Chapter 6. DECISION SUPPORT FOR RESOURCE ALLOCATION FOR HURRICANE RECOVERY

Introduction

The goal of this chapter is to introduce a tool to provide support for VDOT managers in deciding where to allocate funds, personnel, and equipment for disaster post-event and to convey to others their rationale and decisions. The current chapter includes:

- A descriptive scenario describing the motivation for the initiation of a disaster response and the need for effective resource allocation.
- An introduction to the initial objectives considered when deciding where to allocate resources in the event of a natural disaster strike.
- A list of objectives under the following headings, risk reduction, performance gain, and resources.
- Charts displaying the underlying theory of the multi-objective decision making tool.
- A description of the data collected in coordination with this project.
- A case study performed on the data received from VDOT from the Hurricane Floyd post-event project in September 1999.
- Sample charts from the Floyd case study exhibiting the basic functionality of the multi-objective decision making tool.
- Analysis of the findings from the Floyd case study.
- A case study performed on the data received from CDOT (Caltrans) from El Nino storms.
- Sample multi-objective and bar charts from the El Nino case study.
- Analysis of the findings from the El Nino case study.
- Summary of the important points to be considered concerning this chapter.

Purpose and Scope

In September of 1999 Hurricane Floyd struck Virginia, causing significant flood damage, but not a substantial amount of wind damage. The Virginia Department of Transportation Emergency Operations Center received over 100,000 phone calls from Virginia residents in the week following the category one hurricane. The enormous amount of phone calls demonstrates the scale of the impact that a hurricane has on a community as well as the need for a swift, coordinated response by the Virginia Department of Transportation.

Methods and Materials

To effectively aid in the decisions of what highway repair projects to undertake with available funds following a hurricane, multiple objectives need to be considered. The objectives need to be incorporated into a comprehensive tool that effectively communicates relevant data and ideas to decision-makers in VDOT and other state agencies. The tool will need to equitably balance:

- Risk reduction
- Performance gain
- Resources, including cost

Post-event activities include the activities aimed to repair the highway system following a natural disaster, and include those activities taking place in the short, medium, and long-term following the disaster. Examples of post-event activities include debris removal, bridge repair, pavement repair, slope damage repair, etc. The necessary post-event activities can be contrasted against risk reduction, performance gain, and resource use, in order to evaluate the effectiveness of the activities. The evaluation of activities against multiple criteria can help to show the tradeoffs of each activity for every objective. The evaluation of activities against multiple criteria is illustrated in Figure 6.1. The decision of where to allocate resources can be based in part on the performance of the activities against multiple objectives.

In order to evaluate individual activities against risk reduction, performance gain, and resources used, indices of performance have to be created to quantify the objectives. Once the objectives are quantified, the post-event activities are plotted easily in three dimensions.

The following indices of performance are suggested to evaluate the effectiveness of post-event activities:

Risk Reduction

- Lives saved (in week following disaster strike)
- Decrease in safety hazards (in months following disaster strike)
- Decrease in environmental threats (in years following disaster strike)

Performance Gain

- Travel time saved (minutes per peak hour)
- Increase in ADT (average daily traffic)
- Number of lanes cleared (in months following disaster strike)
- Increase in accessible critical facilities by highway network (in week following disaster strike)
- Number of people affected (population density statistics)
- Road type (interstate, primary, or secondary roads)

✍ Length of road section (miles)

Resources

✍ Estimated cost of completion ($)
✍ Use of materials
✍ Personnel

Figure 6.1 shows what the decision tool is attempting to do. A, B, C and D represent various post-event activities, which could include bridge scour, debris removal, slope repair, bridge repair, etc. Performance indices are used to label the horizontal and vertical axes. The activities that perform better against the performance gain metric are positioned above others, whereas activities that perform well against the risk reduction metric will be plotted to the right of others. Activities that maximize both performance gain and risk reduction are plotted in the upper right hand corner of the graph. The activities that are do not perform well against the chosen indices are located closer to the lower left hand corner near the origin.

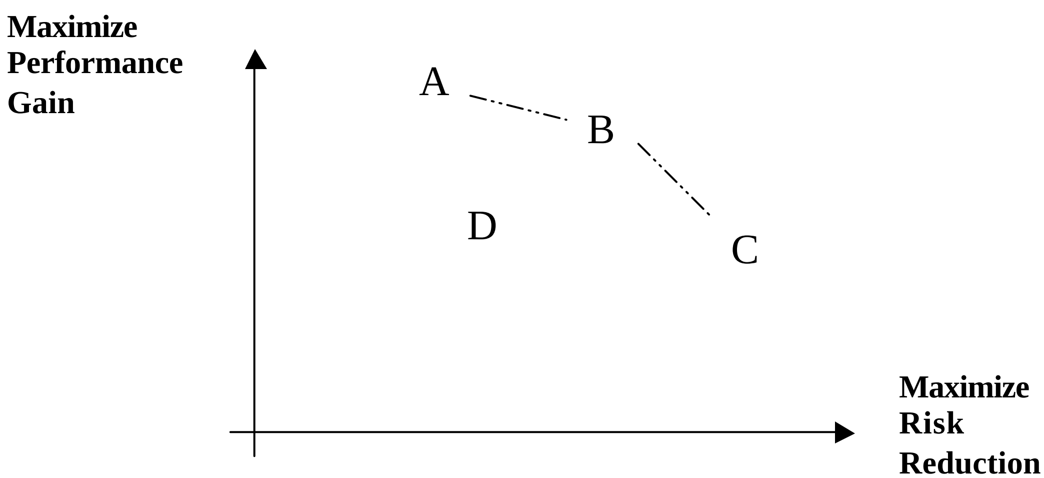

Figure 6.1 Multi-objective tradeoffs in resource allocation in disaster recovery

Figure 6.2 accounts for three objectives by making the size of the data point proportional to the estimated cost of the post-event activity. Larger circles represent activities with relatively large costs, and activities with relatively small costs are represented with smaller circles.

