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Optimizing the Prioritization of Natural Disaster Recovery Projects

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**OPTIMIZING THE PRIORITIZATION
OF NATURAL DISASTER
RECOVERY PROJECTS**

THESIS

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Abstract

Prioritizing reconstruction projects to recover a base from a natural disaster is a complicated and arduous process that involves all levels of leadership. The project prioritization phase of base recovery has a direct affect on the allocation of funding, the utilization of human resources, the obligation of projects, and the overall speed an efficiency of the recovery process. The focus of this research is the development of an objective and repeatable process for optimizing the project prioritization phase of the recovery effort. This work will focus on promoting objectivity in the project prioritizing process, improving the communication of the overall base recovery requirement, increasing efficiency in utilizing human and monetary resources, and the creation of a usable and repeatable decision-making tool based on Value Focused Thinking and integer programming methods.

To My Wife and Two Sons

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Jason M. Aftanas

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OPTIMIZING THE PRIORITIZATION OF NATURAL DISATER RECOVERY PROJECTS

I. Introduction

1.1 Background

Results from the Second U.S. Assessment of Research and Applications conservatively estimates that from 1975-1995 natural hazards have killed over 24,000 people, injured approximately 100,000, and have caused over $500 billion dollars in damage. To put this problem in perspective, that is 23 people killed and one-half billion dollars of damage sustained per week during that 20 year period (Mileti, 1997). Only 17% of these losses were covered by private insurers with the remainder of the burden falling to the public sector (Stehr, 2001). Local governments are given the responsibility of implementing recovery plans and acquiring the resources to carry them out. Local recovery and reconstruction after a natural disaster is primarily an organizational problem (Stehr, 2001:419). In the United States Air Force, Civil Engineer Squadrons are the organizations responsible for the preparation, recovery, and reconstruction of installations prior to and following a natural disaster event.

A natural disaster is the consequence of the combination of a natural hazard and human activities. In other words, if no humans are in the proximity of a natural hazard, such as a tornado in a unihabited area of Nebraska, it can't be called a natural disaster. Natural hazards include earthquakes, avalanches, hurricanes and typhoons, heat wave, ice storms, lahars, landslides, sinkholes, tsunami, volcanic eruption, solar flare, and impact events.

Human vulnerability, sometimes caused by the lack of appropriate emergency management, can lead to financial, structural, and human losses. The ensuing losses depend on the capacity of the population to support or resist the disaster. (Bankoff, 2003)

One of the most common and devastating natural disaster that can occur is a hurricane. Hurricanes may spawn tornados, flooding, landslides, storm surge and hailstorms long after they have moved inland and been downgraded to tropical storm status. Currently, there are 36 USAF Active duty, Reserve, and Guard bases that are located on or near the Atlantic Ocean and susceptible to the direct path of an Atlantic hurricane. Additionally, the USAF has several OCONUS locations such as Andersen, AFB that routinely receive typhoons. Figure 1 shows the location of USAF active-duty bases in the US in relation to the corresponding disaster prone areas of the country.

Figure 1. Map of US Natural Disaster Zones in Relation to USAF Bases

When faced with the task of recovering an installation from a hurricane or any other significant disaster, the decision makers, base leadership, are faced with choosing courses of action to alleviate hardship and restore the mission. Leaders have to determine which facilities and infrastructure to repair first based on how valuable each repair is to the recovery effort. The list of possible considerations is immense and without a strategy for addressing the issue of project preference, or priority, the task of implementing and managing an effective natural disaster reconstruction program is daunting.

For instance, some considerations may be:

- What repairs must be performed first in order to bring the mission back online?
- Is the damage causing a significant health or safety risk?
- What delivery method should be employed in order to expedite the reconstruction process and produce the desired results?
- What repair projects are dependent on predecessor projects that require immediate attention?

One process for evaluating multiple decisions is Decision Analysis (DA). The DA approach incorporates a step-by-step process that aide the decision to make a choice between multiple alternatives during extreme circumstances. Value Focused Thinking (VFT), a specific branch of DA, is utilized in this research to create a strategic model for prioritizing facility and infrastructure reconstruction projects in the wake of a natural disaster at an USAF installation.

1.2 Problem Statement

Currently, I have found no formalized, systematic, and repeatable process for optimizing the prioritization of reconstruction projects in the wake of natural disasters such as hurricanes, earthquakes, tsunamis, or other natural phenomena in either literature or Air Force instructions (AFI's). However, there are several different techniques that have been devised for general project selection that will be reviewed and considered in this research. The USAF has made an effort to standardize its disaster preparation and initial response through the creation of the Contingency Response Plan (CRP) which is described in AFI 10-211 with additional guidance available in AFPAM 10-219 Volumes 1-3. However, these AFIs and pamphlets provide only general recommendations for post-disaster recovery and are primarily concerned with the initial response. The remaining task of reconstructing or repairing damaged buildings and infrastructure is not specifically addressed by these or any other AFI or AFPAM. The development of an objective, accurate, and strategic process to establish a benchmark for prioritizing reconstruction projects vital to the ongoing mission of the United States Air Force is paramount.

1.3 Research Objectives

This analysis will examine the complex problem of identifying, quantifying, and prioritizing base recovery projects following natural disasters by developing a DA tool with the goal of validating base recovery requirements and optimizing the funding and obligation process.

Prioritizing reconstruction projects to recover a base from a natural disaster is a complicated and arduous process that involves many levels of leadership. How projects are prioritized during base recovery effects the allocation of funding, the utilization of human resources, the obligation of projects, and the overall speed an efficiency of the recovery process. The development of an objective and repeatable process for optimizing the project prioritization phase of the recovery effort is the objective of this research. The goal of this research includes: 1) Increasing objectivity in setting prioritizing projects 2) Streamlining the funds request process 3) Decreasing errors in initial funding requirements 4) Improving the leadership's understanding of the overall base recovery requirement 5) Utilizing human resources more efficiently 6) Providing a trainable process that can be exercised annually 7) Illustrating the process for creating a usable and repeatable tool based on D.A. and integer programming (IP) methods.

1.4 Research Focus

This research will focus on developing a value hierarchy using VFT and a complimentary integer program that will address the issue of prioritizing recovery projects after natural disasters.

1.5 Research Questions

The following three research question will be investigated:

1. What does the Air force value in identifying the priorities of a natural disaster reconstruction program?
2. How can the Air Force optimally allocate its resources during a recovery effort?
3. What are the advantages and disadvantages of the new prioritization tool versus the current method?

1.6 Research Approach

The research questions will begin to be addressed through a literature review that focuses on the techniques used by the USAF, academia, and private industry for prioritizing projects. Next, the values essential to prioritizing a reconstruction program will be solicited from USAF Civil Engineer leaders at a vulnerable installation in order to utilize their experience and subject matter expertise. DA, and more specifically VFT along with Integer programming, will be used to develop a decision management model based on the "multiple objective decision analysis/value-focused thinking" concept utilizing the Logical Decisions software package. Most decision problems result from events beyond our control or as a result of the actions of others: competitors develop a better product or service, customers demanding a new feature, government regulations, or circumstances such as recessions and natural disasters (Keeney, 1992). VFT is a method of decision making that focuses on clearly defining and structuring the decision makers fundamental values in terms of objectives and then utilizing these objectives to guide and integrate decision-making (Keeney, 1994).

Traditional decision-making methods focus on evaluating alternatives where as VFT uses values as the primary decision making tool. Focusing the decision maker on the essential activities that need to be identified prior to solving a decision-making problem is a main goal of VFT (Keeney,1994).

This methodology will provide an objective approach for analyzing the project prioritization process and will allow for the exploration of innovative alternatives in the more efficient use of our human and fiscal resources.

1.7 Assumptions and Limitations

This research focuses on how a particular Air Force base determines what recovery projects receive the highest priority after a natural disaster and develops a computer based model for optimizing the allocation of funding resources for that particular installation. This thesis will focus on facility and infrastructure repair requirements but it should be noted that housing repair requirements will exist. Due to the nature of specific funding sources in the federal government and the fact that Air Force leadership views housing as a separate and equally important requirement for recovering a base it will need to be explored in future research. Academia, private industry, and other government agencies will serve as a comparison for this prioritization of construction projects. However, the methods utilized in this research transcend the topic of natural disaster recovery and could be applied to a myriad of project management decisions for any type of organization.

Since the VFT approach is based on the values of the decision maker, in this case a senior level Civil Engineer at the Major Command (MAJCOM) level, there will be bias based on personal preferences and political pressure. However, some bias is expected to play into any decision and capturing this bias in the form of the leader's values is preferred. The foundation of VFT is that knowing what the decision maker values, rather than the available alternatives, is the most important information one can obtain when accurately accessing a decision-making problem (Keeney,1992).

Various bases or subsequent leaders may decide that the values obtained in this research for this particular base are different from their own at their own location. This should not raise concern either. One of the purposes of this research effort is to illustrate the development of a strategic process through the VFT approach and to show that this process is objective with respect to the leader's values and repeatable with future leaders at the appropriate Air Force level. The Logical Decisions software is flexible and the procedures used to develop the model can easily be replicated with the values of the new leadership.

This research will validate the model on a pseudo event compiled from hypothetical data that will be used in lieu of an actual storm. Data such as, cost estimates, scope of work, damage assessments, and contract information from previously funded recovery projects of past events will be used as benchmarks. Afterwards, the decision maker, a USAF Colonel serving as the Air Combat Command A7, will provide feedback in order to adjust the model to reflect a real world decision for the hypothetical reconstruction program.

1.8 Preview of Chapters

The remainder of this thesis is organized as follows, Chapter 2 contains the literature review of crisis management, current decision analysis techniques, a detailed examination of previous methods employed to prioritize construction projects, and a background of the current applications of the Value-Focused Thinking approach to decision-making. Additionally, a brief discussion of the specific integer programming techniques utilized by the model is presented. Chapter 3 consists of an overview of the VFT process including the development of a value hierarchy. Chapter 4 is a complete presentation of the results obtained from the model, as well as, sensitivity analysis and the procedures for adjusting the model. Finally, Chapter 5 summarizes the research and makes recommendations for implementation and future areas of research.

II. Literature Review

2.1 Crisis Management

A crisis can be defined as an event that can result in a severe threat to organizations by disrupting plans, crippling normal operations, endangering human life, and that drastically weakens the effectiveness of a system or regime in a very short time (Farazmand, 2001). Examples of crises include natural disasters such as floods, earthquakes, and hurricanes but also include events such as the Oklahoma City Bombing, the attacks of 9/11, or the stock market crash of 1929. Central to all crises is the sense of urgency that stems from the constantly changing environment in which they occur. The term crisis management refers to the accurate and timely diagnosis of the critical problems resulting from a crisis event (Farazmand, 2001). Crisis resolution requires strategic thinking of contingencies and this is exactly what the VFT hierarchy approach created in the research addresses.

Crises that result from a natural disaster event often result in significant infrastructure damage, deleterious economic impact, and population displacement. Consequently, the recovery efforts often are focused on infrastructure and housing repair, recovery of employment, and the reinstatement of all other economic structures (Vogel, 2001). Our research focuses on the areas of recovery specific to infrastructure.

