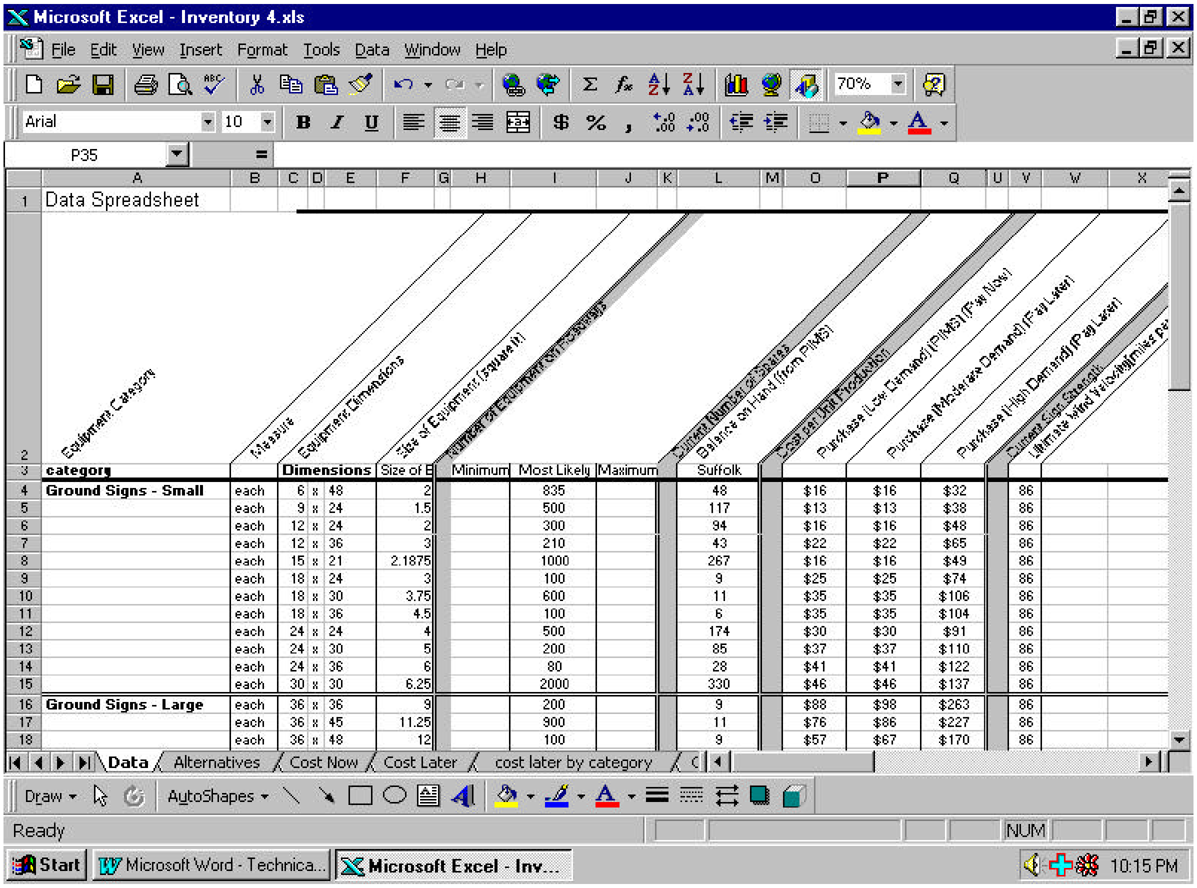


Figure 4.5. Screen Shot of Data Worksheet

Tables 4.6 and 4.7 show the data that may be entered into the worksheet. Table 4.6 shows the portion of this interface that deals with assessment of the current situation including data like the amount of equipment currently on the roadways and the amount of equipment VDOT currently keeps in storage in for the Suffolk District. The "Most Likely" column for the number of equipment installed on the roadways has been populated with data representative of a large scale road system in order to create a preliminary model. Calculations for this model currently use the "Most Likely" figure. However, the model can be repeated to use the minimum and maximum values as well in order to conduct a sensitivity analysis of the model.

Table 4.6. Data Spreadsheet for Spares/Reserves

Equipment Category category	Measure	Equipment Dimensions Dimensions	Size of Equipment (square ft) Size of Equipr	Number of Equipment on Roadways Case Study	Minimum	Most Likely	Maximum	Balance on Hand Suffolk
Ground Signs - Small	each	6 x 48	2			835		48
	each	9 x 24	1.5			500		117
	each	12 x 24	2			300		94
	each	12 x 36	3			210		43
	each	15 x 21	2.1875			1000		267
	each	18 x 24	3			100		9
	each	18 x 30	3.75			600		11
	each	18 x 36	4.5			100		6
	each	24 x 24	4			500		174
	each	24 x 30	5			200		85
	each	24 x 36	6			80		28
	each	30 x 30	6.25			2000		330
Ground Signs - Large	each	36 x 36	9			200		9
	each	36 x 45	11.25			900		11
	each	36 x 48	12			100		9
	each	48 x 48	16			400		36
	each	48 x 60	20			350		17
Sign Poles	each	4"x4"x16'		2		5000		206
	each	6"x6"x18'		4		2500		127
Signs Overhead - panel	sq. ft.	120 x 212	177			70667		
Overhead Sign Mounts	each	2 Pole Span (1 way travel, 2-3				600		0
	each	Cantilever				600		0
	each	Bridge Mount				600		0
	each	Mast Arm or Spans (4 pole) in				1000		1
Traffic Signals	each	Cabinet				1000		1
	each	Signal Heads only				1000		10
	each	Mast Arm only				1000		1
Roadway Lighting	each	Pole and Luminaire (Roadway				1000		0
	each	High Mast Lighting Structures				500		0