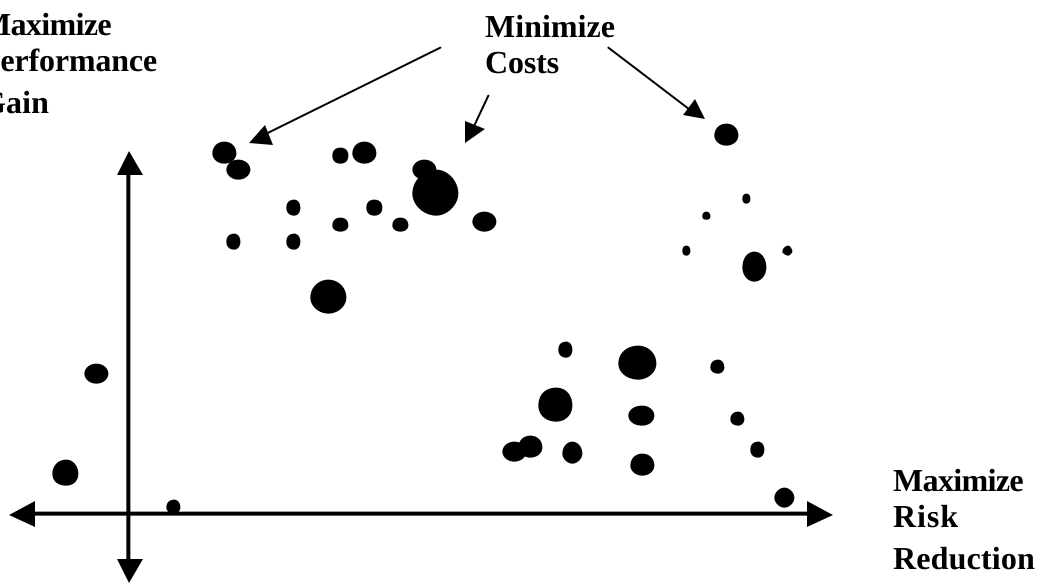

Figure 6.2 Multi-objective tradeoffs in three dimensions in resource allocation for disaster recovery

Results

This section describes the work that has been completed thus far for support for resource allocation. Included is a short synopsis of data collection and examples of a case studies performed using highway post-event data from Hurricane Floyd in Virginia and El Nino Storms in California.

Data Collection

Data collection has been undertaken to provide important information concerning past disaster responses and the post-event activities involved in the response. The data also provides the list of post-event activities to be evaluated in the case studies. Data has been collected in coordination with Mr. Perry Cogburn of the VDOT Emergency Operations Center, and Mr. Jim Varney of the Maintenance Division of the California Department of Transportation. Mr. Cogburn supplied data for VDOT post-event efforts after Hurricane Floyd struck Southeastern Virginia in September of 1999. Table 6.1 shows a sample of the data.

The data include 624 specific examples of post-event activities from thirty-nine separate cities/counties. Twenty-five activities occurred on interstates, 165 on primary roads, and

164 on secondary roads. The information included a description of improvement, costs, and road type.
Mr. Varney has provided information on the post-event efforts following the El Nino storms in February of 1998 for the California Department of Transportation. Table 6.2 displays a sample of the data from the 1998 El Nino recovery.

The data include the 251 different post-event activities completed between February 1998 and June 1999 out of a total of 851 damage sites. The data provided by CDOT is more comprehensive and included the route number, mile markers (California's route mile markers start at zero in each new county), costs, extent of damage, and the severity of damage.

Case Studies

The case studies use real-life data and scenarios to display the effectiveness of the multi-objective charts in properly allocating resources and communicating information efficiently. Case studies consist of the following elements:

- Using data from real-life disaster recovery
- Organizing data for analysis
- Deciding upon performance indices based on supplied and interpreted data
- Creating multi-objective charts and maps using supplied data and performance indices

Hurricane Floyd

The first case study has been performed using the data supplied by VDOT from the post-event efforts following Hurricane Floyd in September 1999. The data is organized into table format using Microsoft Excel. Data was organized into the categories; county/city, improvement type, estimated cost, number of interstate sites, number of primary sites, and the number of secondary sites for each improvement type within a certain county/city.

Performance indices have been generated using the available data. The supplied data could not be measured against most of the preliminary indices, however. The data supplied cost data to satisfy resource use requirements. The data also provided location and road type data that could be used to derive statistics to satisfy performance gain objectives. The data provide little insight into the risk reduction objective. In order to compensate for the lack of risk reduction objective, performance gain indices had to be used on both axes. Location data could be used to find population density statistics related to each post-event activity, and road type data accompanied with location data could be used to find average daily traffic (ADT) data for the area affected by each post-event activity. The three indices, cost, ADT, and population density, have been chosen based on the data available. Activities located in areas with high population and on roads with large daily traffic volume will receive precedent in receiving resources from VDOT.