An artifact is an institutionalized process that can include plans, goals, mission statements, categorization methodologies, clustering methodologies, simulation and gaming techniques, jargon, prioritization listings, and other procedures (West, 2006). The VFT model presented in this research creates an artifact that will serve as a contingency plan for the reconstruction of an Air Force base following a natural disaster crisis.

Robert W. Kates and David Pijawka published an article titled, From rubble to monument: the pace of reconstruction, in which they determined that the reconstruction process that follows a natural disaster can be generalized into four separate stages: (1) the emergency phase, (2) the restoration phase, (3) the replacement reconstruction phase, and (4) the developmental reconstruction phase (Kates and Pijawaka, 1977). The emergency phase begins immediately following the disaster event. It involves search and rescue operations, debris clearing, causality collection, and basic utility and infrastructure restoration. The restoration of utilities can include temporary bridges, temporary water and sewage lines, and generator power to critical facilities and systems. The emergency phase can last for several weeks depending on the severity of the damage caused by the disaster event. The restoration phase encompasses all permanent repairs to infrastructure and facilities (Alexander, 1993). The USAF has Air Force Instructions (AFI) dedicated to rescue and recovery teams, relocating essential equipment prior to the impact of semi-predictable event such as a hurricane, Damage Assessment and Recovery Teams (DART), and utilizes a Survival Recovery Center (SRC) as a central command structure during the emergency phase of a crisis.

This research focuses on the restoration phase, which we commonly refer to as the natural disaster recovery project program. Our VFT hierarchy deals directly with prioritizing the restoration phase projects because there is a lack of formal guidance in this phase of crisis management. The reconstruction replacement and developmental reconstruction phases deal with more broad recovery efforts such as economic recovery and the erection of monuments to commemorate disaster events.

Another reconstruction process has been developed by the United Nations Disaster Relief Agency (UNDRO, 1984). Their process is also a four stage process:

1. Predisaster
2. Immediate Relief Period (impact to day 5)
3. Rehabilitation Period (day 5 to 3 months)
4. Reconstruction Period (3 months onward)

Based on UNDRO's process, our VFT model is developed during or prior to the predisaster phase and implemented during the rehabilitation and reconstruction phases.

Improving the clarity of the decision-making process in a post-disaster environment is an important facet of this thesis. David Alexander states in his book titled Natural Disasters, that the ability of the government to plan for an execute reconstruction has a direct bearing on the post-disaster environment. He suggests that cities, or other entities, should prepare some type of reconstruction plan prior to a disaster striking. Alexander believes that by examining the possible consequences of a disaster prior to it occurring you can mitigate the problems inherent with the reconstruction process and facilitate creative thinking.

Once again, this thesis addresses these suggestions by obtaining the values USAF leaders have in prioritizing a recovery project program prior to any natural disaster occurring in an effort to create a recovery strategy and improve communications.

Recovering a military base, or any other municipal entity, has historically been an organizational problem. Relationships develop between local, state, and federal government organizations to form an emergent recovery organization. On an Air Force base, the composition of the recovery organization would include but is not be limited to: the Wing Commander and his/her direct reporting agencies such as Finance and Wing Safety, Group Commanders, Support Squadron commanders such as Civil Engineering and Security Forces, Major Command (MAJCOM) Staff, local and state public works and transportation authority officials, and expert assistance from the Air Force Center for Environmental Excellence (AFCEE) and the Air Force Civil Engineer Support Agency (AFCESA). After the initial focus of the emergency response phase subsides there is an increased chance of goal conflict between organizations that are competing for limited resources. For instance, the medical group may see a leaking roof in an operating room as the number one priority and the Operation Group commander may view an aircraft wash rack as a higher priority in a coastal environment due to electrolysis caused by the salt air. The reality is that both projects are important but must be funded from the same funding source. Recovering from a natural disaster is often made more difficult by the pressure to rebuild quickly in order to return to normal operations. There has historically been great difficulty maintaining coordination on recovery projects due to their uncertain nature, complexity, and potentially long construction times (Stehr, 2001).

This thesis puts forth a strategy that fosters communication between the competing entities responsible for recovering the base. It captures the values of the organization's leadership structure and quantifies it through the implementation of multi-criteria decision analysis. It creates a policy that has been vetted by the important players in the decision making process. This point is paramount. Several researchers have noted that the degree of integration among organizations that comprise the emergency response network prior to a disaster is a reliable predictor of readiness and response effectiveness (Stehr, 2001)

Local decision makers, such as the Base Civil Engineers (BCE) and project managers (PM) must make strategic choices during the predisaster and recovery phases of a disaster. C.B. Rubin and her colleagues studied 15 community recovery processes and found that the effectiveness of local decision makers increased when they were empowered with the authority and knowledge of how to carry out the recovery.

Rubin recommends five steps to increase a community's chance of having a successful recovery and reconstruction program if and when a natural disaster strikes:

1. Develop a recovery plan based on the strengths and weaknesses of your particular community.
2. Utilize pre-existing community organizations in the recovery process whenever possible.
3. Designate a focal organization or create a recovery response team with representatives of the multiple organizations that will play a major role during the recovery process.
4. Develop and maintain intergovernmental relationships.
5. Learn from other communities' experiences. (Rubin, 1985)

Historically, the AF has been very good at identifying the strengths and weaknesses of predisaster preparation actions through their various exercises such as the annual Hurricane Exercise (HUREX) and the Operational Readiness Inspections (ORIs) which are facilitated by the Wing and MAJCOM Inspector General (IG). Integration of the many organizations a Wing CC has at his/her disposal is also very prevalent with some examples being the Facility Working Group (FWG) and Exercise Evaluation Team (EET). This thesis focuses on the attainment of Rubin's step 3. Since the CE squadron is responsible for all construction on base excluding communications projects, it stands to reason that they naturally lend themselves to becoming a major component of the recovery process. The aforementioned base leadership has the responsibility for the ongoing mission requirements and wartime planning associated with prosecuting the Air Force Mission.

Therefore, delegation of managing the recovery program naturally falls to Support Group CC which is then delegated down to the operational level of the BCE. In the past, requirements and values could have been lost in the translation when delegating downward in an organization. However, the methodology provided here allows the base leadership to formally define what they value most in the recovery process through their involvement in the creation of the VFT hierarchy therefore; discrepancies between what is operationalized and what the base leadership desires should be minimized. The net result is the empowerment of the BCE and PMs to make decisions that they can fill confident in before running them up the chain of command for approval. The final goal is to provide the base leadership with a prioritized list of recovery projects that they can feel confident in because they have been ranked based on the collective values of the leadership. Rubin's step four calls for the development and maintenance of intergovernmental relationships, in this case inter-wing and inter-group relationships. The very nature of the VFT process and the brainstorming exercise used to facilitate the solicitation of values fulfills this recommendation. Finally, Rubin's step five, learning from other community experiences, is an area that needs to be addressed in more detail by the Air Force and Civil Engineering career field particularly but is better suited to a lessons learned type system such as a Community of Practice (CoP). The attempt of this research is to involve a wide range of experience and talent to provide a broad and all encompassing approach to problem solving.

2.2 Crisis Management Case Studies

The following section investigates case studies of several disasters that have occurred worldwide. The first to be examines is Bangladesh's disaster management program which is used to mitigate the effects of seasonal tropical cyclones. Second, a review of the lessons learned from the Great Hanshin-Awaji Earthquake of 1995 is conducted. Finally, an article titled Managing Terrorism as an Environmental Hazard, authored by William Lee Waugh, Jr., provides insight on how managing a natural disaster and a terrorist attack are analogous.

Bangladesh is a country that is very prone to natural disasters such as tropical cyclones, tidal waves, and perennial flooding. One of the most devastating disasters was a tropical cyclone that claimed the lives of over 700,000 people in 1970 (Zafarullah, 2001).

Like most modern countries, Bangladesh has a governmental organization dedicated to disaster relief and theirs is called The Ministry of Disaster Management and Relief (MDMR). This organization is tasked with overseeing disaster mitigation programs and post-disaster relief and rehabilitation programs. The MDMR utilizes public organizations such as the Bangladesh Red Crescent Society (BRCS) and several nongovernmental subject matter experts to form interdisciplinary disaster management committees. In the wake of a natural disaster, the nongovernmental agencies are tasked with rehabilitating local communities and providing relief in the form of food and supplies.

Upon review of Bangladesh's national natural disaster management program Zafarullah identified several shortcoming which are presented in the list below (Zafarullah, 2001).

1. A Lack of Coherent Policies
2. Institutional Constraints
3. Staffing Problems
4. Ineffective Coordination and Collaboration
5. Bureaucratized Response to Natural Disasters
6. Inadequate Research and Evaluation
7. Perversion of Relief Operations
8. Lack of a Participatory Approach

The VFT approach used in this thesis specifically addresses the lack of coherent policies by creating a strategic model that represents the values of the organization's leadership. Furthermore, the brainstorming phase of VFT process fosters participation and collaboration.

The case study of the Great Hanshin-Awaji earthquake of 1995, which was rated at 7.2 on the Richter scale and accounted for over 6308 deaths, reveals the state of affairs of Japan's crisis management system prior to the earthquake and then elaborates on the reforms made to the system. The author of this study, Masaru Sakamoto, provides insight into Japan's crisis management problem areas in the list below (Sakamoto, 2001).

1. Lack of an Up to Date Disaster Management Master Plan
2. Prime Minister not Empowered to take Direct Command
3. Mismanagement and Poor Timeliness of the Self Defense Forces (SDF)
4. Inadequate Training of Crisis Skills and Volunteer Activities (Sakamoto)

Utilizing a VFT model that has been vetted by the leadership of the organization has the effect of empowering the subordinates at the operational level to proceed with the recovery effort in a way that is strategically aligned with the values and goals of the leadership. Since the VFT model proposed by this thesis is in essence a strategic plan for how to quantify damage, mission priorities, and account for the time constraints of a natural disaster recovery program, the absence of one or more key players after a natural disaster event is more easily overcome. Additionally, because the VFT model will need to be revisited and validated by new base leadership every two to three years the recovery and reconstruction phase of the disaster management plan should remain current.

The threat of a terrorist attack on the United States is real in today's world, and thus a great deal of attention has been dedicated to the preparation and recovery from such an attack. Recent events such as the Attacks of 9/11, the Oklahoma City bombing, and the attack on Cobart Towers in Saudi Arabia serve as reminders that we cannot downplay the importance of disaster preparedness. Most infrastructure in the US is susceptible to damage caused by a terrorist attack. Transportation systems and governmental agencies could be interrupted such as in the case of the 9/11 disaster. Perhaps next time our enemies may target our power grid or water systems. It is the duty of the leadership of an organization to prepare for and plan for the recovery from such an attack. One of the most glaring observations made in William Lee Waugh Jr.'s article, Managing Terrorism as an Environmental Hazard*,* is that recovery efforts can overwhelm a local recovery organization following any type of disaster. The author points out that recovery programs often focus on responses to a specific type of disaster (Hurricane, Tornado, Terrorist Attack, etc.) rather on the anticipation of the next event. In other words, recovery programs tend to be retroactive rather than proactive (Waugh Jr., 2001).

