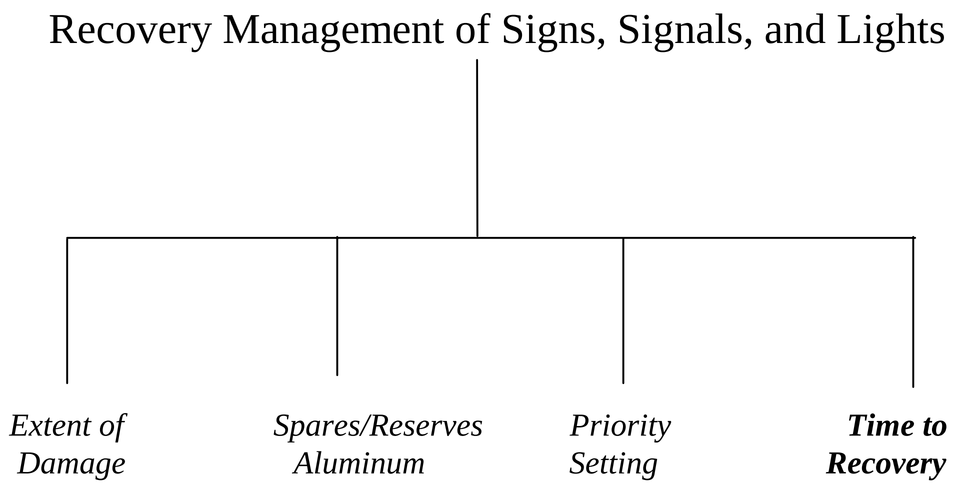
Chapter 5

Time-to-Recovery of Signs, Signals, and Lights of a Hurricane Damaged Highway System



5.1 Introduction

Project management becomes critical following situations where lives and extensive amounts of capital are placed in jeopardy. Recovery efforts following a hurricane strike represent important projects that must be managed carefully, and efficiently, in order to ensure that all systems return to an on-line status in the minimum amount of time possible.

The actions that are required to repair damaged highways following a hurricane can be simulated to produce a better understanding of the nature of these activities. Fortunately, no severely debilitating hurricanes have hit the Suffolk District, but this has meant that no comprehensive recovery plans are in place. Odds are that even when a disaster event is localized to a particular area, a much wider transportation facility location will be impacted. It is necessary, therefore to carefully examine the recovery process that ensues after a natural disaster. This examination is likely to reveal bottlenecks and problem areas that require further analysis, and will hopefully reveal insights into the recovery process that have been previously absent. Most importantly, such an examination allows a better estimate of the time-to-recovery of a highway system.

Time-to-recovery is the focus of this analysis effort, for it provides a good overview of the overall recovery project efficiency. Time-to-recovery also allows the determination of trade-offs between money invested and the speed of recovery. Analyzing overall project management in this manner allows the examination of the entire recovery/repair process, which may involve looking at a timeline that stretches into months, as opposed to just weeks after a hurricane strike. By doing so one brings into consideration factors such as contractor hiring, manufacture of new equipment, installation of permanent repairs, and inspections by VDOT. This allows project management analysis to reveal the critical path of activities that must be completed in order for the time-to-recovery to be minimized.

An analysis of the VDOT recovery/repair process following a hurricane strike is outlined in this chapter. First, a background to project management techniques is presented in *5.2 Background*, followed by the *Technical Approach* which uses mathematical tools to analyze the nature of the recovery project to identify bottlenecks and areas of improvement. The main goals of the study are stated in *5.3.1* Objectives, and the major analysis occurs in *5.3.2 Project Management* and *5.3.3 Project Analysis*. Section *5.3.4 Analyzing Project Completion Times* looks at the overall time to recovery and what its distribution is for the VDOT recovery project. Section *5.3.5 Summary and Conclusions* summarizes the findings of the Technical Approach. Section *5.4 Improving the Project* looks at ways to reduce the time-to-recovery, and how this reduction in time affects the project costs. Finally, *5.5 Project Conclusions* outlines the recommendations generated by this approach to the VDOT hurricane recovery problem, listing items that may help in improving VDOT’s efficiency and effectiveness in the Suffolk District.

5.2 Background

The Virginia Department of Transportation, as part of its preparedness, has an overall emergency response plan in place for Virginia (VDOT Hurricane Evacuation

Routes, 1997). However, the Suffolk District is lacking in a clearly defined recovery plan. Instead, the current procedure is to conduct repairs as soon after a hurricane as possible, and then submit applications for reimbursement from FEMA and FHWA (Cogburn, 1998). There is therefore a need for a coherent and explicit activity list that will aid in understanding the repair process and in turn improving recovery efficiency.

Mathematical networking and simulation techniques can be used to create a project constituted of separate tasks that observe precedence relationships, such as that mentioned above. Florida and California, two states frequented with natural disasters, have employed simulation in part to develop disaster management plans (Della-Giustina, 1994). Mathematical modeling can play an important role in furthering knowledge of current systems that tackle hurricane recovery (Scotti et al. 1994). Further, modeling has aided in determining effective ways of recovering from other natural disasters such as floods and hurricanes, and in setting up disaster recovery plans (Wong et al, 1994).

To create an accurate model that mimics the pressure on a highway system, the demands placed on project management and recovery processes must be examined. Also, the critical path for completing the recovery of signs and signals of the network of roads available to get to a repair site must be established. Such data is necessary before any sort of inventory model can be set up (Hillier and Lieberman, 1995). This information can then be incorporated into mathematical models through the use of simplifying assumptions in order to examine the impact these factors can have on the time-to-recovery (Krajewski and Ritzman, 1987).

Such an approach to examining the nature of project management has not been taken for the Hampton Roads/Suffolk district. Plans for evacuation from these areas that are already in place have led to the identification of roads and highways that play a critical role in evacuation and in returning damaged systems to an online status (Commonwealth of VA, 1996).