Table 4.7 shows the portion of the data entry worksheet that holds the cost data. These costs include in-house production costs and purchasing costs for low, moderate, and high demand. Differences in demand and therefore cost can be caused by the increase in immediate need for equipment following a hurricane. These cost data will be the basis for the model. The ultimate wind speed strength that the equipment was designed to withstand is also included. These data are essential in the calculation of equipment damage.

Table 4.7. Data Spreadsheet Continued

In House Production (Pay Now) (from Guidance Manual)	Purchase (Low Demand) (PIMS) (Pay Now)	Purchase (Moderate Demand) (Pay Later)	Purchase (High Demand) (Pay Later)	Total Cost of replacement + installation	Ultimate Wind Velocity[miles per hour]
$16	$16	$16	$32		86
$16	$13	$13	$38		86
$12	$16	$16	$48		86
$16	$22	$22	$65		86
$24	$16	$16	$49		86
$18	$25	$25	$74		86
$24	$35	$35	$106		86
$30	$35	$35	$104		86
$36	$30	$30	$91		86
$32	$37	$37	$110		86
$40	$41	$41	$122		86
$48	$46	$46	$137		86
$50	$88	$98	$263		86
$72	$76	$86	$227		86
$90	$57	$67	$170		86
$96	$102	$112	$305		86
$128	$178	$188	$533		86
	$13	$27	$40		86
	$50	$101	$151		86
$1,767	$16	$26	$48	$4,500	117
N/A				$70,000	117
N/A	$10,000	$20,000	$30,000	$35,000	117
N/A	$15,000	$30,000	$45,000	$20,000	117
N/A				$65,000	121
N/A	$6,500	$13,000	$19,500	$15,000	121
N/A	$120	$240	$360	$8,000	121
N/A	$2,500	$5,000	$7,500		121
	$53,200	$106,400	$159,600	$76,000	117
	$20,000	$40,000	$60,000	$120,000	117

Table 4.8 gives descriptions of each column of the data spreadsheet.

Table 4.8a. Column Descriptions for the Data Worksheet

Column Title	Description
Equipment Category	Grouping of equipment by function in order to facilitate locating areas of interest. i.e. Signs, Signals, Lights
Measure	One unit of measure For each type of equipment. For example, the signs may be counted by "Each" sign. Aluminum sheeting may be measured per Square Foot, so that the spreadsheet assesses cost, number in storage, etc. by square foot.
Equipment Type	General description of the equipment under consideration. Each of the following columns will be listed by these equipment types. i.e. 30x30 signs, Mounting poles 4"x4"x6'
Amount of Equipment of Roadways: Case Study	Amount of equipment of each type found on the roads the group will sample. These roads will be representative of the roads in the Suffolk District.
Amount of Equipment: Minimum	Amount of equipment of each type currently on the roads in the Suffolk District. This figure will be a low estimation based upon the sample taken from the case study.
Amount of Equipment: Most Likely	Amount of equipment of each type currently on the roads in the Suffolk District. This figure will be the best estimation based upon the sample taken from the case study.
Amount of Equipment: Maximum	Amount of equipment of each type currently on the roads in the Suffolk District. This figure will be a high estimation based upon the sample taken from the case study.

Table 4.8b. Column Descriptions for Data Worksheet Continued

Current amount of Spares: Suffolk District	Amount of equipment currently stored in the Suffolk District Sign Shops and regional sign shops. This information will be derived from the Suffolk PIMS report. It is a sum of the balance on hand for all equipment grouped under that equipment type. i.e. sum of all 30x30 signs on hand
Cost per Unit: In House Production (Pay Now)	The cost of producing a single unit of equipment in house (e.g. by instead of purchasing). For signs, this information is calculated by multiplying the size of the sign by $19.85, the production cost per square foot of sign calculated by the previous capstone project. This number will be helpful in calculating the cost before any hurricane hits.
Cost per Unit: Purchase (Low Demand) (Pay Now)	The cost of purchasing a single unit of equipment in pre-disaster conditions (when demand for equipment is low). This information will be derived from the Suffolk PIMS report. It is an average cost of all the equipment grouped under that equipment type. i.e. average of the different costs for 30x30 signs on hand. This number will be helpful in calculating the cost before any hurricane hits, when demand is low.
Cost per Unit: Purchase (Moderate Demand) (Pay Later)	The cost of purchasing a single unit of equipment after a moderate hurricane has hit when demand is moderate (e.g. a moderate hurricane may mean a moderately raised demand and possibly a slightly higher equipment cost). This information will be found by contacting vendors and contractors. This number will be helpful in calculating the cost after a moderately strong hurricane hits (e.g. Category 1, 2, or 3).
Cost per Unit: Purchase (High Demand) (Pay Later)	The cost of purchasing a single unit of equipment after an extreme hurricane has hit when demand is high (e.g. an extreme hurricane may mean a high increase in demand and possibly a much higher equipment cost). A separate cost might be charged for emergency replacement. For example, contractors may charge a premium for emergency production after a hurricane has hit. This information will be found by contacting vendors and contractors. This number will be helpful in calculating the cost after a strong hurricane hits (e.g. Category 4 or 5).
Current Sign Strength: Ultimate Wind Velocity	The standard of strength of the equipment. This value is the mile-per-hour wind speed that the sign is designed to withstand.