Table 6.1 Sample of Hurricane Floyd post-event data provided by VDOT [Cogburn 2000]

County/City	Type of Improvement	Total Cost	Number of Interstate Sites	Number of Primary Sites	Number of Seconday Sites
Greensville	Slope failure & protective	$13,830	2	0	0
	Slope failure & debris	$98,875	0	4	0
	Debris removal	$44,346	0	0	7
Isle of Wright	Slope failure & bridge	$1,020,630	0	7	0
	Slope failure & debris	$754,754	0	0	12
James City	Debris removal	$7,304	1	0	0
	Bridge, slope failure	$1,703,126	0	9	0
	Debris & protective	$15,000	0	0	6
Southhampton	Slope failure and debris	$57,631	0	11	0
	Slope failure and debris	$144,082	0	0	20
Surry	Slope and bridge failure	$235,439	0	3	0
	Slope failure	$33,381	0	0	1
Sussex	Slope failure	$6,007	1	0	0
	Slope and bridge failure	$206,242	0	3	0
	Slope failure	$51,485	0	0	4
York	Debris and protective	$30,000	1	0	0
	Slope failure and debris	$179,534	0	8	0
	Debris and protective	$90,108	0	0	7
Brunswick	Debris removal	$5,000	1	0	0
	Slope failure and debris	$41,602	0	6	0
	Debris removal	$9,285	0	0	10
Charles City	Slope failure and debris	$26,999	0	5	0
Chesterfield	Slope failure and debris	$128,875	3	0	0
	Slope failure and debris	$23,307	0	4	0
	Slope failure and debris	$28,037	0	0	6
Dinwiddie	Debris and protective	$9,092	2	0	0
	Debris and protective	$19,630	0	5	0
	Slope failure and debris	$108,120	0	0	13
Hanover	Debris removal	$8,592	0	1	0
Henrico	Slope failure and debris	$149,500	6	0	0
	Debris removal	$37,937	0	2	0
Mecklenburg	Debris removal	$5,181	1	0	0
	Slope failure and debris	$35,100	0	6	0
	Debris removal	$5,000	0	0	4

Using the data supplied and the selected performance indices, post-event activities resulting from Hurricane Floyd were charted and mapped in Microsoft Excel. Figure 6.6 shows an example of the data being plotted using the multi-objective analysis.

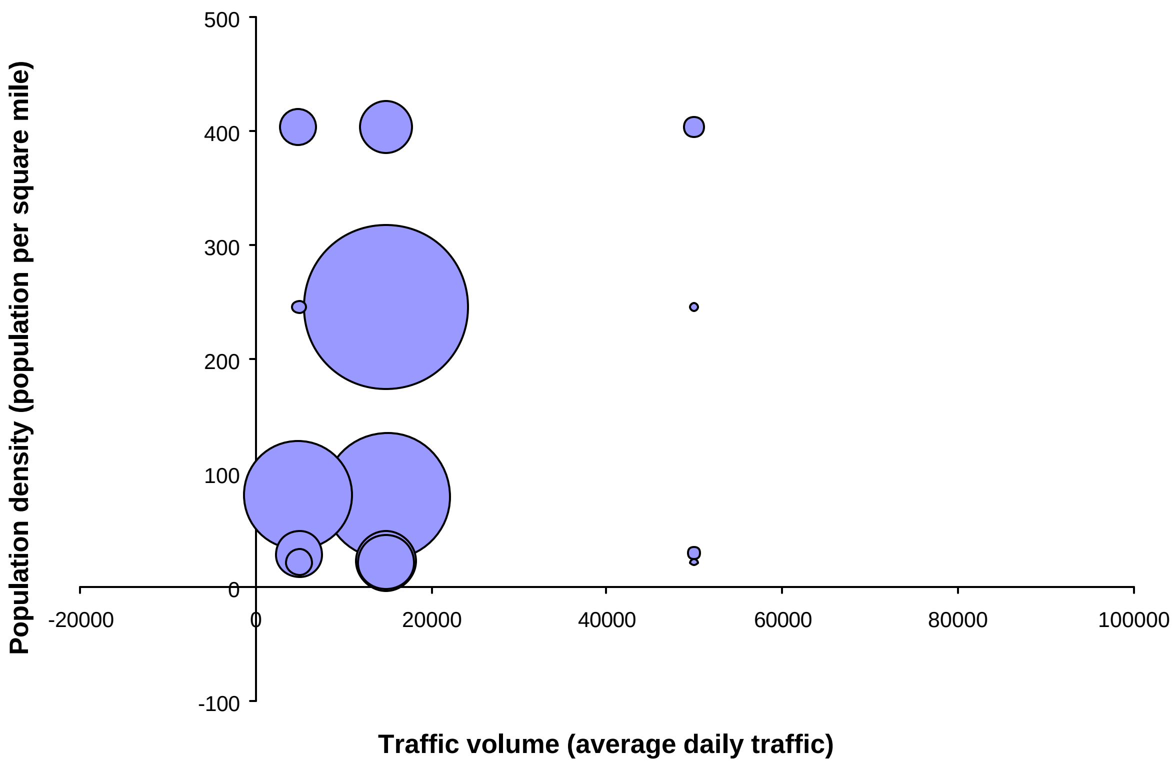

Figure 6.6 Post-event activities plotted for counties in Hampton Roads

In Figure 6.4 and 6.5 activities are arranged and classified by color. Figure 6.4 shows activities arranged by the type of post-event activity. Circles shaded in the same color represent activities of the same type. Figure 6.5 arranges activities by county. Labels indicate activity type.