This project will give a better understanding of what factors govern the time to repair and recovery of damaged signs and signals across a wide region. Through the use of models, the project efficiency, maintenance crew response, time-to-recovery, and repair time variation will be studied.

5.3 Technical Approach

5.3.1 Objectives

The goal here is to gain an insight into the nature of the repair process of a damaged highway, by means of studying recovery projects. VDOT undertakes a series of tasks as soon as a hurricane hits the state, and these tasks make up the overall post-hurricane recovery project:

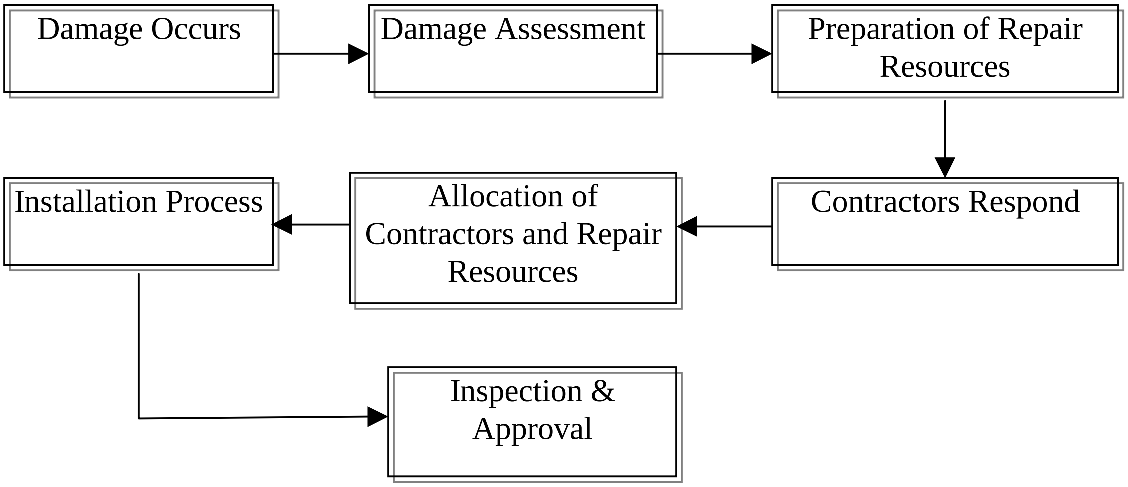


Figure 5.1: Flowchart of the recovery Process.

This process representation can be thought of as the “skeleton structure” representation. The important questions that must now be answered are:

- How can costly project delays be avoided?
- Which activities in the project determine the duration of the entire project?
- How can the effect of limited resources on project duration be determined?
- How can uncertainties be incorporated?
- How can a better estimate of the time-to-completion be obtained?
- What happens to cost when project recovery times are reduced?

5.3.2 Project Management

To answer these questions, Figure 5.1 must be expanded. Using the flowchart as a template, an example of typical repair activities that would be undertaken is listed in Table 5.1 on the following page. VDOT does not have a coherent list of repair activities that take place following a hurricane (Cogburn, 1998), but interviews with VDOT personnel from Richmond headquarters, as well as the Suffolk district department have revealed the layout of post-hurricane activities is similar to that provided in Table 5.1. However, the nature of project management analysis is such that new activities or adjustments to the nature of old activities can be easily accomplished. Therefore, once a list of updated repair activities is prepared, they can be substituted for those in Table 5.1 and an analysis performed in the same manner as will be described shortly.

Table 5.1: Hypothetical repair process activities that would need to be completed for the recovery of a damaged highway.

Activity	Description	Immediate Predecessor(s)
A	Damage assessment conducted	None
B	Requests for resources formulated	None
C	Equipment that must be replaced is defined	A
D	Final repair plans prepared	B
E	Plans and schedules disbursed and responses obtained from VDOT inventories/contractors	C, D
F	Resources and contractors assigned to damaged areas	E
G	Contractors examine inventory	C, F
H	Contractors place order/manufacture equipment	G
I	Install equipment	H
J	VDOT conducts inspections	I
K	Contractors paid	J

Table 5.1 outlines each of the major activities and associates a letter with the activity. Also given are the predecessors to an activity that must be completed before an activity can begin. Therefore, activity E, which is the disbursement of plans and schedules to contractors and VDOT inventories, and the subsequent receipt of their replies, cannot begin before activities C (definition of damaged equipment) and D (the act of repair plan preparation) have been completed. Recovery is considered complete when payment is made to contractors and the repair project can be considered closed.