"Alternatives" Worksheet

The Alternatives Worksheet is the interface into which the different levels of equipment will be entered to evaluate the policies. This worksheet is updateable, allowing VDOT users to enter their own policies for assessment at their own discretion. A column is also included to show the percentage of equipment that is currently stored for the Suffolk District allowing the current level to be compared with the proposed policies during analysis. The alternative levels of spares and reserves are stored as a percentage of each type of equipment currently installed in the Suffolk District. Figure 4.7 displays a screen shot of the Alternatives spreadsheet. The last seven columns are areas to enter the percentages. The graphs to the right of the columns visually display the levels of spares for the alternatives for each broad category of equipment. Comments were also added in the upper right hand corner of the spreadsheet to facilitate data entry and to avoid the need to read an instructions manual. The instructions were added to make the workbook more user-friendly.

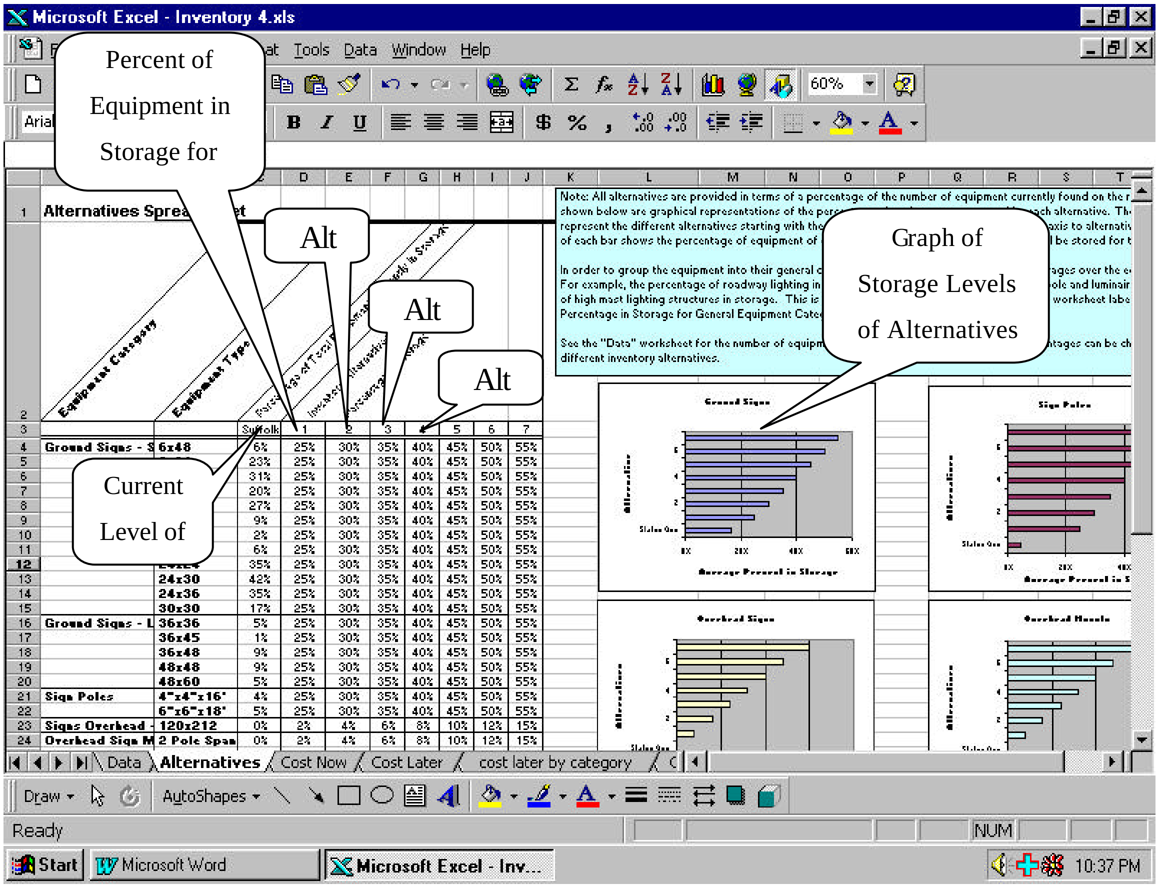


Figure 4.7 Screen Shot of Alternatives Interface

The following Table 4.9 shows a closer look at the columns involved in the alternatives interface.