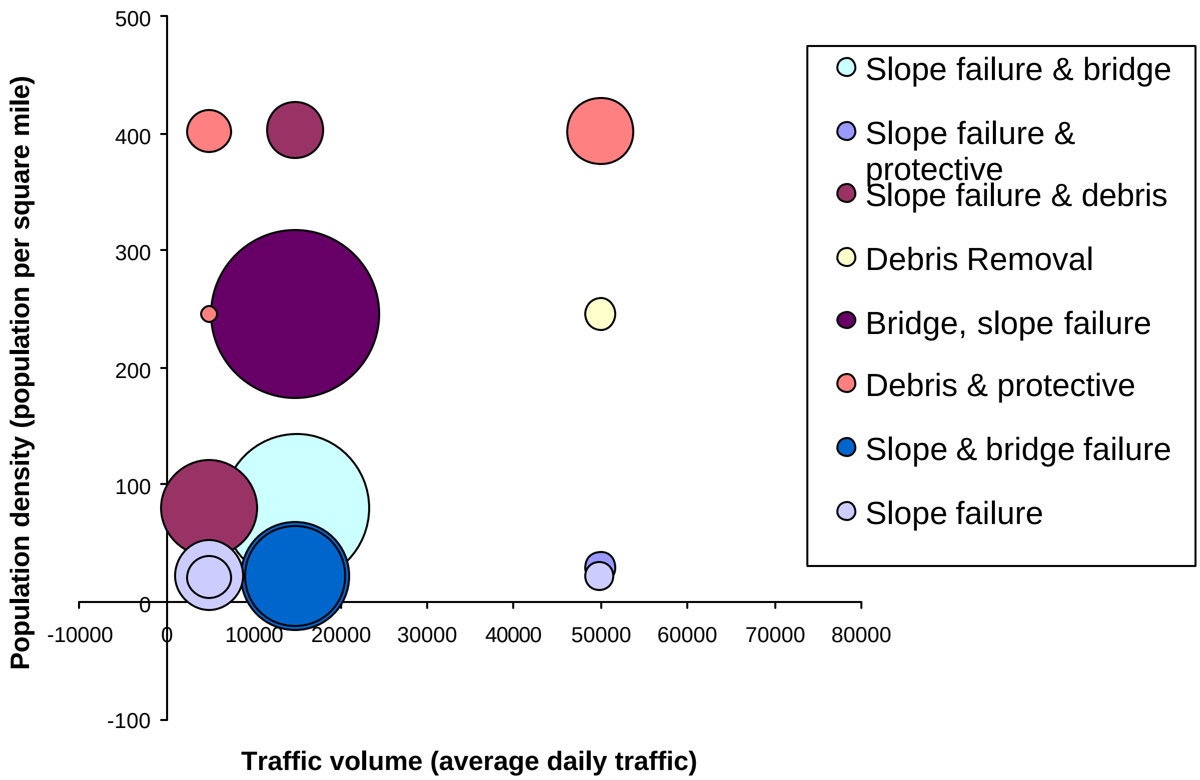

Figure 6.4 Post-event activities plotted for counties in Hampton Roads grouped by activity type