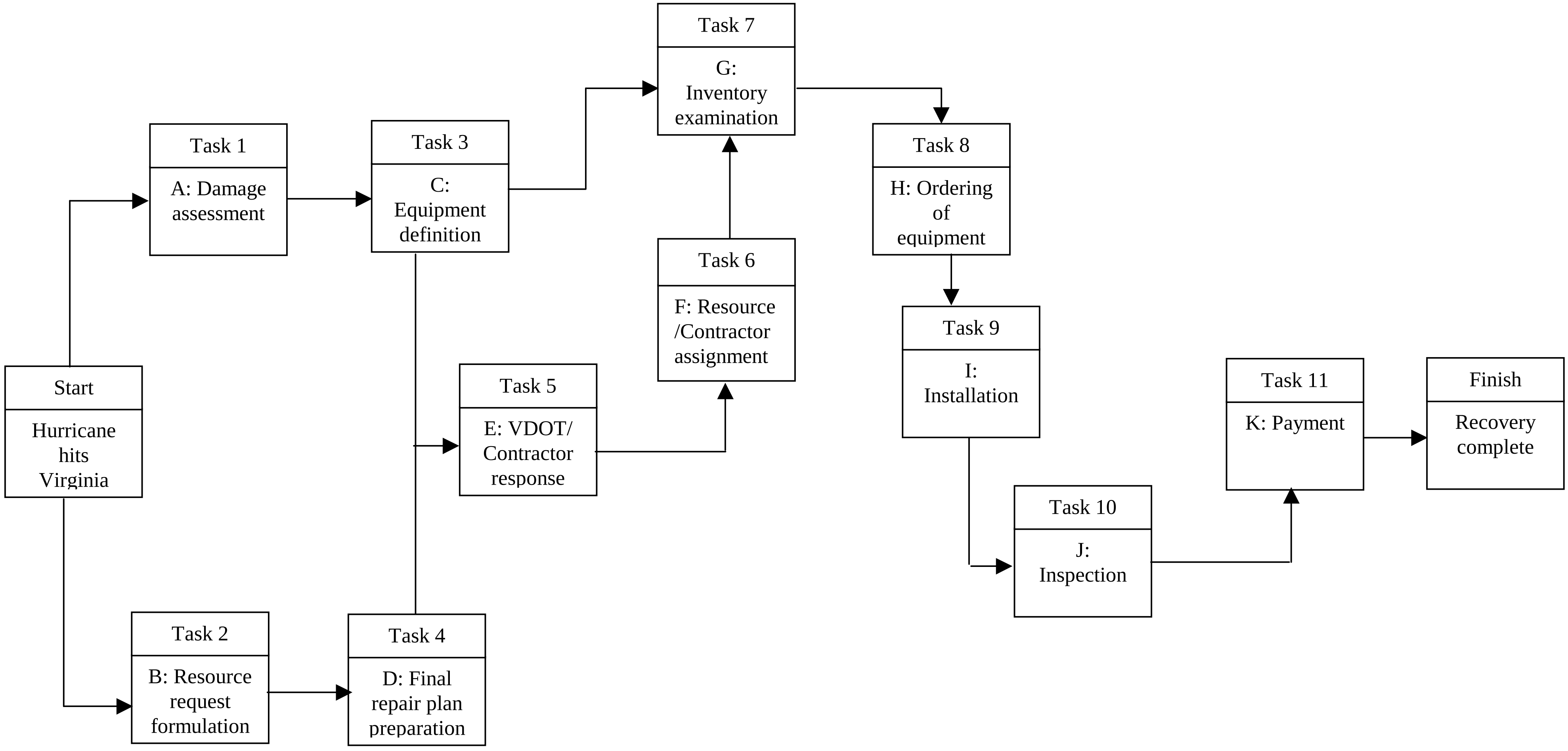


Figure 5.2: Network diagram for project activities showing the relationship between various tasks necessary for project completion.

The next step is to create a network diagram for the project using the activities outlined in Table 5.1. This diagram is presented in Figure 5.2. Here, the activities from Table 5.1 are represented in a network format. The repair project begins on the left, with the start of activities A and B, which then lead into activities C, and D, respectively. Network representation as given in Figure 5.2 gives a fair idea of how activities are related to each other, and how interaction takes place throughout the project lifetime.

At this point, several interesting pieces of pieces of information already make themselves apparent. The act of listing the activities necessary for recovery and then mapping these on a network diagram in itself provides a way of improving project recovery. Furthermore, it is easy to apply Table 5.1 and create Figure 5.2 for any project, which makes this a powerful tool in comprehending project mechanics.

5.3.3 Project Analysis

Two methods are available for the analysis of the project network presented in Figure 5.1. The first is the PERT technique, and the second is the CPM-Cost method. Both PERT and CPM are based on the assumption that project activities having clear beginning and ending points can be identified. It is also assumed that activity sequence relationships can be identified at the start of the project, and specified in a network diagram. Both these assumptions are valid for the VDOT hurricane recovery project.

The PERT technique is probabilistic in nature, and is designed for projects where there is little direct experience with many of the activities and thus little basis for time estimates. The CPM technique is more deterministic in nature, and is designed for projects in which activity times are known with certainty, or at least they can be assumed to be certain. The VDOT recovery process is likely to be more a mix of the two project types described here. However, the PERT method works with approximations whereas CPM requires definite times. The analyses for both methods are similar, but it is unlikely that recovery projects such as those VDOT plans to undertake will always start and finish at their given times. Therefore, this section concentrates on the PERT method of project analysis.

PERT and CPM both provide a visual display of the needed tasks and their ordering, which makes it easy to see how tasks should be placed with respect to each other. They also provide a time-cost trade-off resulting from the reallocation of resources amongst tasks, as well as make available a method for monitoring a project throughout its lifecycle. All calculations performed in the following sections follow standard project management methodology, and a complete listing of PERT and CPM algorithms is available in operations management texts.

5.3.3.1 Estimating Activity Times

To analyze a project using the PERT technique, three estimates are required for each activity that must take place:

- *Most optimistic time, a:* This is the shortest time in which an activity can be completed, if everything goes according to plan.
- *Most likely time, m:* This is the mode of the distribution of the time required to perform an activity. That is, the activity most often requires *m* units for completion. This time would be expected to occur most often, if the activity could be repeated many times under similar circumstances.
- *Most pessimistic time, b:* An estimate of the longest time required to perform an activity, assuming that anything that could go wrong does go wrong.

For the given activities these numbers are provided in Table 5.2 on the next page. These times are estimates based on an examination of current VDOT literature and personal interviews with the Richmond EOC, the Suffolk TMS, and the Charlottesville VTRC staff. The duration estimates are those that would result if a Category II hurricane (95-115mph wind speeds) were to hit the Suffolk District. As mentioned earlier, these unconfirmed numbers can be updated easily without affecting the overall project analysis that follows.