Table 4.9. Alternatives Spreadsheet

Equipment Category	Equipment Type	Percentage of Total Equipment Currently in Storage	Inventory Alternatives Percentage in Storage		
		Status Quo	1	2	3
Ground Signs - Small	**6x48**	6%	25%	30%	35%
	9x24	23%	25%	30%	35%
	12x24	31%	25%	30%	35%
	12x36	20%	25%	30%	35%
	15x21	27%	25%	30%	35%
	18x24	9%	25%	30%	35%
	18x30	2%	25%	30%	35%
	18x36	6%	25%	30%	35%
	24x24	35%	25%	30%	35%
	24x30	42%	25%	30%	35%
	24x36	35%	25%	30%	35%
	30x30	17%	25%	30%	35%
Ground Signs - Large	**36x36**	5%	25%	30%	35%
	36x45	1%	25%	30%	35%
	36x48	9%	25%	30%	35%
	48x48	9%	25%	30%	35%
	48x60	5%	25%	30%	35%
Sign Poles	**4"x4"x16'**	4%	25%	30%	35%
	6"x6"x18'	5%	25%	30%	35%
Signs Overhead - panel	**120x212**	0%	2%	4%	6%
Overhead Sign Mounts	**2 Pole Span (1 way travel, 2-3 lanes)**	0%	2%	4%	6%
	Cantilever	0%	2%	4%	6%
	Bridge Mount	0%	2%	4%	6%
Traffic Signals	**Cabinet**	0%	2%	4%	6%
	Signal Heads only	1%	2%	4%	6%
	Mast Arm only	0%	2%	4%	6%
Roadway Lighting	**Pole and Luminaire (Roadway Lighting)**	0%	2%	4%	6%
	High Mast Lighting Structures	0%	2%	4%	6%

Table 4.10 shows the description of each column in the Alternatives spreadsheet. The columns holding different inventory policies have been combined into one description since they share the same definition. Some of the columns have been referenced from the data worksheet in order to facilitate understanding of the calculations.

Table 4.10. Column Descriptions of the Alternatives Worksheet

Column Title	Description

Equipment Category	Grouping of equipment by function in order to facilitate locating areas of interest, i.e. Signs, Signals, Lights. This column will reference the "Equipment Category" of the "Data" worksheet. Changes to this column should be made in the "Data" worksheet.
Equipment Type	General description of the equipment under consideration. Each of the following columns will be listed by these equipment types, i.e. 30x30 signs, Mounting poles 4"x4"x6'. This column will reference the "Equipment Type" of the "Data" worksheet. Changes to this column should be made in the "Data" worksheet.
Percentage of Equipment Currently in Storage	The percentage of equipment that Suffolk is currently storing, i.e. number in storage/number on roads. This column references the "Data" worksheet for data needed to make the calculations.
Inventory Alternative (Percentage in Storage) Alternatives i = 1,2,3,4,…	The percentage of equipment suggested by policy i. This will be determined and entered by a team member, e.g. Alternative 1: 10% 30x30 signs, 15% Steel poles, etc.

"Pre-Hurricane Cost of Spares" worksheet

The Pre-Hurricane Cost of Spares worksheet will include the cost of each inventory policy. That is, it will calculate the cost to bring the current inventory level up to the levels of the proposed policies.

Table 4.11. Pre-Hurricane Costs Spreadsheet

Equipment Category	Equipment Type	cost now of doing nothing	Cost of Spares for Alternatives (storage cost not included) 1	2	3
Ground Signs - Small	6x48	$0	$2,596	$3,270	$3,944
	9x24	$0	$102	$419	$737
	12x24	$0	$0	$0	$176
	12x36	$0	$205	$432	$658
	15x21	$0	$0	$544	$1,367
	18x24	$0	$396	$520	$644
	18x30	$0	$4,909	$5,969	$7,029
	18x36	$0	$659	$832	$1,006
	24x24	$0	$0	$0	$30
	24x30	$0	$0	$0	$0
	24x36	$0	$0	$0	$0
	30x30	$0	$7,770	$12,341	$16,912
Ground Signs - Large	36x36	$0	$3,592	$4,468	$5,344
	36x45	$0	$16,188	$19,592	$22,996
	36x48	$0	$907	$1,191	$1,474
	48x48	$0	$6,514	$8,550	$10,586
	48x60	$0	$12,515	$15,622	$18,729
Sign Poles	4"x4"x16'	$0	$14,042	$17,404	$20,767
	6"x6"x18'	$0	$25,031	$31,314	$37,597
Signs Overhead - pan	120x212	$0	$22,613	$45,227	$67,840
Overhead Sign Mount	2 Pole Span (1 way travel, 2-3 lanes)	$0	$0	$0	$0
	Cantilever	$0	$120,000	$240,000	$360,000
	Bridge Mount	$0	$180,000	$360,000	$540,000
Traffic Signals	Cabinet	$0	$123,500	$253,500	$383,500
	Signal Heads only	$0	$1,200	$3,600	$6,000
	Mast Arm only	$0	$47,500	$97,500	$147,500
Roadway Lighting	Pole and Luminaire (Roadway Lighting)	$0	$1,064,000	$2,128,000	$3,192,000
	High Mast Lighting Structures	$0	$200,000	$400,000	$600,000