A primary goal of the VFT model used in this thesis is be proactive and provide a strategic decision-making tool that will allow decision makers in all levels of leadership to understand how the post-disaster reconstruction of the base will be prosecuted. The model provides a clear picture of when and why a particular repair project will be accomplished. The model is valid for any type of natural disaster and can be applied to a man-made disaster such as a terrorist bomb attack.

The common theme of the crisis management literature is that little work has been done to improve the rehabilitation and reconstruction periods of the reconstruction process. Another theme is that a strategic approach that facilitates involvement and collaboration is in order. For these reasons, and many more, this thesis utilizes the VFT process to address the problems with natural disaster recovery.

The following sections of chapter 2 review the pertinent Decision Analysis literature and the specific methods used for project selection and disaster management. A great deal of emphasis is given to the Analytical Hierarchy Process and the Analytical Network Process because of their prevalence in the project selection articles published in several of American Society of Civil Engineering journals.

2.3 Decision Analysis

The primary area of research that this thesis focuses on is Decision Analysis (DA). DA is defined as a set of quantitative methods for analyzing decisions based on the axioms of consistent choice. Decision Analysis is a normative approach that provides a systematic quantitative approach to making better decisions. It also provides a practical and defensible analysis of decision-making problems where there is uncertainty involved. But the DA field is not relegated to just decision trees anymore. The use of influence diagrams to improve communication between analyst and managers, algebraic formulation methods and utility functions to model attitudes toward risk taking and tradeoffs, sensitivity analysis using tornado diagrams and graphs, and advances in computer applications are allowing analysts to model real-world decisions more efficiently (Kirkwood, 2000).

The Harvard Business Review recently published and article in the January 2006 issue of Best of HBR coauthored by John S. Hammond, Ralph L. Keeney, and Howard Raiffa titled The Hidden Traps in Decision Making. In this article these accomplished decision analysts discuss common poor decision-making traps. The traps are being cautious to a fault, having overconfidence, being highly impressionable, sticking with the status quo, looking for evidence to confirm one's own preferences, and throwing money at a problem rather than admitting that one made a wrong decision. The fact that this article is published in HBR is particularly relevant because it shows a trend toward mainstream acceptance of the concepts of decision analysis by businessmen and a willingness by DA academia to transcend from the traditionally quantitative disciplines of DA to a more universally understood practical explanation. (Hammond and others, 2006)

Currently there are several different methods of DA being employed in industrial, military, and academic settings. In order for an application to be considered Decision Analysis, the application must explicitly analyze alternatives for a decision problem using judgmental probabilities and/or subjectively assessed utility/value functions. (Keefer and Kirkwood, 2004) Kirkwood presents the most prevalent application developments in the DA field in the list below.

1. Value Focused Thinking
2. Decision Conferencing
3. Stochastic Trees
4. Development of Computer Software and Related DA tools

Table 1 lists the number of Decision Analysis application articles by area over the time periods of 1970-1989 and 1990-2001 from Kirkwood's research. Not included in this data are applications related to multi-criteria decision-making or the analytical hierarchy process (AHP) (Keefer and Kirkwood, 2004).

Table 1. Decision Analysis Application Articles by Application Area

	1970-1989	**1990-2001**
Energy	**24**	**26**
Bidding (and pricing)	N/A	5
Environmental Risk	3	3
Product and project selection	4	7
Regulation	5	N/A
Site Selection	8	N/A
Strategy	N/A	3
Technology Choice	4	5
Miscellaneous	N/A	3
Manufacturing and Services	**16**	**23**
Budget Allocation	3	N/A
Finance	N/A	2
Product planning	4	5
R&D project selection	N/A	8
Strategy	5	7
Miscellaneous	4	1
Medical	**16**	**5**
Military	**N/A**	**13**
Public Policy	**20**	**13**
Standard Setting	8	N/A
Miscellaneous	12	13
General	**9**	**6**

A particularly significant observation from table 1 is the increased use of DA for project planning and strategy both which relate highly with the purpose of this thesis.

Table 2 illustrates the number of published application articles arranged according to methodology over the time periods of 1970-1989 and 1990-2001 and was also taken directly from Kirkwood's research (Keefer and Kirkwood, 2004).

Table 2 Decision Analysis Application Articles by Methodology

	1970-1989	**1990-2001**
Strategy and/or objectives generation	N/A	42
Problem structuring/formulation	24	34
Decision trees	36	N/A
Probability assessment	15	22
Utility/value assessment	28	28
Communication/facilitation	23	29
Group decision making (issues)	13	12
Implementation	N/A	27

Once again we see a trend towards an increased number of published DA application articles on strategy and/or objective generation, problem structuring and formulation, communication/facilitation, and implementation articles. All of these application areas are addressed within the Value-Focused Thinking Method utilized by this research.

The remainder of the literature review focuses on recent uses of decision analysis in the areas of project selection, construction management, project management, crisis management, and military program management. Of particular interest is the area of project selection. Badri et al. (2001) found that there are thirteen different methods for project selection to include scoring, ranking, decision trees, game theory approach, Delphi Technique, fuzzy logic, analytical hierarchy process, goal programming, analytical hierarchy process in conjunction with goal programming, dynamic programming, linear 0-1 programming, quadratic programming, and non-linear programming (Badri and others, 2001).

From these methods several models for multi-criteria decision-making have been derived. Finally, the literature review concludes with an explanation on why VFT is being explored in this thesis as a strategy for optimizing the prioritization of natural disaster recovery projects.

2.4 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a multi-criteria decision making approach that arranges factors in to a hierarchic structure. The purpose of the hierarchy is to provide an overall view of the issues associated with the decision-problem and to allow decision makers to consider the magnitude of the issues in relation to their level in the hierarchy. In order to construct the hierarchy properly using this method the following steps must be taken:

1. Represent the problem as thoroughly as possible but not so thoroughly as to lose sensitivity.
2. Consider the environment surrounding the problem.
3. Identify the issues or attributes that contribute to the solution.
4. Identify the participants associated with the problem.

The AHP does not require that the hierarchy be complete. This means that issues situated higher in the hierarchy do not have to function as criteria for all of the elements in the levels below it. This is markedly different from the VFT approach that is presented later in chapter 3. The AHP is focused on addressing the scaling of measurements and how to correctly combine the priorities that result from these measurements. AHP utilizes two types of scales; standard and relative.

Examples of standard scales are the inch, pound or temperature scales such as the Fahrenheit scale. When using the AHP, a scale of measurement consists of a set of objects, a set of numbers, and a mapping of objects to the numbers. A tenet of this method is that a carefully designed standard scale can preserve certain numerical relationships in the measurement, or mapping as it is referred to in AHP, of the objects thus providing a baseline for comparative measurements of the same object. A relative scale measures intangible properties such as political clout, love, impressions etc. Relative scales for a property are used to represent subjective understanding. AHP uses paired comparisons to evaluate the hierarchy by taking two elements and evaluating them on a single property without regard for the other elements in the hierarchy. This process is carried out until every element has been paired and compared for all of the properties in the hierarchy. A matrix of pairwise ratios is then created from the evaluation of the element pairs. This results in priority vectors for each object based on it evaluation on a particular element. These priority vectors are then multiplied by the global priorities of the hierarchy criteria to determine the score for each object.

In 1987, G.W. Simpson and J.K. Cochran published a paper titled, An Analytic Approach Prioritizing Construction Projects, in the Civil Engineering Systems Journal, which used the AHP to prioritize an Air Force construction program using Williams Air Force Base (WAFB).

Their AHP hierarchy considered the following attributes when evaluating project alternatives for the USAF:

- **Support Mission** = Does the project directly support the flying mission of the base?
- **Risk Assessment Code** = Does the project have a risk assessment code assigned for a safety, fire or health violation?
- **Energy Conservation** = Does the project demonstrate a cost savings due to energy reduction?
- **Maintain Facility** = Is the project needed to maintain or upgrade an existing facility?
- **Avoid Obsolescence** = Is the project needed to replace an obsolete or outdated system?
- **New Requirement** = Is the project in support of a new requirement as directed by a higher level?
- **Disposal Program** = Is the project involved with the base disposal plan?
- **Environmental** = Is the project needed to correct or improve an environmental concern?
- **Funds Availability** = What type of funding is involved?
- **Cost Scope** = Is an approval level being approached or exceeded?

These attributes are a good representation of what is considered when prioritizing a project list under normal conditions. As you will see in this research, the values that are important to decision makers during a non-disaster period do not always mimic the values that are important during a disaster recovery period (Simpson and Cochran, 1987).

I have expounded on the AHP because it is the basis for the following (2) sections which incorporate modified versions of the AHP in their research applications and is prevalent in construction project election literature.

2.5 Analytical Network Process

The analytical network process (ANP) is a multi-criteria decision-making model (MCDM) that has been developed to address complex decision problems with a network structure where interdependence exists in the model. The analytical techniques used in ANP are based on the more general AHP model.

Cheng and Li's article, Analytic Network Process Applied to Project Selection, published in the *Journal of Construction Engineering and Management* in April 2005 uses ANP to empirically prioritize a set of construction projects by using a five-level project selection model. Their model incorporates both qualitative and quantitative approaches to solving the decision-making problem.

The qualitative steps are (Cheng and Li, 2005):

1. Identify the decision problem.
2. Ensure the decision problem can be solved using ANP.
3. Decompose the unstructured problem into sets of manageable and measurable levels. The top level should be the decision problem with the bottom level being the alternatives.
4. Determine who should be responsible for making the decision.

The qualitative steps are (Cheng and Li, 2005):

1. Set up a quantitative questionnaire for collecting data from decision makers using a nine-point priority scale and pair-wise comparison.
2. Estimate the relative importance between two elements of the elements in each matrix and calculate the eigenvector of each of the developed matrices.
3. Measure the inconsistency of each of matrices using the consistency ratio
4. Place eigenvector of the individual matrices to form the supermatrix.
5. Ensure that the supermatrix is column stochastic and raise the supermatrix to high power until the weights have been converged and remain stable.

Cheng and Li break down the construction project selection problem into five levels. The first level is the decision making problem; the project priority list. The second level includes the primary decision makers, which includes management, the public, and the company board of directors. The third level is composed of six criteria that pertain to the decision makers from level two. These criteria are: (1) operational, (2) managerial, (3) financial, (4) technological, (5) legal, and (6) environmental. The fourth level further breaks down each criterion into measurable units. For example, the operation criterion has a measure called project duration, which is measured in days. The final level of the ANP hierarchy represents the project to be selected, the alternatives.

As in the AHP, paired comparisons are used evaluate the hierarchy by taking two elements and evaluating them on a single property without regard for the other elements in the hierarchy. This process is carried out until every element has been paired and compared for all of the properties in the hierarchy. A matrix of pair-wise ratios is then created from the evaluation of the element pairs.

This results in priority vectors for each object based on it evaluation on a particular element. These priority vectors are then multiplied by the global priorities of the hierarchy criteria to determine the score for each object.