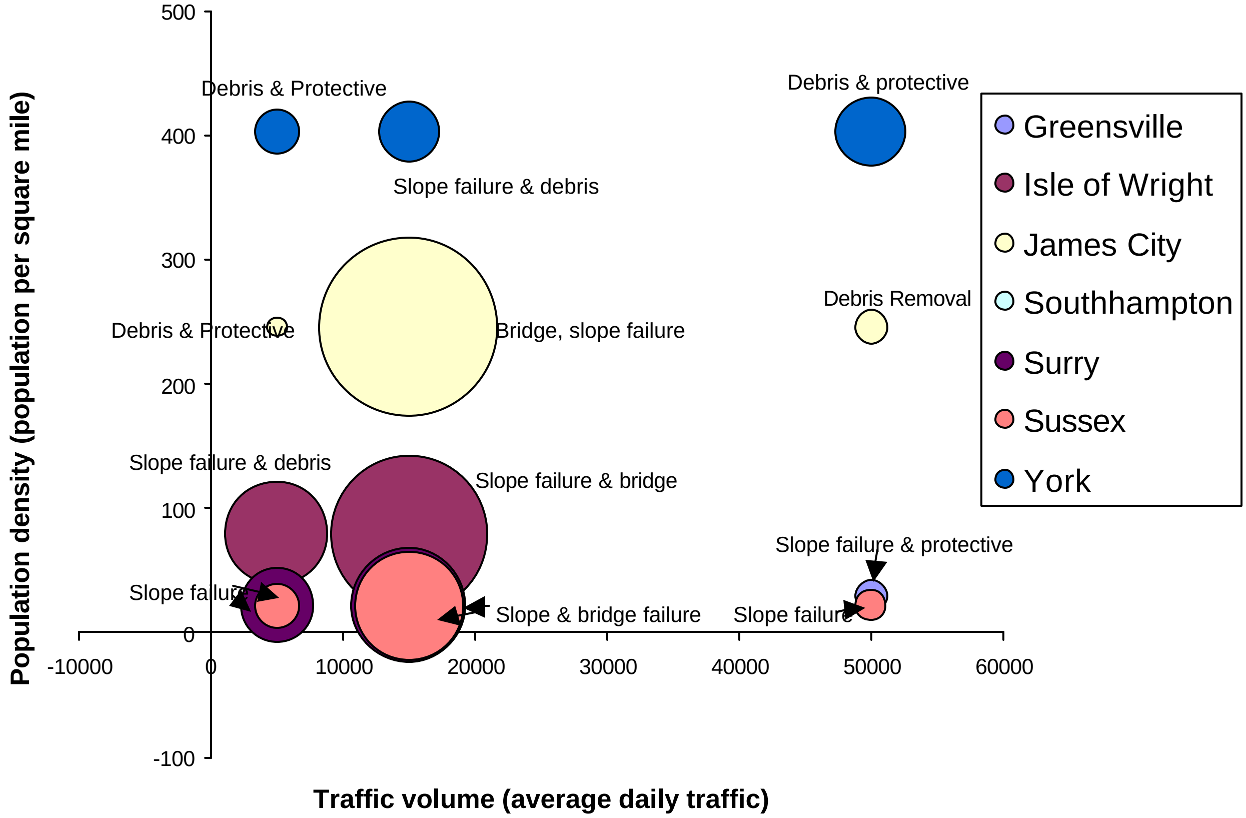

Figure 6.5 Post-event activities plotted for counties in Hampton Roads grouped by county

Charts were created for individual counties and cities as well. The charts were then placed on top of the corresponding location. Figure 6.7b includes the charts. The legend to the charts for individual counties and cities is included in Figure 6.7a.

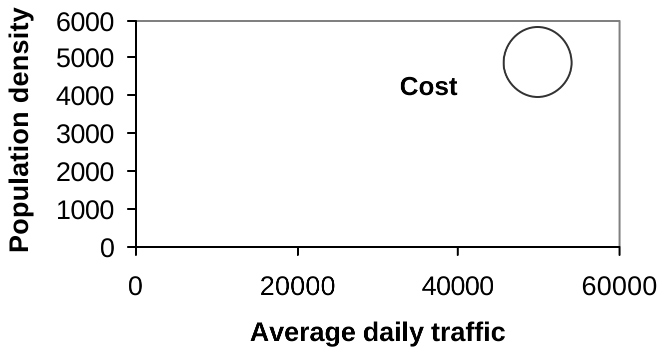

Figure 6.7a Legend for charts located within Hampton Roads map below

Figure 6.7b Map of Hampton Roads with multi-objective charts for labeled cities/counties

El Nino Storms (California)

Another case study was performed using the data supplied by CDOT from the post-event efforts following the El Nino storms of 1998. The data was organized into table format using Microsoft Excel. Data was organized into the categories of district, county, route, mile marker, cost, extent of damage, and the cause of the damage.

From here, performance indices had to be generated using the available data. The supplied data could not support the initially generated performance indices, however. The data supplied estimated cost data to satisfy resource use requirements. The data also provided route numbers and mile markers that could be used to derive statistics to satisfy performance objectives. The fact that specific locations are given with the El Nino data will allow for much more specific ADT data to be collected. More specific ADT data will provide better insight and allow for further analysis beyond what was done in the Floyd case study. The mile marker data also gives insight into the severity of the damage. The extent of damage statistic also provides insight into the current state of the road and to whether or not the road is passable. Abbreviations for the extent of damage and the causes of the failure are given below.

Cause (Primary cause(s) of failure)

SL = Slide (landslide above roadway)
SP = Slipout (landslide below roadway)
WO = Washout
BS = Bridge scour
CF = Culvert failure
FR = Fire
HS = High surf
GW = Groundwater
OT = Other

Extent (Severity of Damage)

CL = Complete loss
LL = 1 or more lanes lost
PL = Partial lane lost
BL = Bridge Loss
PD = Pavement damage
BD = Bridge Damage
SL = Shoulder loss
SD = Slope damage
CL = Culver loss
FL = Flooding

Table 6.2 offers a sample of the El Nino data provided.

Table 6.2 Sample data from 1998 El Nino storms provided by CDOT [Varney, 2000]