Table 4.11 shows a sample of the Pre-Hurricane Costs Spreadsheet in the workbook. Table 4.12 gives a description of each column in the spreadsheet as well as the calculations embedded in the columns that were used to arrive at the numbers shown in the in Table 4.11. Some data was referenced from the data entry spreadsheet to facilitate understanding of the calculations.

Table 4.12. Column Descriptions for the Pre-Hurricane Costs of Spares Worksheet

Column Title	Description
Production Cost per Unit of Spare (Pay Now)	References 'Cost per unit: Purchase "Low Demand" from "Data" worksheet
Cost of Total Spares Currently on Hand	Amount of spares currently stored by Suffolk * Cost per unit spare
Cost for Spares of Alternatives	Percentage of equipment stored in Alternative i * Number of Equipment on Roadways (Most Likely) * Cost per unit spare

“Post-Hurricane Cost of Recovery” Worksheet

The Post-Hurricane Cost of Recovery worksheet includes the calculations for the number of signs damaged in each hurricane category. It will also include post-hurricane cost consequences of each hurricane category. That is, this spreadsheet calculates the cost to replace the damaged equipment that still needs to be restored after the spares have been depleted. Each hurricane will cause a different amount of damage and will lead to different post-hurricane consequences for each alternative. Therefore, each alternative is evaluated for each hurricane category. Tables 4.13 to 4.15 show portions of the Pre-Hurricane Costs spreadsheet. Figure 4.13 includes calculations for the extent of damage caused by the different hurricane scenarios. The calculations in this section of the Post-Hurricane Cost worksheet include the fraction of the installed equipment that will be damaged, the amount of equipment on the roadways, and the amount of actual equipment damaged. The fraction of equipment that may be damaged by each hurricane category is calculated using the methods described in the Upgrading chapter.

Table 4.13. Post-Hurricane Cost Spreadsheet (Equipment Damage)

Equipment Category	Equipment Dimensions	(percentage of equipment destroyed) for Hurricane Categories: I	II	III	IV	V	Number of Equipment Destroyed (min) for Hurricane Categories: I	II	III	IV	V
Ground Signs - Small	6x48	16%	27%	40%	53%	60%	135	225	335	439	503
	9x24	16%	27%	40%	53%	60%	81	135	200	263	301
	12x24	16%	27%	40%	53%	60%	48	81	120	158	181
	12x36	16%	27%	40%	53%	60%	34	57	84	110	126
	15x21	16%	27%	40%	53%	60%	161	270	401	526	602
	18x24	16%	27%	40%	53%	60%	16	27	40	53	60
	18x30	16%	27%	40%	53%	60%	97	162	240	315	361
	18x36	16%	27%	40%	53%	60%	16	27	40	53	60
	24x24	16%	27%	40%	53%	60%	81	135	200	263	301
	24x30	16%	27%	40%	53%	60%	32	54	80	105	120
	24x36	16%	27%	40%	53%	60%	13	22	32	42	48
	30x30	16%	27%	40%	53%	60%	323	540	801	1052	1204
Ground Signs - Large	36x36	16%	27%	40%	53%	60%	32	54	80	105	120
	36x45	16%	27%	40%	53%	60%	145	243	361	473	542
	36x48	16%	27%	40%	53%	60%	16	27	40	53	60
	48x48	16%	27%	40%	53%	60%	65	108	160	210	241
	48x60	16%	27%	40%	53%	60%	56	95	140	184	211
Sign Poles	4"x4"x16'	16%	27%	40%	53%	60%	807	1350	2004	2629	3010
	6"x6"x18'	16%	27%	40%	53%	60%	403	675	1002	1314	1505
Signs Overhead - panel	120x212	2%	7%	16%	29%	39%	1620	4939	11606	20814	27763
Overhead Sign Mounts	2 Pole Span (1 way tr	2%	7%	16%	29%	39%	14	42	99	177	236
	Cantilever	2%	7%	16%	29%	39%	14	42	99	177	236
	Bridge Mount	2%	7%	16%	29%	39%	14	42	99	177	236
Traffic Signals	Cabinet	2%	6%	14%	27%	37%	17	56	142	268	367
	Signal Heads only	2%	6%	14%	27%	37%	17	56	142	268	367
	Mast Arm only	2%	6%	14%	27%	37%	17	56	142	268	367
Roadway Lighting	Pole and Luminaire (F	2%	7%	16%	29%	39%	23	70	164	295	393
	High Mast Lighting St	2%	7%	16%	29%	39%	11	35	82	147	196

Table 4.14 shows the portion of the post-hurricane cost calculations that deal with the amount of surplus or shortage that is projected to occur for each inventory policy in the event of each hurricane scenario. The negative values shown in the spreadsheet represent a shortage of equipment. This shortage means that more will have to be invested after the hurricane to restore the equipment that the inventory policy did not account for. The positive values represent a surplus of equipment after a hurricane has struck. This surplus implies that more equipment was stored than was needed. The sample of the spreadsheet shown in Table 4.14 shows the current policy as well as a policy that proposes a rather low level of inventory. Therefore, most of the numbers here are negative, implying a shortage.