2.6 Fuzzy Set Approach to Project Selection

Fuzzy logic is a technique that enables a computer to emulate the human reasoning process through the creation of a "fuzzy set." A "fuzzy set" is defined mathematically by assigning to each person involved in a decision making process a grade. The larger the grade the greater the member's weight is for making the decision. The fuzzy logic system does not claim global independence or exhaustiveness. Some of the weaknesses of fuzzy logic include incompatibility with other control and decision-making systems that are based on analog or symbolic representations of understandable variables. Furthermore, as the number of individuals in the "fuzzy set" increases, so do the number of rules. The same is true for an increase in the number of overlapping subsets representing each variable quantity. (Machacha and Bhattacharya, 2000)

Machacha and Bhattacharya (2000) researched a fuzzy logic based approach for selecting a new software package for an engineering firm. For simplicity they decided to test only the software's online help capability and the availability of written documentation.

Twenty experts in the engineering firm's decision making process were asked questions based on documentation and help capabilities of certain software packages. The rating criteria used are as follows:

- **<u>Documentation</u>** = {inadequate, adequate, extensive}
- **<u>Help</u>** = {undesirable, acceptable, desirable}

For example, they asked, "What if you think the software could give you 95% online help?" The "fuzzy value" based on scale of 0 to 1 returned was 0.8. This means that the decision maker in question believed that 95% online help capability equated to 80% of the ultimate desirable online help capability. Similar questions are asked to obtain the complete ranges for the help and documentation for all of the fuzzy subsets. After the subsets are defined, rules are established for obtaining the overall rating of a software package. The three rules used in there study included:

1. If a software package has inadequate documentation and undesirable help than rate it = worst
2. If a software package has adequate documentation and acceptable help than rate it= good
3. If a software package has extensive documentation and desirable help rate it = best

Finally, a fuzzy association matrix (FAM) is evaluated based on the two variables, help and documentation, by using an algorithm programmed in the Qbasic software package is to determine the best software package choice.

The fuzzy logic based method is an alternative based approach to decision-making. It uses human inferences to provide an output based on relatively weighted variables. One of the strengths of this method is that it attempts to obtain the desires and sentiment of the experts in the decision-making process and arrange them such that a computer can mimic the human decision making process using an algorithm. However, since the system is based on relative weights, if the experts change, the entire process needs to be repeated. Finally, when considering a problem with a high number of decision variables the process of creating rules and evaluating the FAM could become cumbersome. This method lends itself to decision-making problems that have a high degree of uncertainty but a fairly small number of decision variables.

2.7 Need-Based Project Prioritization

The Kansas Department of Transportation (KDOT) has been utilizing a Needs-Based methodology for highway project prioritization since 1979. Highway repair, maintenance, and expansion projects represent major capital investments that insure the viability of billions of dollars of infrastructure assets. These projects represented 45% of the 4.4 Billion dollar Kansas State Highway Program budget between 1989-1999. The KDOT model for prioritizing projects has been repeatedly validated by the Kansas State Legislature several times and most recently in 2004. A 94% approval rating for the model was obtained through a survey of KDOT officials. (Kulkarni and others, 2004)

The Needs-Base Project Prioritization Model (NBPPM) developed by KDOT is a multi-criteria decision analysis tool adapted from the work on measurable value functions of Dyer and Sarin (1979) and Keeney (1980).

The process used to develop the NBPPM is as follows:

1. Define the objectives, attributes, relative weights and adjustment factors
2. Develop a multi-attribute need function
3. Develop a database of attributes and adjustment factors
4. Develop a computer program to facilitate the calculation of need scores
5. Select candidates projects based on overall need score

The need function used is presented below:

$V(x_1, x_2, \ldots\ldots x_n) = \sum k_i v_i(x_i)$

Where $v_i(x_i)$ = single attribute need function (SAF) over the set of relevant attributes Xi;

k_i = the relative weight of attribute X_i; and $\sum k_i = 1$

The overall need function is scaled from 0 to 1 where the higher the score on a measure the greater the need. In this method, several single-attribute needs functions are developed and in many cases adjustment factors are applied to account for mitigating circumstances. An example of the use of an adjustment factor is the measurement of an attribute called accident potential. Let’s say that the alternative (project) being scored is a two-lane road with narrow lanes and shoulder. This alternative would score very high (high potential for accident). However, if mitigating circumstances such as low traffic volume were considered using an adjustment factor (a_{ij}) (where a_{ij} represents the jth adjustment factor for the ith attribute) the score of an alternative based on its potential for an accident by considering the traffic volume would be lessened.

The adjusted single attribute need function is presented below:

Adjusted $v_i(x_i) = [u(a_{i1}) * u(a_{i2}) \ldots\ldots u(a_{in})] * v_i(x_i)$

Where $u(a_{ij})$ = the normalized adjustment factor (Kulkarni and others, 2004)

Finally, the individual score for an attribute is given by:

$X_1 = k1 * v_1(x_1) *[u(a_{11}) * u(a_{12}) \ldots\ldots u(a_{1n})]$

It should be noted that the adjustment factors themselves are merely single attribute functions (SAF) themselves. So in the previous example what you have is a SAF for "traffic volume" adjusting the SAF for "potential for accident". This process could be potentially confusing to a decision maker in my opinion. Conversely, in the VFT process, the objectives in the hierarchy are deconstructed until we reach measurable objectives that have one single dimension value function (SDVF). In VFT, "potential for accident" would have been an objective without a SAF and it would be measured by several SDVF such as "traffic volume". Additionally, VFT uses direct weighting in its hierarchy where the NBPPM utilizes a relative weighting scheme. Again, decision makers do not as easily understand making changes to a relative weighting system when compared to a directly weighted model.

2.8 Goal Programming

Badri and his colleagues (2001) developed a 0-1 goal-programming model for project selection to determine the optimal set of information systems (IS) projects for the Dubai Medical Center in the United Arabic Emirates. The system uses LINDO software and the Lexico –optimization function to select the set of projects that maximizes the benefit/cost ratio, minimizes risk, maximizes user/decision maker satisfaction, minimizes completion time, and minimizes training time.

The 0-1 goal programming method is very basic in nature. This model is based on a binomial Pareto preference linear programming method with multiple objectives. The objective of this approach is to select the optimal set of projects that minimizes the deviations between the actual decision variable scores and their targeted goals. The steps for the creation of this type of model as described by Badri and his colleagues (1999) are presented below:

1. Define the objective of the model
2. Determine and define the decision variables
3. Develop the linear constraints complete with targeted values
4. Develop the multiple objective function
5. Determine the preference structure for evaluating the multiple objective function
6. Obtain the raw data scores for each project on each decision variable
7. Program model in linear programming software package and evaluate alternatives based on model preferences and constraints

(Badri and others, 2001)

The strength of this model is that it includes all of the constraints relevant to selecting the optimal set of projects. These constraints are based on the decision variables that have been deemed important by the decision makers responsible for the IS program. Also, the formulation of the objective function and scoring of the constraints is easily understood by the decision maker. However, since the model is not weighted, it relies solely on Pareto preference in determining which decision variables have more impact on the final selection of projects. In other words, you know only that for instance b/c ratio is more important than user preference, but not how much more important. This makes it hard to adjust the model to more accurately reflect the decision maker's desired outcome.

2.9 Decision Support Model

Igal Shohet and Eldad Perelstein (2004) developed a multifaceted building maintenance management model that focused on solving the problem of resource allocation in rehabilitation projects. Their model takes a different approach to decision making than most of the previously mentioned techniques because it first focuses on eliminating unfeasible solutions and then uses a methodology for identifying three to five near-optimal solutions. The model can be implemented based on a maximization of benefits and a fixed budget or based on a minimization of cost while emphasizing the performance of the buildings.

Shohet and Perelstein (2004) present the three general stages for executing this model below:

1. A physical-functional survey of the existing condition of the building in the light of its future purposes;
2. The systematic creation, on the basis of previous stage, of three to five alternatives for rehabilitation, renovation or construction; and
3. Development of a quantitative model for resource allocation and using it to maximize the overall expected benefit while adhering to the constraints on the extent of investments, the annual maintenance costs, and the required service life.

Their model is basically a linear programming optimization program that uses dynamic programming to determine the optimal solution based on multiple objective functions with multiple constraints. Their model considers the following constraints:

- **C** = Construction and rehabilitation costs
- **F** = Performance Level of the building measured by Building Performance Indicator (BPI)
- $\mathbf{L_{min}}$ = Minimum Required Service Life
- $\mathbf{L_{max}}$ = Maximum Desired Service Life
- **M** = Total Annual Maintenance Costs
- **D** = Duration of Implementation; which is basically time to construct or complete rehab

Additionally, this model suggests that the degree of importance or urgency for a project should be considered and suggests creating a coefficient factor.

(Shohet and Perelstein, 2004)

However, the authors are very ambiguous on how to develop this coefficient except to say that it is the product of the performance scores of a project and the weight given to that project based on the decision makers preferences. In VFT, we value the decision maker's preferences so much in the decision-making process that we focus a majority of our effort on soliciting there values, the degree of importance of these values to the decision maker, and finally an objective and repeatable way to measure these values.

This model takes a holistic approach by looking at a wide range of factors such as maintenance costs, construction costs, life cycles, and project duration to obtain a decision as to which of three to five predetermined alternatives to choose from.

A shortcoming of this method is that it is computationally intensive and therefore not easily manipulated for a circumstance that requires the user to consider a large number of alternatives simultaneously.

To illustrate this problem, the methodology of choosing the alternatives requires the user to evaluate each alternative based on the following six quantitative criteria (Shohet and Perelstein, 2004):

1. The amount of initial capital resources
2. The level of performance to be achieved as a result of implementing the alternative
3. The economic service life of a particular alternative
4. The predicted annual maintenance costs
5. The life cycle costs, and
6. The duration of rehabilitation/rebuilding work

Additional qualitative criteria such as required logistics, urgency, and safety conditions should also considered prior to choosing the near-optimal solution set of three to five alternatives. As you can see, this method is very thorough but also time and labor intensive. In the chaos of a post-disaster recovery operations, time and labor resources are scarce and this precludes this model form being used to answer our research questions.

2.10 USARMY and USAF Project Prioritization Mechanisms

The following section discusses the two primary methods currently used by the USARMY and the USAF to prioritize restoration projects. Restoration projects include repairing or replacing facilities and infrastructure systems due to inadequate recurring maintenance and catastrophes or other causes (Department of the Air Force AF 32-1032, 2003:20). The restoration and maintenance funding category is the category that most of our natural disaster recovery projects would fall under.

The U.S. Army Installation Decision Support Model (IDSM) and the U.S. Army Builder Database are decision-making tools for the Army senior leadership the gives them the ability to develop infrastructure management goals with a prioritization system. ISDM encapsulates the facility condition status and options for facility requirements to allow projects to be selected based on those requirements. ISDM also describes how each facility project impacts management goals and selects the optimal projects to fund. Interestingly, this model does not allow each stakeholder to defend their facility project, as is the case the USAF’s Facility Working Board (FWB) system.