Table 5.2: Time estimates for the activities necessary for hurricane recovery

Activity	Time estimates (weeks)		
	Most optimistic *a*	Most likely *m*	Most pessimistic *b*
A – Damage assessment	2	3	4
B – Resource request formulation	1	2	3
C – Equipment definition	1	2	3
D – Final repair plan preparation	1.5	2	3
E – Response from VDOT/contractors	2	3	5
F – Resource and contractor assignment	1	2	3
G – Inventory examination	1	1.5	2
H – Ordering equipment	2	4	6
I – Installation	5	6	10
J – Inspection	2	3	4
K – Payment	3	4	5

5.3.3.2 Calculating Time Statistics

The three time estimates for each activity provide enough information to calculate the mean and the variance of a probability distribution for each activity. Since PERT is probabilistic in nature, it makes sense to calculate the uncertainties involved with the time estimates of each activity – which is, in effect, the calculation of a mean and variance. These two numbers are then used to calculate the probability distribution of each activity, and here PERT developers favor the beta distribution because of its non-symmetric nature. This beta distribution can take on a variety of shapes (as opposed to a normal distribution) and thus allows the mode (the most-likely time) to fall anywhere between the end-points (the most-pessimistic and the most-optimistic times).

For the recovery effort, the mean for the beta distribution is given by the following weighted average of the three time estimates:

$$t_e = \frac{a + 4m + b}{6} \qquad \text{(Equation 5.1)}$$

It is important to note that the most likely time is weighted four times greater than the most pessimistic or most optimistic time estimate.

As an example, the expected time for activity E, the disbursement of plans and schedules to VDOT and its contractors is

$$t_e = \frac{2 + 4(3) + 5}{6} = \frac{19}{6} = 3.17\text{wks} \approx 22\text{ days}$$

From this calculation it is apparent that the expected time to completion does not have to equal the most likely time.

The variance of any activity is given by

$$\sigma^2 = \left(\frac{b - a}{6}\right)^2 \qquad \text{(Equation 5.2)}$$

The variance increases as the difference between the most optimistic and the most pessimistic time estimates increases. This implies that the less certain a person is in estimating the actual time for an activity, the greater will be the variance. Again, for activity E, the variance is

$$\sigma^2 = \left(\frac{5 - 2}{6}\right)^2 = 0.25$$

Table 5.3: Expected activity times and variations

Activity	Time Estimates (weeks)			Activity Statistics	
	Most optimistic (a)	Most likely (m)	Most pessimistic (b)	Expected time (t_e)	Variance (σ^2)
A – Damage assessment	2	3	4	4	0.11
B – Resource request formulation	1	2	3	2	0.11
C – Equipment definition	1	2	3	2	0.11
D – Final repair plan preparation	1.5	2	3	2.1	0.06
E – Response from VDOT inventories and contractors	2	3	5	3.2	0.25
F – Resource and contractor assignment	1	2	3	2	0.11
G – Inventory examination	1	1.5	2	1.5	0.03
H – Ordering equipment	2	4	6	4	0.11
I – Installation	5	6	10	6.5	0.70
J – Inspection	2	3	4	3	0.11
K – Payment	3	4	5	4	0.11

In the VDOT recovery project, the greatest uncertainty lies with the time estimate for activity I (the installation process), followed by activity E (the response from contractors). Both the expected times and the variances for each activity will be useful in performing the analyses that follow. Already it is apparent that the installation process is the most time consuming and variable activity in the project, and will require further attention later on.