Table 4.14. Post-Hurricane Spreadsheet Continued (Shortage or Surplus)

Number of Damaged Equipment not in Storage current level					For Alternative 1					For Alternative 2				
Do Nothing					for Hurricane Categories:					for Hurricane Categories:				
I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
-87	-177	-287	-391	-455	74	-17	-126	-230	-294	116	25	-84	-189	-252
36	-18	-83	-146	-184	44	-10	-75	-138	-176	69	15	-50	-113	-151
46	13	-26	-64	-87	27	-6	-45	-83	-106	42	9	-30	-68	-91
9	-14	-41	-67	-83	19	-4	-32	-58	-74	29	6	-21	-47	-63
106	-3	-134	-259	-335	89	-20	-151	-276	-352	139	30	-101	-226	-302
-7	-18	-31	-44	-51	9	-2	-15	-28	-35	14	3	-10	-23	-30
-86	-151	-229	-304	-350	53	-12	-90	-165	-211	83	18	-60	-135	-181
-10	-21	-34	-47	-54	9	-2	-15	-28	-35	14	3	-10	-23	-30
93	39	-26	-89	-127	44	-10	-75	-138	-176	69	15	-50	-113	-151
52	30	4	-21	-36	18	-4	-30	-55	-70	28	6	-20	-45	-60
15	6	-4	-14	-20	7	-2	-12	-22	-28	11	2	-8	-18	-24
7	-210	-471	-722	-874	177	-40	-301	-552	-704	277	60	-201	-452	-604
-23	-45	-71	-96	-111	18	-4	-30	-55	-70	28	6	-20	-45	-60
-134	-232	-350	-462	-531	80	-18	-136	-248	-317	125	27	-91	-203	-272
-7	-18	-31	-44	-51	9	-2	-15	-28	-35	14	3	-10	-23	-30
-29	-72	-124	-174	-205	35	-8	-60	-110	-141	55	12	-40	-90	-121
-39	-78	-123	-167	-194	31	-7	-53	-97	-123	49	10	-35	-79	-106
-601	-1144	-1798	-2423	-2804	443	-100	-754	-1379	-1760	693	150	-504	-1129	-1510
-276	-548	-875	-1187	-1378	222	-50	-377	-689	-880	347	75	-252	-564	-755
-1620	-4939	-11606	-20814	-27763	-206	-3525	-10193	-19400	-26349	1207	-2112	-8779	-17987	-24936
-14	-42	-99	-177	-236	-2	-30	-87	-165	-224	10	-18	-75	-153	-212
-14	-42	-99	-177	-236	-2	-30	-87	-165	-224	10	-18	-75	-153	-212
-14	-42	-99	-177	-236	-2	-30	-87	-165	-224	10	-18	-75	-153	-212
-16	-55	-141	-267	-366	3	-36	-122	-248	-347	23	-16	-102	-228	-327
-7	-46	-132	-258	-357	3	-36	-122	-248	-347	23	-16	-102	-228	-327
-16	-55	-141	-267	-366	3	-36	-122	-248	-347	23	-16	-102	-228	-327
-23	-70	-164	-295	-393	-3	-50	-144	-275	-373	17	-30	-124	-255	-353
-11	-35	-82	-147	-196	-1	-25	-72	-137	-186	9	-15	-62	-127	-176

Table 4.15 contains the portion of the Post-Hurricane Costs spreadsheet that deals with the actual costs of the alternatives. These calculations combine the amount of damaged equipment with the cost of replacement resulting in a cost to replace the damaged equipment. The sum of each column represents the total cost for each alternative in each hurricane scenario.

Table 4.15. Post-Hurricane Costs Continued (Cost of Recovery)