District	County	Route	Mile	Mile	Cost	Extent of Damage	Cause of Damage
1	DN	199	6	5.9	$250,000	CL	SL
1	DN	101	12.5	12.1	$200,000	SL, SD	WO, HS
1	DN	101	15.2	22.8	$200,000	LL	SP
1	DN	101	15.4		$550,000	SD	SP
1	HUM	101	0.4		$600,000	SL, SD	SP, WO
1	HUM	200	2.2	2.1	$140,000	LL, SL, SD	SP, CF
1	HUM	96	3.1	3	$200,000	LL	SL
1	HUM	96	16.6	16.7	$135,000	LL, SL, SD	SL
1	HUM	96	16.7	16.6	$600,000	LL, SL, SD	SL
1	HUM	96	19.9		$1,600,000	PL, SL, SD	SP
1	HUM	101	22.9		$2,630,000	CL,PL,SD	SL
1	HUM	96	23.9		$200,000	LL	SP, GW
1	HUM	96	27.3		$500,000	LL	SP, GW
1	HUM	101	31.26		$350,000	SL, SD, CL	WO, CF
1	HUM	101	134.5		$270,000	SD	SL, GW
1	LAK	20	27	26.9	$230,000	LL, SL, SD	SL
1	LAK	20	28		$200,000	PL	GW
1	MEN	101	4.5		$1,400,000	LL	SP
1	MEN	1	4.7	4.9	$1,600,000	PL	SP
1	MEN	1	5	4.7	$200,000	LL	SP
1	MEN	1	6.7	6.8	$350,000	LL, SL, SD	SP, CF
1	MEN	101	6.9		$600,000	SL, SD	SP, WO
1	MEN	128	7.7	3.5	$400,000	PL, SL, SD	SP
1	MEN	20	8.8		$300,000	CL	SP
1	MEN	253	10.3	10.2	$630,000	LL, SL	WO
1	MEN	20	15.5	15.4	$630,000	LL, SL SD	SL
1	MEN	162	16.7		$1,200,000	PL,SL,SD	SP
1	MEN	20	20.3	20.2	$500,000	CL	SL
1	MEN	20	26	25.9	$380,000	SL	SP
1	MEN	128	34.1	34	$200,000	LL, SL, SD	SP
1	MEN	101	34.4	34.9	$630,000	LL	SL
1	MEN	101	37.8		$2,300,000	SL, SD	SP
1	MEN	1	41.1	41.2	$400,000	LL, SD	SP
1	MEN	1	41.1	41	$300,000	PL, SL SD	SP
1	MEN	1	41.3	41.2	$450,000	LL, SL, SD	SP
1	MEN	101	76.5		$700,000	SL	SP

Using the data supplied along with the ADT, population density, cost, mileage, and extent of damage statistics, multi-objective charts, as well as bar charts have been created to provide insight into the post-event after the El Nino storms.

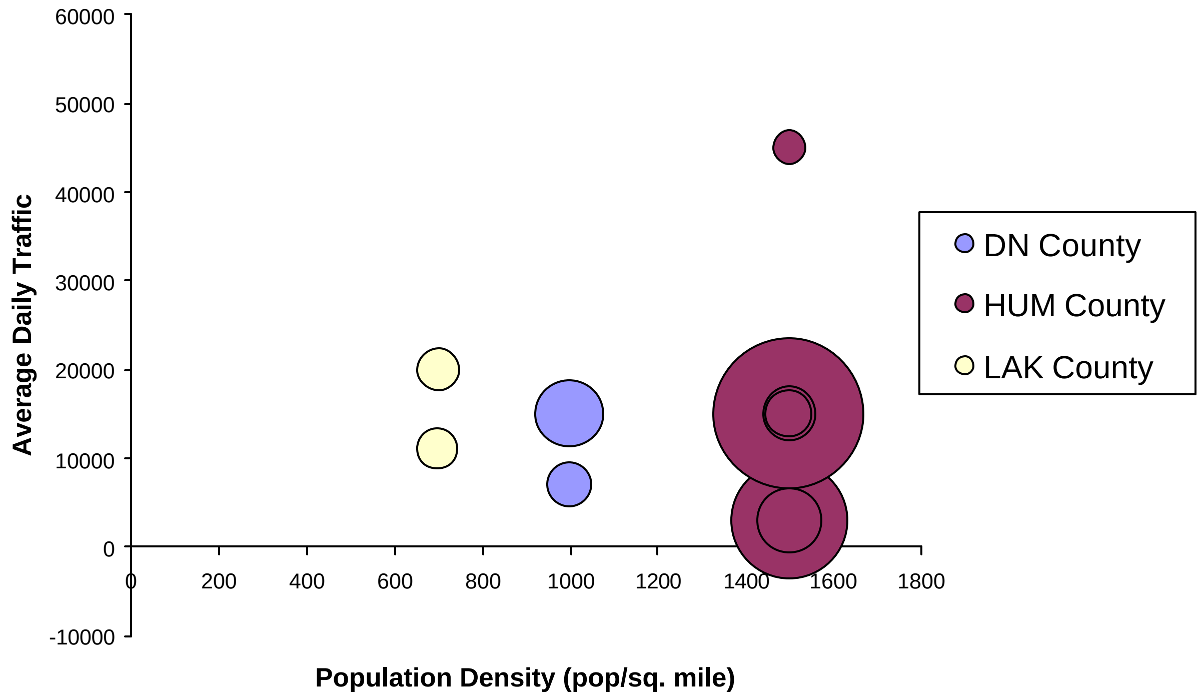

Figure 6.8 Post-event activities in DN, HUM, and LAK counties evaluated against ADT, population density, and cost.