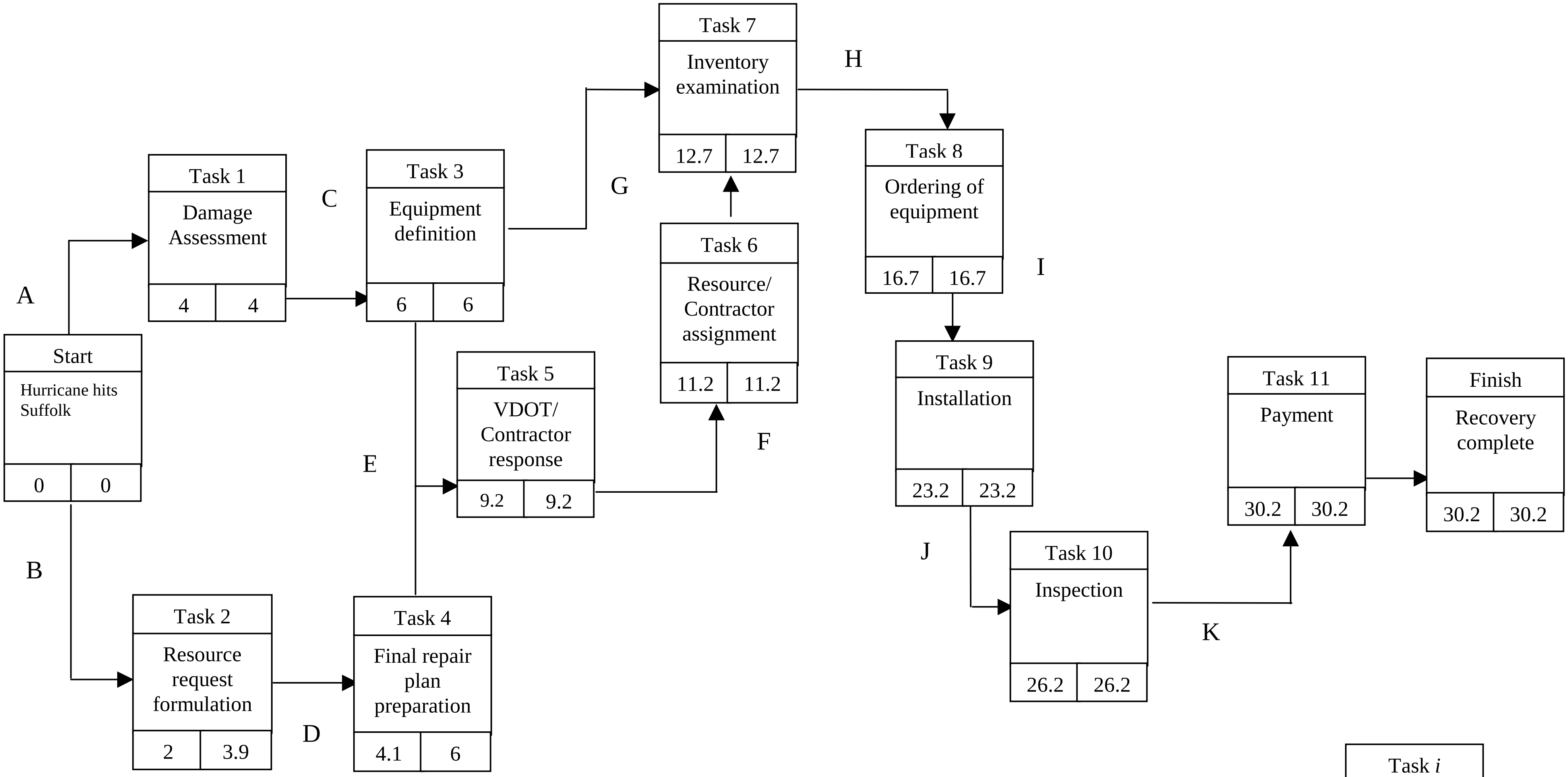
5.3.3.3 Determining the Critical Path

One of the biggest uses of the ordering of tasks and their expected completion times is the time-to-completion. If all tasks were to be performed in a linear fashion, then the complete project would last the sum of the expected values of all tasks – over 34 weeks (over eight and a half months). However, many of these activities can be performed simultaneously, and only the precedence relationships are required to establish a schedule. Figure 5.3 realizes this assumption, and shows that the recovery project can be completed in much less time than 34 weeks.

To determine the earliest completion time of this project, the critical path must be calculated, which is the sequence of activities, from start to finish, having the greatest cumulative elapsed time. The critical path is important, because it defines the completion time of the project, and any delays in the activities along the critical path cause a delay in project completion. First, two other numbers must be calculated.

Earliest expected achievement date (TE): Using Figure 5.3, we can calculate the earliest possible completion dates – this is simply the sum of all the earliest expected achievement times for all the events. In other words, this number shows what the earliest time for activity initiation is.

Latest allowable achievement date (TL): As above, the latest possible completion date for an event can be calculated from Figure 5.3. This date is the latest date that an event can be completed and still allow the project to finish on time. In other words, this number shows what the latest time for activity initiation is.



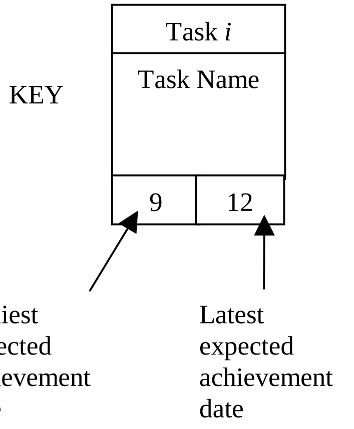


Figure 5.3: Network diagram for project activities showing the earliest expected achievement dates, latest allowable achievement dates, and the critical path.

Using the above two numbers and Figure 5.3, Table 5.4 can be compiled. This lists each event, together with its earliest expected achievement date (TE) and its latest allowable achievement date (TL). If there is a difference between the two times, then the activity is said to possess slack. Slack is the “free time” available in the project – if delays start occurring, they can be absorbed by using up this free time that is present. It is precisely those activities that possess the minimum slack time that are placed on the critical path.

Table 5.4: The calculation of critical paths

Event	TL (weeks)	TE (weeks)	Slack (weeks)	Critical Path
A	4	4	0	Yes
B	3.9	2	1.9	No
C	6	6	0	Yes
D	6	4.1	1.9	No
E	9.2	9.2	0	Yes
F	11.2	11.2	0	Yes
G	12.7	12.7	0	Yes
H	16.7	16.7	0	Yes
I	23.2	23.2	0	Yes
J	26.2	26.2	0	Yes
K	30.2	30.2	0	Yes

The critical path, as mentioned earlier, is important because it defines the completion time of the project. Any delays on this path cause delays in the project. Going back to Figure 5.3, the events on the critical path can be identified by looking at those activities whose earliest completion dates are equal to their latest completion dates. This implies that the activity has no slack time available. On the other hand, activities such as the formulation of resource requests give a difference of 1.9 weeks (3.9 – 2), meaning that even if this formulation is delayed by almost two weeks, the recovery project can still proceed as planned.

Therefore, the critical path in the VDOT recovery process -- if a Category II hurricane were to hit the Suffolk district -- is constituted by A-C-E-F-G-H-I-J-K, with the only activities not being included on this path being activities B and D. The time duration of this path is equal to 30.2 weeks, or just over 7 and a half months.

5.3.4 Analyzing Project Completion Probabilities

Since the time estimates for the activities in a PERT network involve some uncertainty, it is useful to provide a measure of the probability for completing a task in a specific amount of time. To do this, the probability distribution of the completion date for an event must be calculated.

For the recovery project, the mean is the sum of the expected activity times on the critical path, which is equal to 30.2 weeks. Similarly, the variance of the project time distribution is equal to the sum of the variances of those activities on the critical path. For the VDOT recovery example, this figure is 1.64.