Cost to Replace Damaged Equipment not in Storage — Current Level — Do Nothing					Alternative 1 for Hurricane Categories:				
I	II	III	IV	V	I	II	III	IV	V
1,400	2,866	4,628	12,627	14,684	0	270	2,032	7,436	9,493
0	229	1,059	5,560	7,014	0	127	958	5,255	6,709
0	0	420	3,061	4,160	0	96	724	3,973	5,073
0	296	888	4,363	5,400	0	91	683	3,748	4,785
0	50	2,203	12,788	16,559	0	330	2,483	13,628	17,399
177	446	770	3,239	3,806	0	50	373	2,049	2,616
3,031	5,334	8,104	32,259	37,110	0	425	3,194	17,531	22,382
351	728	1,182	4,845	5,639	0	70	523	2,869	3,662
0	0	803	8,117	11,601	0	305	2,294	12,592	16,076
0	0	0	2,275	3,957	0	147	1,107	6,077	7,759
0	0	165	1,714	2,458	0	65	490	2,690	3,434
0	9,603	21,550	98,936	119,861	0	1,833	13,779	75,625	96,550
2,271	4,393	6,945	25,272	29,282	0	391	2,943	14,495	18,506
11,495	19,874	29,947	104,886	120,470	0	1,546	11,619	56,321	71,905
476	1,201	2,073	7,413	8,710	0	134	1,005	4,691	5,989
3,191	8,051	13,894	53,225	62,545	0	897	6,740	33,682	43,001
7,402	14,536	23,113	88,945	103,167	0	1,316	9,893	51,400	65,622
16,161	30,780	48,357	97,758	113,152	0	2,697	20,273	55,633	71,026
27,784	55,102	87,944	179,046	207,809	0	5,039	37,881	103,952	132,715
42,109	128,403	301,752	999,050	1,332,603	5,362	91,656	265,006	931,210	1,264,763
0	0	0	0	0	0	0	0	0	0
275,019	838,626	1,970,807	5,301,562	7,071,596	35,019	598,626	1,730,807	4,941,562	6,711,596
412,529	1,257,940	2,956,210	7,952,342	10,607,395	52,529	897,940	2,596,210	7,412,342	10,067,395
204,253	716,675	1,834,541	5,210,614	7,133,328	0	469,675	1,587,541	4,840,114	6,762,828
1,611	11,071	31,708	92,956	128,452	0	8,671	29,308	89,356	124,852
78,559	275,644	705,593	2,004,082	2,743,588	0	180,644	610,593	1,861,582	2,601,088
2,438,505	7,435,820	17,474,485	47,007,179	62,701,488	310,505	5,307,820	15,346,485	43,815,179	59,509,488
458,366	1,397,711	3,284,678	8,835,936	11,785,994	58,366	997,711	2,884,678	8,235,936	11,185,994

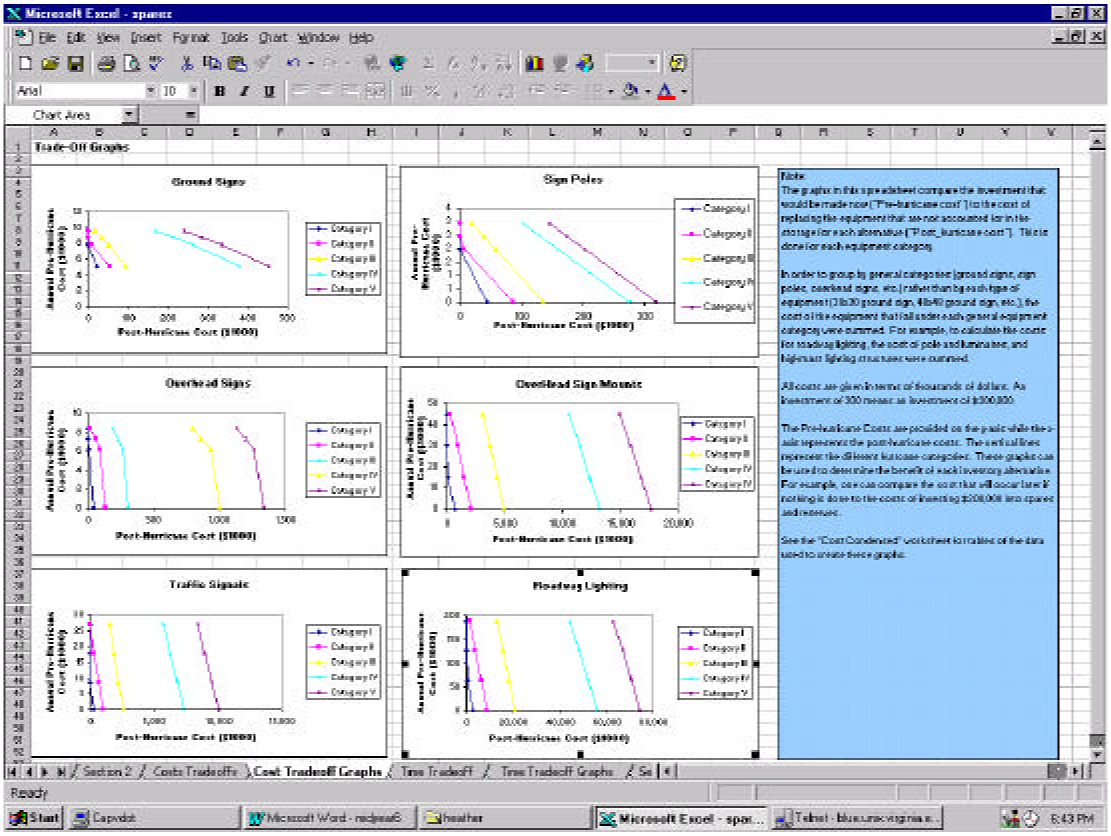
Table 4.16 gives the definitions of the columns found in the Post-Hurricane Cost spreadsheet as well as the calculations used to arrive at the numbers found in Tables 4.13 to 4.15. Some columns that were referenced from the data entry spreadsheet, like the number of equipment on the roadways and the ultimate wind velocities of the equipment, were excluded from the Table 4.13 in order to save space. However, they exist in the actual workbook and their descriptions are given in Table 4.16.