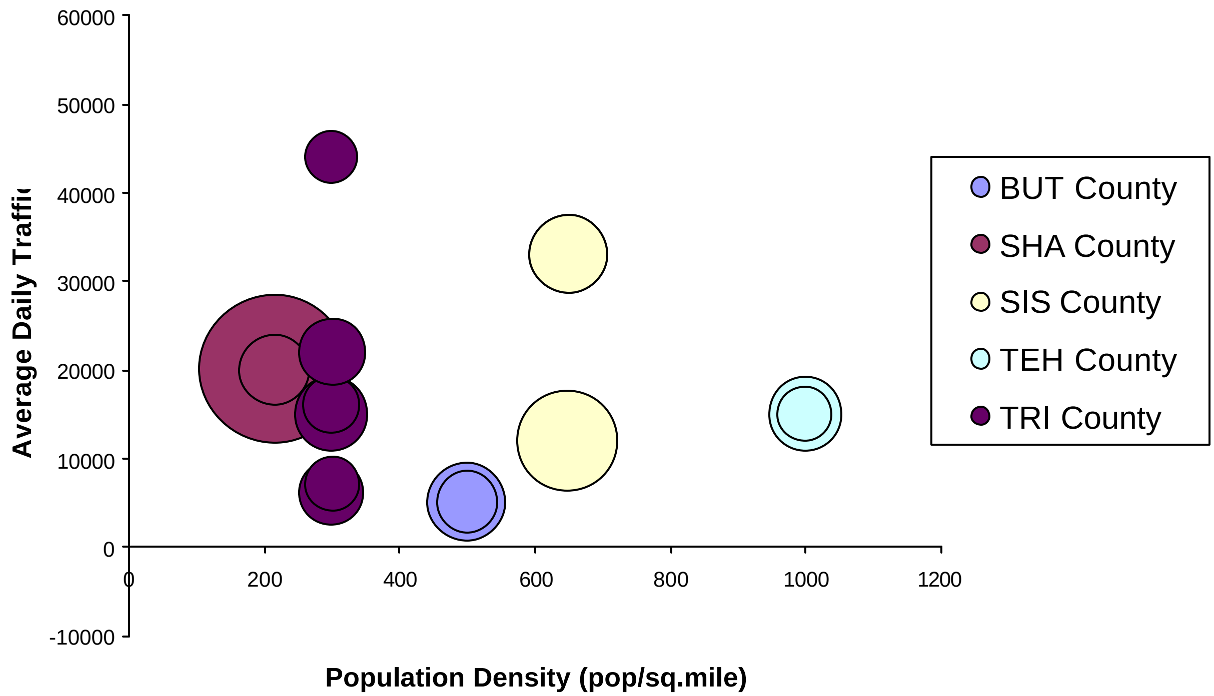

Figure 6.9 Post-event activities for BUT, SHA, SIS, THE, and TRI counties

Using the extent of damage data, it is also possible to group activities by the extent of damage and total cost of each activity. The plots are in bar chart format. The table to the right of the charts shows the types of damage done. Many extent of damage scenarios are plotted. Figure 6.10a shows the axis for the bar charts in more detail.