Using these numbers it is possible to plot a normal probability curve for the completion time for the recovery project, which for this project is provided in Figure 5.4. This figure shows the normal probability curve for the critical path consisting of A-C-E-F-G-H-I-J-K. Creating a normal probability plot also allows us to calculate the probability that the project length exceeds a certain time limit. For example, using the normal probability tables, the probability that:

Project completion time ≥ 32 weeks = 0.14

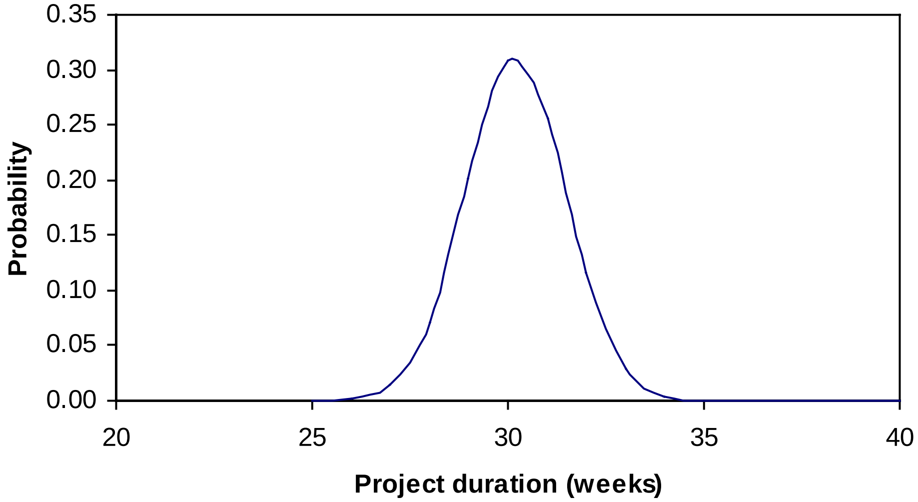


Figure 5.4: Project completion time distribution

Therefore, there is a 14% chance that the recovery project will be delayed. It is important to recognize the fact that this analysis hinges on the identification and characteristics of the critical path. If other activities are introduced, or if some are removed from the project task list, then the nature of the critical path changes, and with it change the probabilities of completion.

An example of a change in the critical path is when an unusually fast completion time occurs for those activities on the critical path. For the VDOT case this would happen if activities A and C were completed ahead of schedule. In other words, damages could be assessed quickly (activity A) if storms were concentrated in only one area, and the equipment that needed replacement could be defined quickly (activity C) if the damaged roads consisted of small stretches of a highway. If the combined expected duration of tasks A and C is 3 weeks, then the critical path changes. Now, tasks Band D take on greater importance since they take much longer to complete (a combined time of over 4 weeks). The expected time to completion for the path B-D-E-F-G-H-I-J-K is longer (28 weeks, two days), than the new expected time to completion for the path A-C-E-F-G-H-I-J-K (27 weeks, one day). Therefore, path B-D-E-F-G-H-I-J-K is now the new critical path. This result is shown graphically in Figure 5.5.

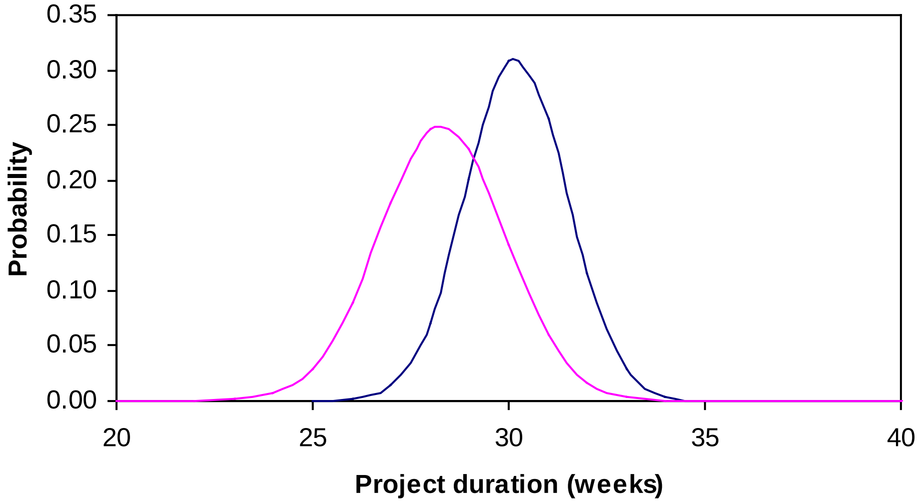


Figure 5.5 Probability distributions for the critical path and the possible next longest path

The new, lower curve to the left (representing the critical path B-D-E-F-G-H-I-J-K) of the old probability plot shows that it is possible for the VDOT project to be completed in less time than is currently the case. The faster completion time (28 weeks, 2 days) becomes possible when activities A and C are completed much quicker than expected.

5.3.5 Summary and Conclusions

This analysis used the current flow of VDOT recovery activities and assigned each activity a most optimistic time, a most likely time, and a most pessimistic time (*5.3.3.1 Estimating Activity Times*). These numbers then made possible the calculation of means and variances for each activity in the recovery list (*5.3.3.2 Calculating Time Statistics*). Doing so has revealed that activity I, the installation procedure, is the lengthiest task and is the task that is most variable in nature.

Using the information from sections 5.3.3.1 and 5.3.3.2, the critical path for the recovery project was calculated in section 5.3.3.3 (*5.3.3.3 Determining the Critical Path*). This critical path was then used to examine the effects on time-to-recovery for the overall project, as well as examining what effects the changes in the critical path has on the time-to-recovery (*5.3.4 Analyzing Project Completion Probabilities*).