Table 4.16. Column Descriptions for Post-Hurricane Cost of Recovery Worksheet

Column Title	Description
Equipment Category	Referenced from "Data" worksheet (see table 4.8)
Equipment Type	Referenced from "Data" worksheet
Number on Roadways	Referenced from "Data" worksheet "Number on Roadways: Most Likely"
Ultimate Wind Velocity	Referenced from "Data" worksheet
Extent of Damage without Upgrading (for each hurricane category)	Percentage of equipment damaged by each hurricane category. See below for calculations.
Amount of Equipment Destroyed (for each hurricane category)	The amount of equipment that is destroyed by each hurricane category. (See upgrading spreadsheet section for these calculations)
Amount of Damaged Equipment not in Storage	Amount of equipment that is damaged in the hurricane that was not accounted for by the spares. That is, this value is the amount of equipment that must be replaced after a hurricane hits and the spares have been exhausted. e.g. (Percentage of equipment stored for Alternative 1) * (Amount of Equipment currently on Roads) – (Amount of equipment destroyed in Category 2)
Cost to Replace Damaged Equipment not in Storage	Cost to buy or produce the replacement equipment that was not accounted for by the spares. That is, this value is the cost to replace the equipment for each hurricane category after the spares have been exhausted. i.e. Cost per Unit Purchase (Moderate Demand) * Amount of Damaged Equipment not in storage. Each column in this category can be summed resulting in a total "cost later" for each hurricane category within each alternative.

The first output worksheet contains a trade-off analysis between the current investment and the cost of repairing the highways later. The representation of these calculations in the evaluation tool is shown in Figure 4.7.

Figure 4.7. Screen Shot of Cost Trade-off Output



As shown in Figure 4.7, a trade-off graph is given for each broad category of equipment. These graphs are useful in showing VDOT representatives the post-hurricane cost consequences of investing a certain amount into spares and reserves before the hurricane hits. By representing this information graphically, the user can more easily compare the consequences of the investments of the different alternatives. For example if the user was interested in traffic signals, he/she can look at the traffic signal graph and determine the post-hurricane cost that is associated with each investment. Text has also been added to the spreadsheet to facilitate user understanding of the graphs.

Further Considerations

Data has already been collected and incorporated into a spreadsheet to transform it into useful information. Table 4.17 shows the sources of such data.

Table 4.17. Sources for the Data Used in the Spreadsheets

Data Obtained	Source
Current balance on hand (signs)	PIMS Report
Current balance on hand (signals)	Willie Byrum – Suffolk District Traffic Signal Inventory
Production cost of signs	PIMS report, Paul Bolderson
Cost of storage (signs)	Capstone Report (1997-1998)
Cost of sign posts	Travis Bridewell's Hurricane Preparedness Committee report
Purchase cost of overhead mount, signal, and lighting equipment	David Williams, BLC Construction, Inc.
Replacement costs – temporary and permanent - for signs(overhead, cantilever, shoulder) and signals	Travis Bridewell's Hurricane Preparedness Committee report
Replacement costs of high mast and regular lights (purchase and installation costs combined).	Guidance Manual
Cost to install sign, signal, and lighting equipment	Sylvia Taylor, Baldwin Line Constr. Of MD, Inc.
Time to manufacture signs	Paul Balderson, Tour of Culpeper Regional Sign Shop
Time to manufacture and deliver overhead mount, signal, and lighting equipment	David Williams, BLC Construction, Inc.
Time to install sign, signal, and lighting equipment.	Sylvia Taylor, Baldwin Line Constr. Of MD, Inc.

The data were obtained by contacting VDOT representative, visiting sign shops, contacting vendors and contractors, and reading published VDOT materials. The spreadsheet that has been created around this data is updateable should new data become available. The spreadsheet can also be expanded to take into consideration other factors as described in the following sections.

Alternatives Involving Upgrading

With different levels of upgrading that will be considered, the impacts on extent of damage will be changed, and in turn, the consequences of each alternative will change.

The inventory policies can therefore be evaluated according to different upgrading alternatives as well.

Alternatives Involving Temporary Replacement

Currently, temporary replacement options are available for the replacement of highway equipment. These options include placing stop signs at intersections to temporarily replace damaged signals and mounting signs on the ground rather than immediately replacing overhead signs. In the long run, this equipment would need to be replaced permanently as well, but the extra cost of purchasing temporary equipment may be justified when considering the benefits to the recovery time. Temporary replacement may be a good option for restoring the highways to a functional state, while the needed resources are being manufactured and delivered. The costs and benefits of temporary replacement should therefore be considered as well.