Instead, it provides objective guidance using computer support for selecting infrastructure projects based on Army senior leadership goals. The advantages of the IDSM model is that it provides an objective process for Army leadership to prioritize projects for funding decisions as well as provide immediate feedback on the impact of those decisions. However, Army condition assessments are extensive and the overall facility condition is based on the rating of each subsystem (Tenorio, 2005). (Lind, 2006)

The Army also uses an expedient infrastructure assessment software tool called BUILDER™ developed by the U.S. Army Construction Engineering Research Laboratories (USACERL) in conjunction with the University of Illinois at Urbana-Champaign (UIUC). BUILDER™ is a software package that is a multi-functional database used to prioritize facility projects based on the facility's current condition, funding requirements, and life-cycle costs. BUILDER™ is very flexible and can provide a GIS interface, a link to asset management and maintenance software called MAXIMO, conductivity to computer aided drafting files, and long-range planning capabilities. This tool is commercially available through UIUC and should be considered for long-range infrastructure sustainment, restoration, and maintenance project planning. Currently, BUILDER™ does not offer a disaster management or recovery module as it is configured to aid in maintenance rather than reconstruction. (ERDC, 2006).

The USAF leadership relies on the Facility Investment Metric (FIM) to prioritize its restoration and modernization projects. The FIM includes only R&M projects that are funded through Operations and Maintenance (O&M) dollars. It does not include sustainment projects, designs, or studies or other funding accounts such as Military

Family Housing, Defense Commissary Agency, or Environmental (Department of the Air Force AFI32-1032, 2003:37).

The FIM prioritizes projects based on their facility class and impact on the mission. Facilities are grouped into the eleven main classes below:

1. Operations and Training
2. Mobility
3. Maintenance and Production
4. Research Development
5. Training and Education
6. Supply
7. Medical
8. Administrative
9. Community Support
10. Military Family Housing & Dormitories
11. Utilities and Ground Improvements

The impact to the mission is based on the following three categories:

1. <u>Critical</u>

    - Significant loss of installation/tenant mission capability and frequent mission interruptions
    - Work-arounds to prevent significant installation/tenant mission disruption and degradation are continuously required
    - Risk Assessment Code (RAC) I
    - Fire Safety Deficiency Code (FSDC) I

2. Degraded

    - Limited loss of installation/tenant mission capability
    - Work-arounds to prevent limited installation/tenant mission disruption and degradation are often required.
    - RAC II or III
    - FSDC II or III

3. Essential

    - Marginal or little adverse impact to installation/tenant mission
    - Some work-arounds may be required
    - Projects to prevent obsolescence
    - Any requirement that does not meet Critical or Degraded criteria
    - Included in this rating category are requirements that would (1) improve the quality of life in work and living centers, (2) improve productivity and (3) lead to reduced operating costs (i.e., some facility consolidation and energy conservation initiatives)

Facilities and infrastructure projects are prioritized at the Facility Working Board (FWB). The FWB uses the Facility Investment Metric (FIM) requirements matrix which is a tool that shows the facility class and impact rating for a particular project in the rank order of class importance (Tenorio, 2005).

	IMPACT RATINGS		
Facility Class	**Critical**	**Degraded**	**Essential**
Operations and Training			
Mobility			
Maintenance and Production			
RDT&E			
Supply			
Medical			
Administrative			
Community Support			
MFH			
Dormitories			
Utilities and Ground Improvements			

Figure 2 Facilities Investment Metric Matrix
(Department of the Air Force AFI 32-1032, 2003:38)

Additionally, each organization on an installation has some political influence on where their particular projects finally get ranked on the priority list. This is unlike the Army's ISDM model where subjective political influence has been factored out. The FIM and FWB processes seem to be adequate at some installations and inadequate at others based on feedback from contemporaries in the Civil Engineering career field. But, at all locations the FWB is an iterative process that takes months to accomplish and is heavily reliant on information from the FIM, which is generated annually and very time and labor intensive to complete.

After a natural disaster or terrorist attack occurs, time crunches and public pressure to restore the environment back as soon as possible are tremendous and real. Neither the USARMY nor the USAF project prioritization systems are flexible or expedient enough for such a task. The need for an expedient and objective strategy for prioritizing projects following a disaster is at the forefront of this thesis.

2.11 Prioritization of Schedule Dependencies in Hurricane Recovery

A study was conducted by the Center for Risk Management of Engineering Systems and the Dept. of Systems Engineering of the University of Virginia in 2005 to determine schedule dependencies linked to transportation agencies before and after hurricane recovery. The study used over 500 personal interviews of various state, federal and local agencies directly involved in hurricane recovery efforts. The interviews asked specific questions to identify scenarios in which interactions between the agencies and their transportation agency counterparts were causing delays in the recovery or planning efforts. The study identified 48 different scenarios that were then classified into 10 functional units. A chart directly adapted from this study is depicted on the proceeding page:

Table 3. Number and Percentage of Dependency Scenarios Collected that are Associated with Each Functional Unit within State Transportation Agency (Lambert, 2002)

Unit Type	Number of Cases	Percent of Total
Administration	3	6.2
Environmental, Regulatory Affairs	2	4.2
Equipment	4	8.3
Finance	2	4.2
Information Management	15	31.3
Legal/Authorization	2	4.2
Materials	2	4.2
Operations	11	22.9
Personnel	3	6.2
Structure	4	8.3
Total	48	100

The results indicate that the information management function of the transportation agencies represented 31.3% of the total schedule dependencies followed by the operations function with 22.9%. The information functional is responsible for providing accurate information regarding road status, evacuations, environmental requirements, hazardous material and other pertinent information. The operations unit includes responsibilities of all on-site field units and maintenance units. The next two highest categories were the equipment and structure functions at 8.3% of the dependencies each. These functions provide the equipment needed for clean-up and repair of infrastructure. These four main functions are responsible for 69.8% of the schedule dependencies and they have corresponding functionals in an Air Force civil engineering (CE) squadron. The SRC is the hub for disaster planning and recovery information and is heavily manned with civil engineer squadron personnel. The on-site maintenance capability and structure repair capability is also provided or coordinated within CE. During the post-disaster recovery CE is also the focal point for construction and readiness information management, equipment, structure repair, and personnel to aid the recovery effort.

2.12 Disaster Prediction Models

While reviewing the background literature for this thesis, two crisis management computer simulation models were discovered. The first was the commercially developed Consequences Assessment Tool Sets (CATS) from the SAIC Corporation. The second model was the Hurricane Loss Projection Model (HLPM) developed by the State of Florida in conjunction with the National Oceanic and Atmospheric Agency (NOAA), Florida State University, Florida International University, and the University of Miami.

CATS is a computer simulation model that can estimate hazards, casualties, and damages that are the result of natural phenomena, such as hurricanes and earthquakes, or man-made disasters, such as terrorist attacks, weapons of mass destruction, or industrial accidents. The innovation that CATS brought to the crisis management arena was conductivity between databases, ground-based communications, and satellite communications networks. This in turn provided a user-friendly Geographical Information Systems (GIS) interface with available real-time decision making information to the users in the Emergency Operations Center (EOC). CATS is widely accepted worldwide with users in both the military and civil emergency management communities (SAIC, 1999).

The HLPM utilizes atmospheric science, engineering, and financial/actuarial components to predict damages to insured residential property following a hurricane. HLPM can model several different simulated storms while varying their life cycle, intensity, and threat area in order to predict the future damages of a real storm.

Information generated by the storm simulation component of the model is then provided to the engineering and loss models to predict damages to insured residential structures and the average expected annual loss on dollars. (Powell, 2005)

Theses models are an important step forward in helping the world's crisis managers effectively predict the type of damage that can be caused by a disaster event as well as the monetary requirements that will be necessary during recovery. This thesis does not attempt to predict damage caused by natural or manmade disasters. Instead, this thesis concentrates on the strategic prioritization of recovery projects in an effort to streamline the process and optimize the value obtained from these projects.

2.13 Integer Programming (Knapsack)

Initially, it is very likely that financial resources for recovery will be limited. In general, the Air Force will fully fund a recovery program but not release the entire amount at one time. The reason for the time-phased release of recovery funds is due to the fact that contingency funds must be available for other future events. An example of this is Hurricane Dennis that struck the gulf coast of Florida and Alabama in August 2005. This storm landed as a category two with the center of the eye located approximately 20 miles west of Hurlburt Field, Florida. The damage to the base was estimated at 11 million dollars. An initial drop of $1 million was allocated to fund the most pressing projects with the remainder of the funding to be allocated after the hurricane season had ended. Just one month later, hurricane Katrina devastated the city of New Orleans and leveled Kessler AFB in Mississippi. Subsequently, all remaining contingency funds were being redirected to those area, and rightly so.

The dilemma that disaster recovery project managers had a Hurlburt Field was to answer the question: "What projects should be funded with the limited amount of financial resources available to us at this time?" A linear programming knapsack program will be used to aid the decision makers in answering that question. A integer-programming knapsack program is used in situation where there are multiple, and sometimes conflicting, objectives to solve problems such as project selection, capital investment, and budget control (Cho and Kim, 1997). A 0-1 knapsack problem is one that restricts number of each item, in our case a particular project, to zero or one.

A 0-1 knapsack problem can be formulated as follows:

Maximize

$$\sum_{j=1}^{n} v_j x_j$$

Subject to:

$$\sum_{j=1}^{n} c_j x_j \leq F$$

$$x_j = 0 \text{ or } 1 \qquad j = 1,\ldots,n$$

Where n= number of item projects, x_1 through x_n. Each item x_j has a value v_j = the value score and a dollar value c_j. The maximum dollar value that we can fund is F =*construction budget*. For the purposes of this thesis the "Solver" add-in function of Microsoft Excel will be utilized exclusively. Defining the p_j using a proven DA technique such as VFT is the focus of this research.

2.14 Why VFT?

Throughout this exhaustive literature review I have not been able to locate a reviewed publication that details a DA-based methodology for prioritizing reconstruction projects following disasters. Furthermore, after reviewing the current crisis management literature, there seems to be a lack of research in the general area of disaster recovery strategies. Much of the research I have uncovered has been in the areas of project selection. However, most of these methods have been alternative based. Several theses have been done using VFT for selecting or prioritizing projects, but I have found none that specifically address the problem of prioritizing recovery projects following disasters. It is for these reasons and more that I am conducting this research using VFT.

III. Methodology

3.1 Overview

Prioritizing a disaster recovery construction program is often difficult because of competition for scarce resources, i.e. funding, contractors, materials, time and labor. Internal and external pressure to restore infrastructure and operations back to their pre-disaster status may cloud a decision–making process. Subsequently, the enormous effort required to discern which projects provide the greatest value to the recovery process is at the core of the problem. What is needed is a strategic approach that aids the decision maker in this endeavor. This particular problem is by nature a perfect candidate for the multiple-objective decision analysis process Value-Focused Thinking (VFT).

VFT is a methodology for multi-criteria decision analysis that is rooted in the concept that the most important elements in a decision are the values of the leadership. VFT relies on a hierarchical value structure and measures that are used to evaluate current and newly formed alternatives. The processes of building a value hierarchy, creating measures, weighting the hierarchy, developing single dimension value functions, and evaluating alternatives as prescribed by VFT provides the leadership an introspective view of how their values determine the ranking of the alternatives.