The analysis shows that the current setup of activities is fragile and highly dependent on almost all tasks being completed on time if recovery is to be accomplished. It is impossible to complete the project within less than 7 and a half months, unless those activities on the critical path are speeded up. Therefore, VDOT needs to focus more on the activities on the critical path to manage the overall project. The time estimates used to prepare this analysis depend on the resources assigned to each task. For example, it is possible that if more personnel are assigned to the assessment of damage (activity A), then A will transform into a non-critical activity.

Splitting tasks up so that many different activities can be performed simultaneously speeds up project times. This is evident from the fact that whereas the VDOT project lasts 7 and a half months under the current configuration, if only one activity was performed at a time the project duration would be a full month longer. Therefore, it better to try to diversify those activities that take place sequentially (one after the other), instead breaking them out into parallel tasks (occurring simultaneously). This allows different pathways for the same activity and creates greater slack time, so that if one activity lags behind schedule, the delay can be absorbed by the early completion of an alternate activity.

An analysis of Figure 5.5 reveals that there is considerable overlap between the probability distributions of the two critical paths. Both paths are dependent on each other because they share common activities. A change in the completion times of activities A, B, C, and D produces an overall shortening of project completion by about half a month. Therefore, it is necessary to examine these activities more closely and determine if they can be simplified, or split up, to reduce completion times.

5.4 Improving the Project: Time-Cost Trade-offs

The reduction in project times can be accomplished by devoting more resources to each task in the recovery project. However, this is wasteful. Furthermore, reducing the task times of non-critical activities, such as activity B, will not reduce the project completion time. On the other hand, reducing the task time of a single task on the critical path by one week will reduce the completion time of the entire project by one week. Adding resources to a task time to reduce its time is known as crashing the task.

The original time estimates to complete the task is called the normal time (NT), and the cost of completing the task in this time is known as the normal cost (NC). The shortest possible time in which an activity can be completed is called the crash time (CT), and has associated with it a crash cost (CC**)**. Therefore, the per time unit cost of reducing a task time, called the per unit crash cost will be:

$$\text{per unit crash cost} = (CC-NC)/(NT-CT) \tag{Equation 5.3}$$

For the VDOT project, these figures are provided in Table 5.5. These costs are estimates based on interviews with VDOT staff, as well as analysis performed by Capstone team members. Also, the costs listed are based on a moderate hurricane strike of Category II (95-115 mph wind speeds) and the damage that this causes. Some costs such as contractor and VDOT inventory responses (task E), and payment costs (task K) are the administrative costs that would be involved with these activities. NT is equivalent to the expected completion time in section 5.3.3.1, while CT is equivalent to the earliest possible completion time. The crash cost per week is calculated by subtracting the NC from the CC.

Table 5.5: Normal and crash data for the VDOT Hurricane recovery project

Task	Normal Time (wk)	Crash Time (wk)	Normal Cost ($)	Crash Cost ($)	Crash Cost per week
A*	4	2	35,000	50,000	$15,000*
B	2	1	15,000	20,000	$5,000
C*	2	1	5,000	7,000	$2,000*
D	2.1	1.5	10,000	15,000	$5,000
E*	3.2	2	5,000	10,000	$5,000*
F*	2	1	7,500	9,000	$1,500*
G*	1.5	1	5,000	6,000	$1,000*
H*	4	2	50,000	75,000	$25,000*
I*	6.5	5	2,500,000	3,500,000	$1,000,000*
J*	3	2	30,000	40,000	$10,000*
K*	4	3	10,000	15,000	$5,000*

*Task is on the original critical path.

Crashing a non-critical task is pointless, as reducing its completion time does not reduce the overall project time-to-completion. Therefore, only the critical tasks that can be crashed are to be considered. Through PERT, the tasks that are to be crashed are chosen in order of increasing expense. Therefore, the task with the smallest crash cost in Table 5.5 (task G) is chosen to be crashed first. Thus, G is reduced from 1-and-a-half to 1 week in length, and the project cost increases by $1,000. The next task to be crashed is F, since it has the next highest crash cost. This progression continues until all critical tasks have been crashed. Figure 5.6 shows how the VDOT hurricane recovery project cost increases as tasks continue to be crashed:

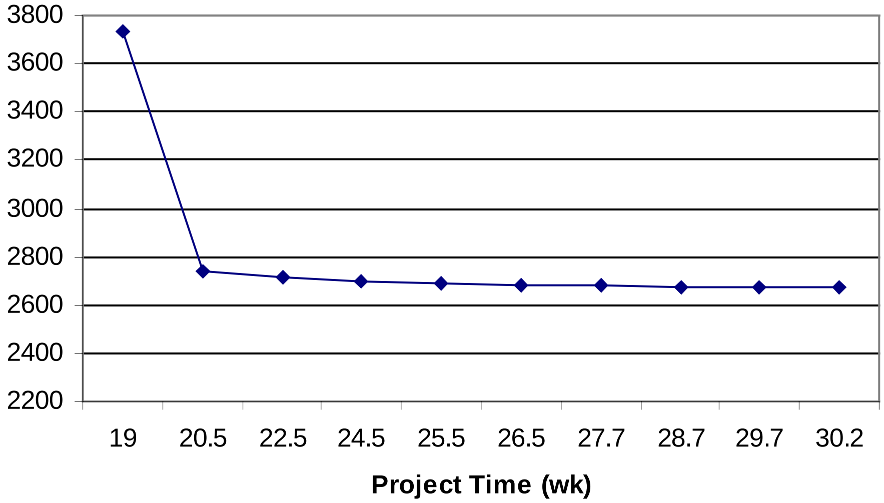


Figure 5.6 Project cost as a function of completion time for the VDOT hurricane recovery project

As can be seen from Figure 5.6, the project costs remain stable for a continued reduction in project time. However, there is a significant jump that occurs when trying to reduce project times to below 20 weeks, which is when task I (the actual installation process) must be crashed. From this plot it appears that VDOT can reduce its overall project time by almost ten weeks while not increasing costs by much. Trying to reduce the time-to-recovery beyond the 20th week is not recommended until the equipment installation process is examined and improved so that it initially incurs lower costs, and thus can be crashed without causing an excessive rise in expenditure.