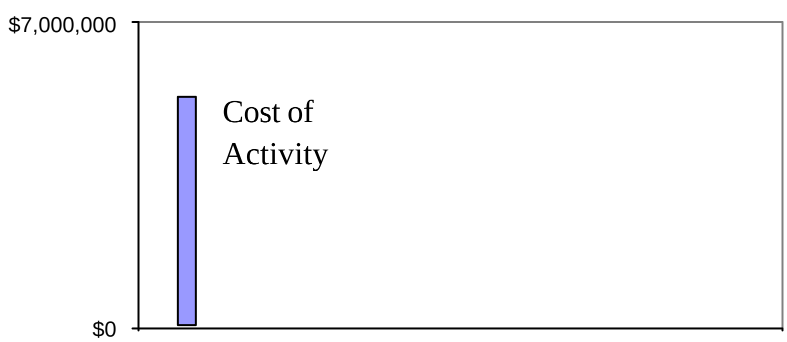

Figure 6.10a Legend for California bar charts

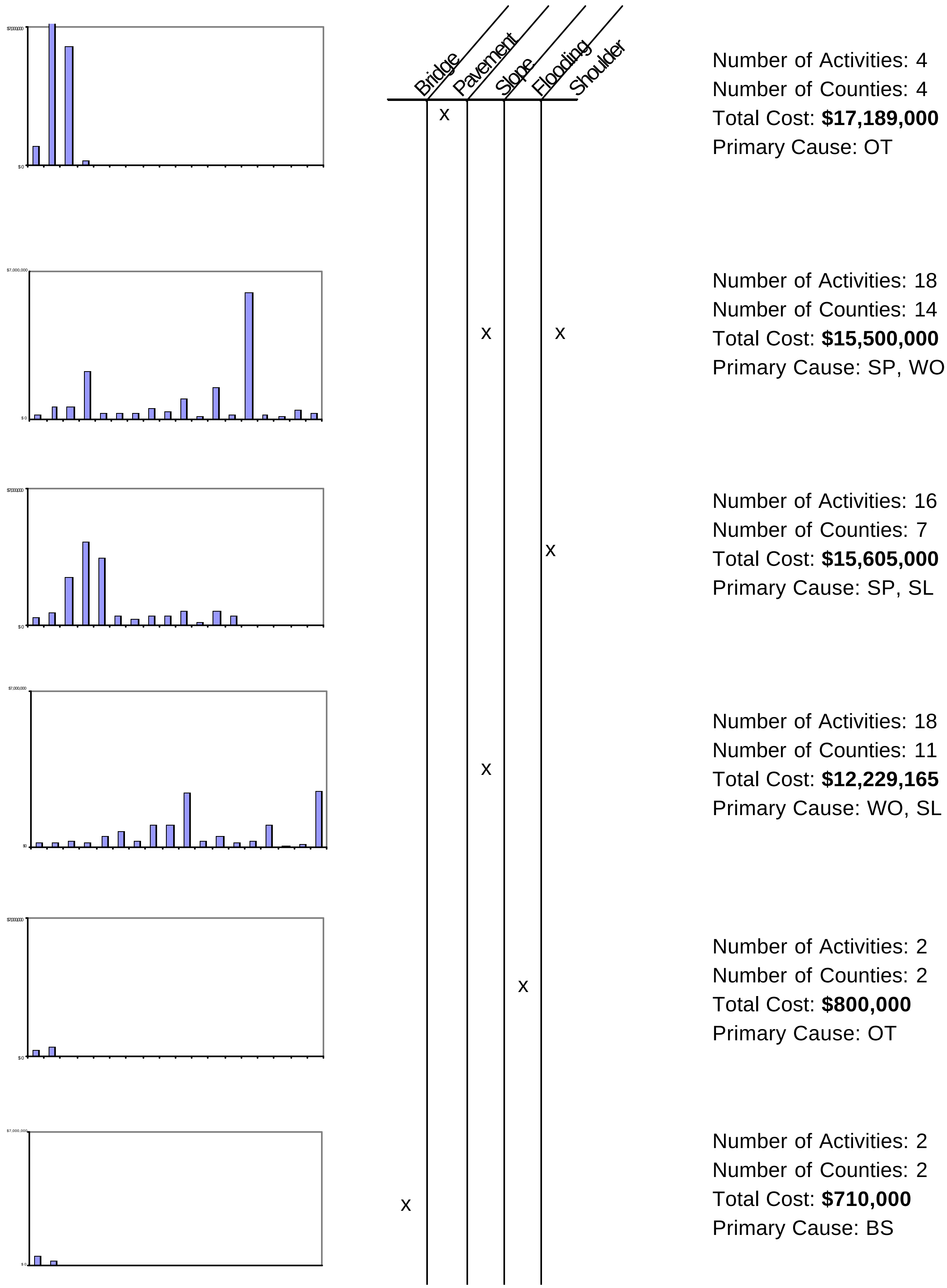

Figure 6.10b Bar charts exhibiting costs of post-event activities of certain type. Type is defined by middle grid.

Conclusion

The purpose of this project was to develop a method to systematically prioritize post-event activities in order to effectively aid in decisions concerning resource allocation for VDOT in the event of a natural disaster. A tool was developed that utilized multi-objective decision analysis in order to prioritize post-event activities based on available data. Data was collected through contacts in the VDOT and the California Department of Transportation, and was used to conduct two case studies. The data provided for both studies had to also be used to determine the performance indices/objectives to use to prioritize and evaluate the effectiveness of the post-event activities. Initially the objectives were to fall under the three categories of risk reduction, performance gain, and resources used. Due to a lack of available data for risk reduction and performance gain indices, new indices had to be produced from the given data. The indices that resulted were average daily traffic, population density, and total estimated cost. The indices were chosen because of their availability and effectiveness in evaluating post-event activities. The third factor to consider in resource allocation decisions would be cost.

There was much to be learned from the first case study involving Hurricane Floyd data. Available data could not always provide answers to the desired questions. Suitable and effective indices were found by extrapolating the data. The indices of performance used in the Hurricane Floyd case study can be used as a foundation for all further uses of the multi-objective tool. It is important to note that the roads with the highest volume of traffic are where the majority of the resources will be allocated. The charts are now driven by costs and the impacts on population, rather than performance gain and risk reduction. The charts are not limited to average daily traffic and population density statistics for use as performance indices. Any available ordinal statistic can be used, depending on what information an agency finds effective in prioritizing post-event activities.

In regards to the multi-objective charts, more specific post-event data was provided for the California Department of Transportation's post-event following the El Nino Storms, including route numbers, mile markers, and a description of the extent of damage. Specific route numbers and mile markers meant that more specific average daily traffic information could be found for each post-event activity, in comparison with the average daily traffic data collected for Hurricane Floyd post-event activities, where the average daily traffic statistic had to be generalized for the three different road types (Interstate, Primary, and Secondary). More specific average daily traffic data should mean that the spatial orientation of the activities in the chart is more varied and should allow for keener prioritization of activities.

The description of the extent of damage allowed for bar charts to be created in the El Nino Storms case study including the cost associate with each damage type. The charts are listed from greatest expenditure to least expenditure in Appendix E. With pavement damage post-event activities resulting in the highest number of funds allocated, and bridge damage as the least number of funds required. The bar charts give insight into what kinds of activities the majority of resources are going to, and the relevant cost of each of the activities. Through a collection of similar data relating to other post-event efforts, agencies can use the data to project to future storms and help in preparing for future storms.

Recommendations

In the future VDOT should:

- Consider a systematic approach to disaster recovery, including the use of the multi-objective decision tool for resource allocation.

- Use the approach to improve the allocation of resources to diverse projects.

- Represent the variety of post-event projects across regions.

- Discover the balance among all project impacts and costs. Multi-objective charts should be driven by impacts on the surrounding community and the costs associated with each activity.

- Project from past storms to the needs arising from future storms.

- Perform similar case studies on post-event efforts for different categories of hurricanes (I – V). Comparison of post-event efforts for different severities of storms can help coordinate pre-event activities.

- Consider duration of post-event activity as a performance gain criterion and for calculating present value of post-event activities.

- Use multi-objective tool as a way of creating a common terminology amongst VDOT analysts. Common terminology can lead to a rehearsed, structured pre- and post-event for a natural disaster.