This chapter presents the process for creating the VFT model to demonstrate a practical application for the VFT process that will enhance the USAF's ability to recover bases following a disaster. The methodology as presented can be repeated for any Air Force installation, but can also be adapted for other organizations, public or private, that are tasked with the care of vital infrastructure assets.

Figure 3 illustrates the 10-step VFT process that has been adapted from the work of Shoviak (2001). Steps 1 through 7 will be discussed in this chapter.

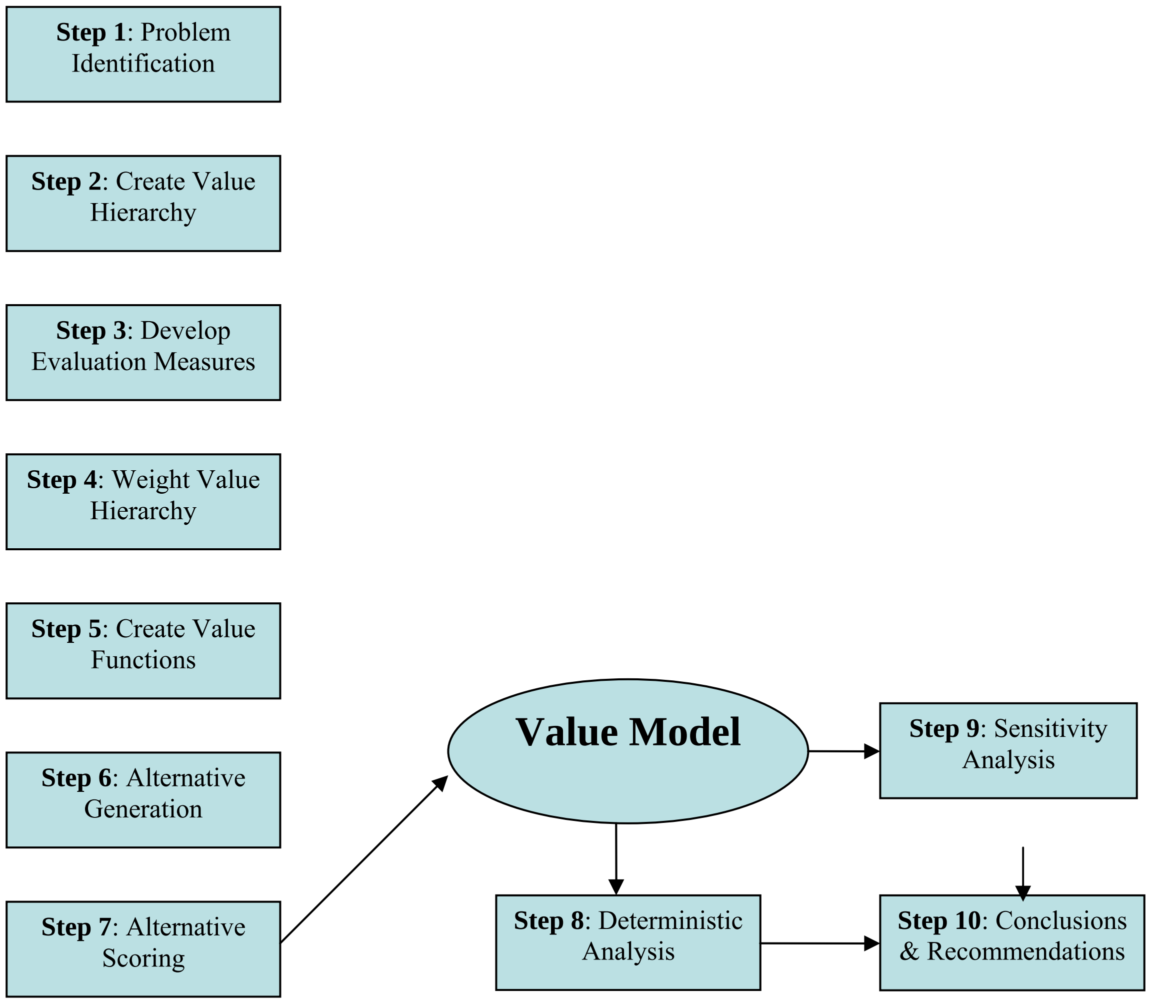


Figure 3. Value-Focused Thinking 10-Step Process (Shoviak, 2001)

3.2 Problem Identification

The first step in solving any decision-making problem is to identify the problem itself. This research addresses the problem of determining what an Air Force Base Commander values when prioritizing a natural disaster reconstruction program so that an objectively prioritized reconstruction program can be developed. Secondly, this research attempts to determine how the Air Force can optimally allocate its financial resources during a recovery effort through the use of a knapsack integer program.

3.3 Constructing the Value Hierarchy

Value hierarchies are constructed for several reasons. One reason is to guide the collection of information by specifying the values that are important to a decision maker. Another reason is to help identify and construct alternatives. By eliciting a leader's wants and needs in terms of values, alternatives not previously considered may immerge. The facilitation of communications is also enhanced by a value hierarchy because the stakeholders in the decision can clearly see the reasons for the decision. Finally, the evaluation of alternatives can be accomplished by utilizing the framework of the value hierarchy coupled with its mathematical functions to rank alternatives (Kirkwood, 1997). Ralph Keeney has acknowledged the numerous benefits of using value focused hierarchies as decision-making tools. These benefits are presented in figure 4.

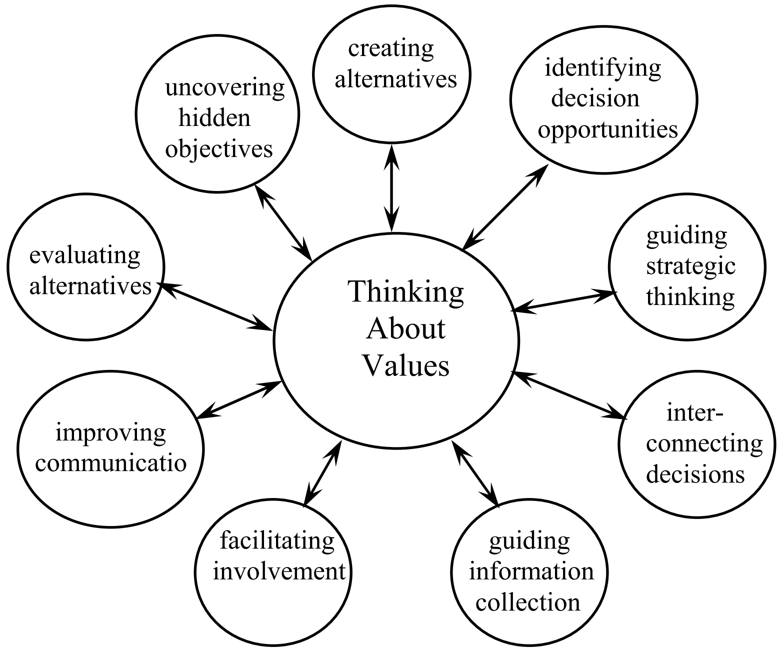


Figure 4 Kenney's reasons for a VFT approach (Keeney, 1992)

The two approaches for developing a value hierarchy are the "top-down" or "objective-driven" approach and the "bottom-up" or "alternatives-driven" approach. The use of either depends on whether or not the alternatives are available at the time the hierarchy is being developed. In our case, the alternatives are not known because a disaster event has not yet occurred for us to evaluate. Therefore, the "top-down" approach of the VFT process is applicable and preferred.

The sources of information for the values and measures used in this research were obtained by a combination of reviewing relevant literature and investigative empiricism, or in other words, by simply asking the stakeholders themselves. The method used to solicit the values for the hierarchy was a brainstorming exercise. First, stakeholders from all levels of the civil engineering decision-making process at a Hurlburt Field AFB, which has a long history of natural disaster recovery, were invited to a value-solicitation workshop.

Each member was provided a background briefing of VFT and the thesis problem. A copy of the background briefing can be found in Appendix B. The group was asked to brainstorm the values they felt were important when considering which projects should be prioritized above others in a disaster recovery construction program. The MAJCOM Civil Engineer, a USAF Colonel, chaired the decision-making team composed of military, civilian and contracted personnel from all levels of civil engineering leadership (See Appendix B for a detailed list). This team was free to voice their opinions on the values that were being brainstormed in an open environment. Each value that was suggested was written down but no person was attributed to it. This is important in creating an open forum to generate as many possible values from all levels of leadership. In the end, the MAJCOM CE had final say on whether a value was pertinent. At the conclusion of the brainstorming exercise, the group was instructed to discuss the values and determine which particular values were the most important to the decision-making process. Once selected, those values would adorn the first tier (Top) of the value hierarchy which is presented in Figure 5. A properly organized value structure is hierarchical. So, as you proceed from the top tier to the bottom tier, a more detailed understanding of how to determine the top priority project becomes evident. Table 4 provides definitions for each of the values in the first tier of the hierarchy.

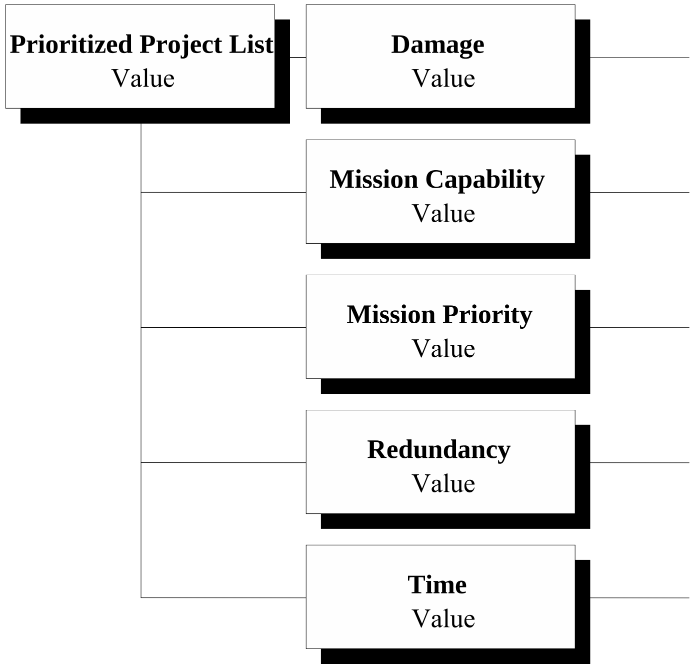


Figure 5. The Top Tier of the Value Hierarchy

Table 4. Definitions of the Top Tier Values

Damage	Type and amount of damage that a repair project addresses
Mission Priority	The rank of a facility, network, or structure on the Mission Priority List (MPL) that a repair project addresses
Mission Capability	Percentage of the base mission restored by a repair project
Redundancy	The availability of alternate facilities, networks, or structures for damage addressed by a repair project
Time	The amount of time needed to contract, deliver materials, and construct a particular repair project and the number of successor projects of a particular repair project

The group immediately determined that Mission Priority, Mission Capability, Damage, Redundancy, and Time were first tier values. The redundancy value was agreed on as a first tier value because any project that addresses damage to a facility, network, or structure that has alternate facilities, networks, or structures already available should be downgraded when compared to a similar project that has no alternative for relocating or rerouting its damaged function. Time was defined to include all aspects of the construction project that have a direct effect on the time it takes to deliver a completed reconstruction project. It is assumed that projects that require more time must be initiated earlier on in the recovery process. Time should play a significant role in determining the rank of recovery projects and this was the justification for its placement in the first tier.