5.5 Areas of Further Study

Further examination and study will involve examining those project areas on the critical path and determining how changes to these activities affects the overall project. Most likely, the installation process will be the activity with the most uncertainty involved. Therefore, further study would involve analysis of the installation process, and in this case computer simulation can be employed, as given below.

The simulation model for the installation process will study the existence of a maintenance crew as it:

1. Retrieves replacement equipment from an inventory. This is the act of the repair crew arriving at the inventory location and accessing it. The crew then removes all items that it will substitute for damaged equipment, leaving the inventory depleted by that amount.
2. Travels to the location where the damaged equipment needs to be replaced. Travel times to a location are calculated by taking the distance to the repair site and dividing by the speed of travel for the repair crew. One of the simplifying assumptions in the creation of a model is that roads will be clear and accessible to the repair crews. Future work on this project can include the assumption that certain roads are difficult to traverse and then examine the effect this has on the days-to-recovery.
3. Repairs the equipment and travels to the next site. Repair involves a repair time that depends on the nature of the material being replaced and the complexity of the replacement procedure. Repair time is most accurately modeled using random

probability distributions. Traveling to the next site will again involve a travel time based on the speed of travel and the distance to the next repair site.

4. Repair crew returns to home base once it runs out of equipment and/or finishes fixing the last site on its list.
5. Home base uses the inventory to replenish the crew’s equipment. This phase is the replenishing phase for the repair crew. The inventory’s reaction to the repair crew’s return and the demand for further material will provide valuable insight for the management of an inventory of damageable equipment.

This cycle then begins again. To set up this model, information is needed about the path the maintenance crew will follow on its repair mission. The crippling of an important road will mean that a different, and possibly longer, route will have to be followed. Also, details as to the nature of equipment that is being replaced are needed. If a road is in critical condition and needs a signal to return to a normal traffic flow, the repair crew will have to make that trip immediately, thus ignoring several sites along the way where replacements are needed. Therefore, before the simulation is begun, it must be determined whether it is considered better to fix several sites or to concentrate on the more important areas.

Table 5.6: Important variables that will be employed in computer modeling

Variable name	**Nature**	**Comments**
Travel time	Time needed to reach destination	Distance to location / speed of repair crew
Repair time	Time needed to repair damaged equipment	Random probability depending on complexity of operation
Inventory access time	Time spent in accessing the inventory	Dependent on spare availability
Delay time	Unforeseen delays (waiting in queue for replacement equipment)	Exponentially distributed
Replenishment	Equipment retrieval time	Discrete distribution
Total time to recovery	Days/weeks/months	A sum of all the all the model times
Total cost	Cost of plan	
Equipment status	Most critical in need of repair / not critical	Different models will consider different scenarios

5.6 Project Conclusions

5.6.1 Summary

Although the analysis of projects using PERT and CPM methods reveals that critical paths are the areas that require most scrutiny, it is probably as important to direct attention to near-critical paths. These are paths of activities that *could* become critical if one of the other activities falls behind in its schedule. Since there are a number of activities going on during hurricane recovery, any one of these activities can slip and cause another critical path to emerge. It is therefore necessary to perform the analyses presented here for a number of scenarios, such as those involving the delay of certain key tasks.

From the analysis performed in this thesis, it is clear that VDOT's current hurricane recovery procedures are highly dependent on a number of activities being completed on time. The flow of activities is such that the majority of them are placed on the critical path, and therefore the projects time-to-recovery suffers adversely should any of these activities start lagging behind schedule. Most importantly, the study of VDOT's post-hurricane behavior has revealed that the emergency equipment installation procedure is by far the longest lasting and most variable task.

Also, analysis reveals that up to a certain point, tasks on the critical path can be speeded up, or crashed, without a significant increase in cost. Although the speeding up of tasks places greater pressure on the resources employed (equipment and repair crew for example) this may be prudent to do under extreme situations since there is no great increase in costs. An example of such a situation would be the aftermath of a moderate hurricane that has left access to hospitals and emergency services completely blocked for a community.

5.6.2 Recommendations

VDOT must now conduct the following activities in keeping with the results of this study:

- Collect detailed data on its post-hurricane equipment installation behavior. This means analyzing its repair crew activities, its road clearing activities, and its inventory for spare emergency equipment.
- Use this data to try to split equipment installation tasks into parallel operations
- Try to examine the impacts of assigning more resources to the installation task. This can be the assignment of more labor, more equipment, or more finances.
- Examine different overall configurations for its activities than currently exist. This thesis has studied the configuration as it currently exists. By trying to diversify and split the tasks VDOT can create for itself greater flexibility in organization. A reconfiguration of tasks can thus easily provide better recovery times by shuffling critical and non-critical tasks. For example, trying to combine tasks G and H (the inventory examination and ordering of equipment, respectively) would mean that the overall critical path, and therefore the overall time-to-recovery, would be reduced.
- Attempt to study its overall post-hurricane behavior along the lines of the analysis performed in this chapter and determine where further time and costs

can be saved. The time-cost trade-off section of this analysis methodology (*5.4 Improving the Project*) shows that costs rise slowly as recovery time is reduced. By conducting this same analysis for each task VDOT can determine how each activity contributes to the rises in cost.

Although this study has focussed mostly on hurricane effects, the overall template of project management can be applied to blizzard recovery, forest fire recovery, and earthquake recovery. The analysis performed in this chapter is of a general nature, designed to provide insights into the components that constitute a large project. As such, the project examined here can be easily modified to include the study of different highways, communities, repair crews, and geographical locations.