With the top tier identified, the group was instructed to place the remaining values from the brainstorming list under the appropriated first tier values. For instance, under Damage the group intuitively placed the values Cosmetic, Interior, Infrastructure, and Structural. Following some more discussion they eventually placed the value of Safety under the Damage value. This choice was decided after debating over the definition of the Safety value. Safety was defined as the degradation of a facility, network, or structure has to meet safety and fire codes, which can easily be construed as damage. Table 5 succinctly defines each damage branch value.

Table 5. Definitions of the Damage Branch Values

Cosmetic	Cosmetic damage addressed by a recovery project
Interior	Interior damage addressed by a recovery project
Infrastructure	Infrastructure damage addressed by a recovery project
Safety	Safety or fire code deficiency addressed by a recovery project
Structural	Structural damage addressed by a recovery project

Mission Capability, Mission Priority, and Redundancy did not have a values place under them, and for good reason. These values did not require any further refinement in order to develop their evaluation measures; however, the Time value did acquire four values for its branch. Three of these values - Contractor Availability, Material Availability, and Project Duration - are directly related to how fast a particular project can be completed.

The Predecessor value is not as insightful. The completion of a predecessor project directly effects the completion date of its successor project(s) and therefore is justified as a Time branch value. See Table 6 for the definitions of the time branch values and figure 6 for the value hierarchy completed through the second tier. Notice that the measures for Mission Capability, Mission Priority, and Redundancy have already been identified in figure 6. These will be discussed in more detail in section 3.4 of this chapter.

Table 6. Definitions of the Time Branch Values

Contractor Availability	The availability of contractors to perform the work specific to a particular recovery project
Material Availability	The availability of material needed to perform work specific to a particular recovery project
Predecessor Projects	How many successor projects a particular recovery project has
Project Duration	The estimated construction time of a recovery project

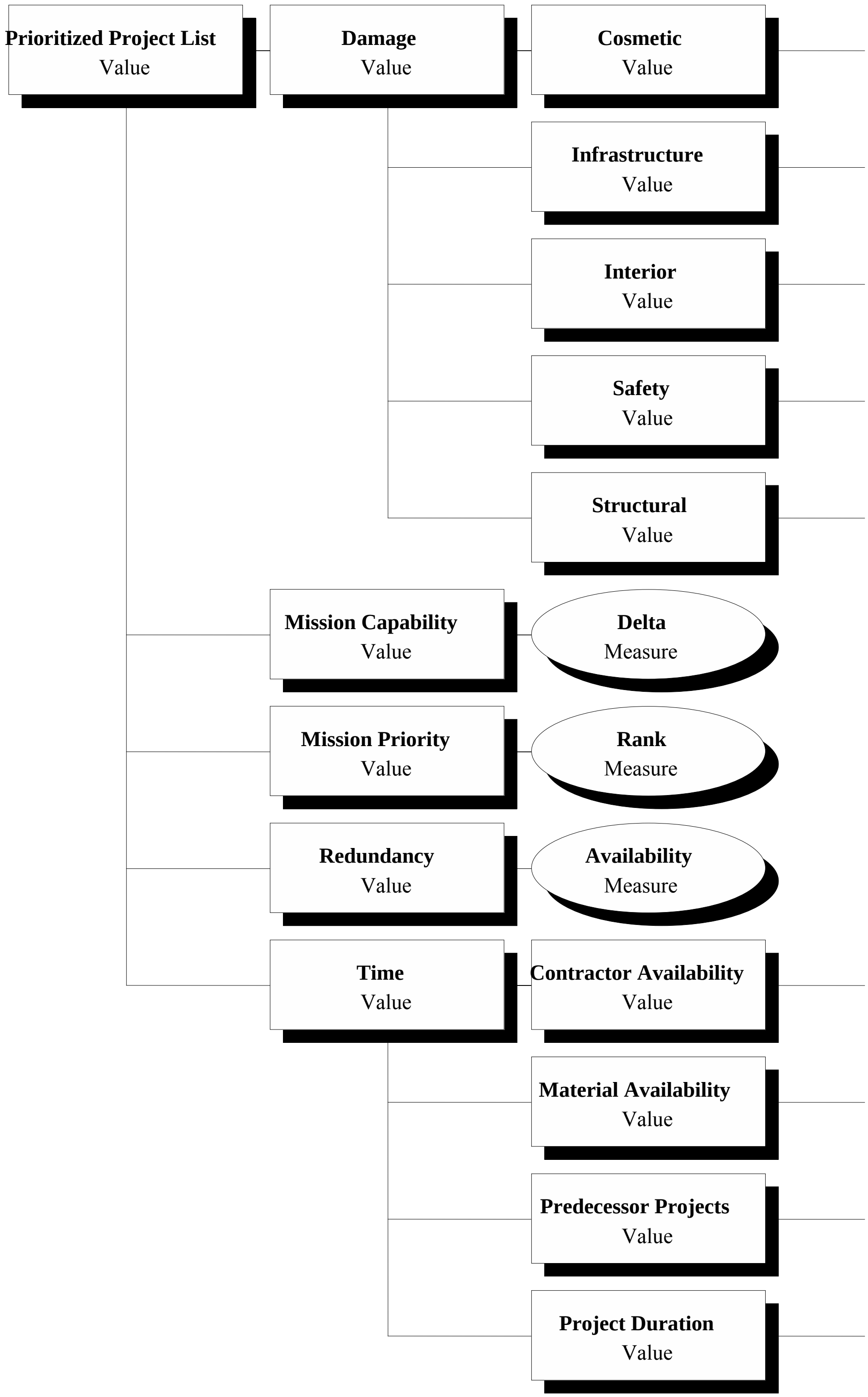


Figure 6. The Value Hierarchy through the Second Tier

With the second tier now fully established, the group decided to further clarify the Infrastructure value by adding a branch. Since infrastructure damage is generally reported based on its type, the group thought it prudent to expand the infrastructure value as illustrated in Table 7.

Table 7. Definitions of the Infrastructure Tier Values

Electric	The amount and type of electrical infrastructure damage a repair project addresses
Natural Gas	The amount and type of natural gas infrastructure damage a repair project addresses
POL	The amount and type of POL infrastructure damage a repair project addresses
Sewage	The amount and type of sewage infrastructure damage a repair project addresses to include storm and sanitary sewers
Transportation	The amount and type of transportation infrastructure damage a repair project addresses
Water	The amount and type of water infrastructure damage a repair project addresses

The group still had some values from the brainstorming session that remained, but decided that these values were extraneous based on the following desirable properties of value hierarchy proposed by Kirkwood:

1. Completeness – The values in each tier of the hierarchy must adequately cover all concerns necessary to evaluate the overall objective of the decision.
2. Nonredundancy – No two values in the same tier of the hierarchy should overlap.
3. Decomposability – No score for a value in the lowest tier is influenced by the score of another value in the lowest tier. In other words, each evaluation measure receives a score that is independent of another evaluation measure.
4. Operability – An operable value hierarchy is one that is understood by the person who uses it.
5. Small size – A hierarchy that is as small as possible while remaining complete is preferred due to the efficiencies gained in alternative measurement and communication. (Kirkwood, 1997)

The two properties that our decision maker was most concerned with were small size and completeness. These two properties seem to conflict, but are very important to our problem. The leaders did not want to create a hierarchy that would require too many resources to evaluate, but at the same time they were aware of the importance of including all of the important considerations in prioritizing disaster recovery. In the end, the decision maker settled on the following value hierarchy seen in figure 7.

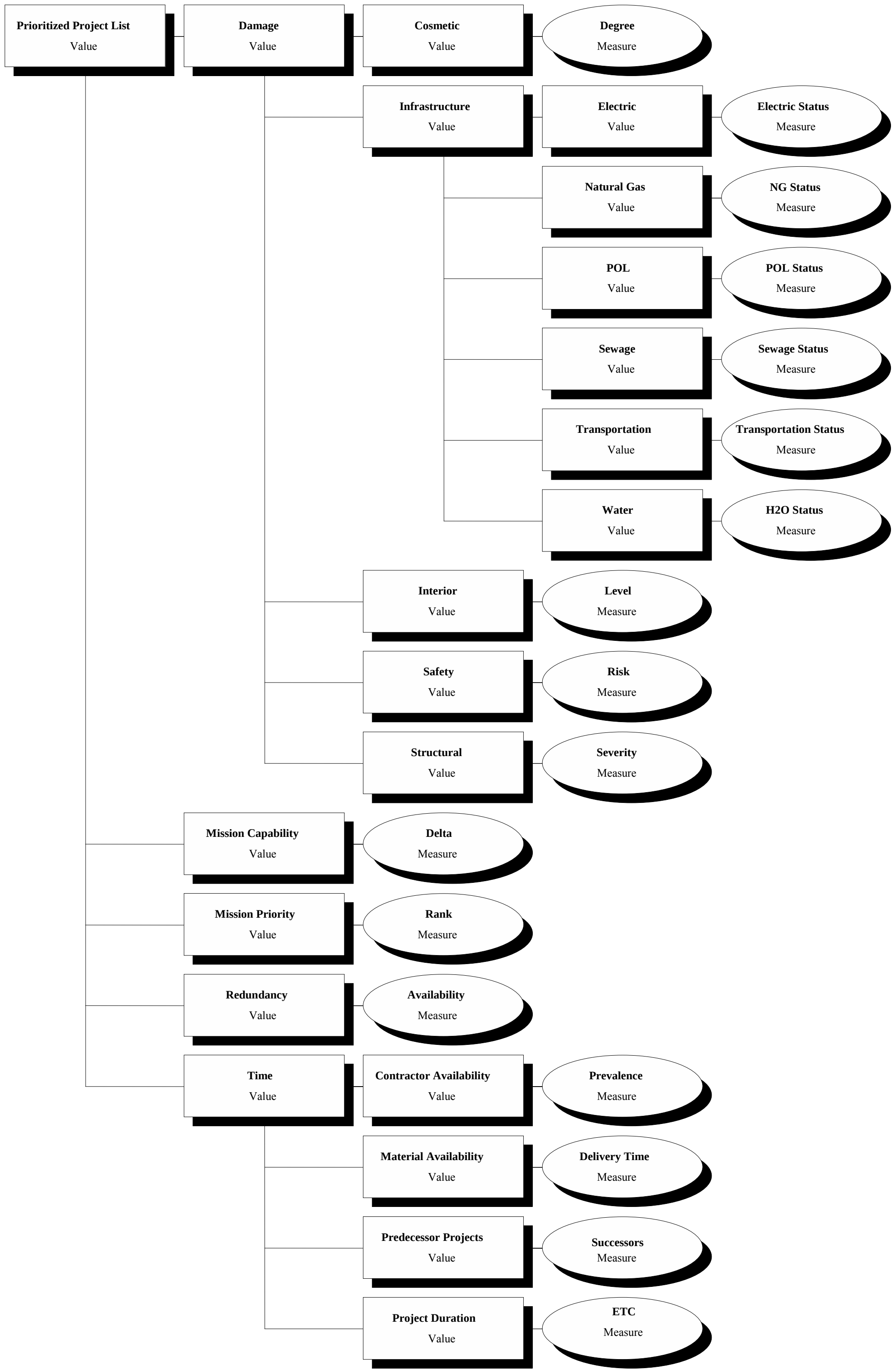


Figure 7. The Complete Value Hierarchy

3.4 Developing the Evaluation Measures

The development of the evaluation measures was initially discussed at the value solicitation workshop. Table 8 displays each evaluation measure along with its respective definition.

Table 8. Description of Evaluation Measures

Degree	The measure of the degree of cosmetic damage addressed by a particular reconstruction project
Electric Status	The measure that determines whether a project addresses electrical damage that is systemic, localized, temporarily repaired, or nonexistent
NG Status	The measure that determines whether a project addresses natural gas damage that is systemic, localized, temporarily repaired, or nonexistent
POL Status	The measure that determines whether a project addresses POL damage that is systemic, localized, temporarily repaired, or nonexistent
Sewage Status	The measure that determines sewage damage addressed by a project (storm/sanitary) as systemic, localized, temporarily repaired, or nonexistent
Transportation Status	The measure that determines whether a project addresses transportation damage that is systemic, localized, temporarily repaired, or nonexistent
H2O Status	The measure that determines whether a project addresses water resource damage that is systemic, localized, temporarily repaired, or nonexistent
Level	The measure of the level of interior damage addressed by a particular reconstruction project
Risk	The measurement of the estimated risk to human life associated with not immediately undertaking a particular project; high, moderate, low
Severity	The measure of the severity of the structural damage addressed in a particular reconstruction project; catastrophic, moderate, nominal, no structural damage
Delta	The measure of the percentage of mission capability brought back on line by the completion of a particular reconstruction project
Rank	The direct numerical position of a particular project on the mission priority list with the higher value being given to the higher position
Availability	The measure of the number of facilities, networks, or structures available as alternatives for a project
Prevalence	Measures the number of contractors available on the market to complete a particular reconstruction project
Delivery Time	The material delivery time measured in weeks for a particular project
Successors	The number of successor projects of a particular recovery project
ETC	A direct measure of the days needed to complete a particular reconstruction project called the estimated time to complete

If you quickly observe the first tier measures you may be inclined to view Delta and Rank as dependent on one another since the both appear to be measuring a project's contribution to restoring the mission. On the contrary, they are both independent of each other. Delta measures a projects contribution to the recovery of the base mission in terms of percentage restored where as Rank refers to where a project resides on the predetermined Facility Priority List (FPL). Since infrastructure networks such as water distribution, lift stations, electrical circuits etc., are not included in the FPL, an infrastructure project takes the rank of the highest facility it services. Additionally, a facility or infrastructure network restoration project that has successor projects will take the rank of the highest ranked facility among the successor projects. This insures that these projects are properly accounted for with respect to rank. Here is a scenario that explains how Rank and Delta are independent of each other. A recovery project on the number one ranked facility, usually the runway at most bases, may be a project to re-stripe the parking apron which has faded due to ponding water. Since these markings are faded, controllers on the ground are required to guide the aircraft in over a longer distance causing a 2% degradation of the mission and hence, a raw score of 1 for Rank and 2% for Delta. Another recovery project may be to totally replace an Aircraft Wash Rack. The Wash Rack may rank in at 10 on the FPL but at the same time since Aircraft now must find timely and costly alternatives for corrosion control the mission may be degraded by 30%. If only Rank is considered the airfield will score higher with all other measured considered equally. But when you take into account both the importance of the facility to the mission (Rank) and the percentage of the mission brought back by the completion of a particular project (Delta), the Aircraft Wash Rack is the clear winner.

Due to time and resource constraints, the single dimension value function (SDVF) of each measure could not be determined with full-group participation. It was subsequently decided that the group chair, the MAJCOM CE, would be the sole decision maker for the remainder of the research. The methods used to create the SDVFs for each measure are presented in section 3.6. The MS Power Point presentations that document the unabridged evaluation measure definitions and SDVF creation process are included in Appendix B.

3.5 Weighting the Value Hierarchy

A value hierarchy is weighted so that the decision maker's perception of how important each value is to the decision-making process is reflected in the model. Weighting is presented globally or locally. The local weighting system presents the weights of values in relation to the specific branch of a tier in which they reside. The values in that specific branch must collectively sum to one. Local weighting is useful when soliciting weights for values from the decision maker because you can directly input the weights into the hierarchy. The global weighting system presents the weights of values in relation to the same branch across the entire hierarchy. When using global weights, the sum of all the weights in a branch must add to one. Global weighting is useful because it provides the decision maker insight into how each value contributes to the overall scoring of an alternative.

Our weights were obtained directly from the decision maker using the swing weighting procedure as an initial starting point. Based on discussions with the decision maker, the values were ranked in order of importance for each branch.

For instance, the first tier has only one branch containing the following values in rank order of importance: Mission Priority and Mission Capability, Damage, Redundancy, and Time. After the rank had been determined, each value was then represented in terms of the least important value for that branch. For the branch of the first tier of our hierarchy, Time was the least important value. Mission Priority and Mission Capability were determined to be six times more important than Time. Damage was determined to be five times more important than Time and Redundancy was stated to be twice as important than Time.

The following equations (1.0) are then derived and solved in terms of Time:

$$W_{\text{Mission Capability}} = 6 * W_{\text{Time}}$$

$$W_{\text{Mission Priority}} = 6 * W_{\text{Time}}$$

$$W_{\text{Damage}} = 5 * W_{\text{Time}}$$

$$W_{\text{Redundancy}} = 2 * W_{\text{Time}}$$

$$W_{\text{Mission Capability}} + W_{\text{Mission Priority}} + W_{\text{Damage}} + W_{\text{Redundancy}} + W_{\text{Time}} = 1$$

$$6 * W_{\text{Time}} + 6 * W_{\text{Time}} + 5 * W_{\text{Time}} + 2 * W_{\text{Time}} + W_{\text{Time}} = 1 \qquad (1.0)$$

This process was carried out for each branch in the hierarchy and then the results were briefed back to the decision maker. A copy of these briefings can be found in Appendix B. For the first tier branch, the swing weights were accepted by the decision maker. However, in some branches the decision maker made adjustments to the swing weights based on expertise and experience. The completely weighted hierarchy can be viewed in figure 8.

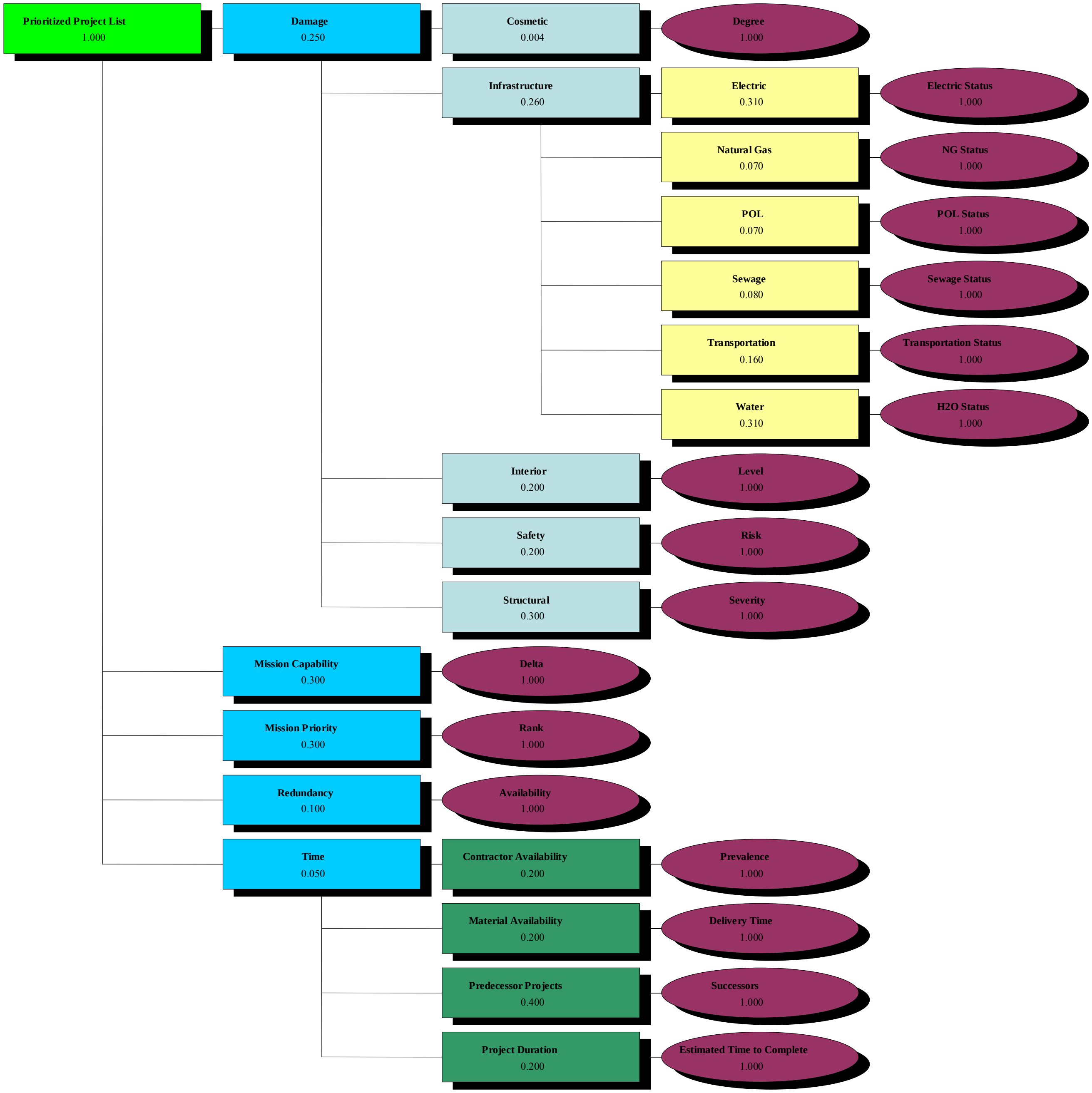


Figure 8. The Complete Value Hierarchy with Local Weights

3.6 Creating the Value Functions

The VFT process creates SDVFs for measures in order to score alternatives based on a common unitless scale. A function v(x) is only considered a value function if is true that v(x') > v(x'') if and only if $x' > x''$ where x' and x'' are specified but arbitrary levels of x (Kirkwood, 1997). Simply stated, a value function exists if and only if an alternative that scores higher than another on a certain measure ranks higher than the alternative that scores lower on the same measure while holding all other scores equal.

Several properties must be adhered to when creating a SDVF in order for the value hierarchy to properly rank alternatives. The first property is monotonicity. The monotonicity property requires that all functions increase or decrease monotonically so that either higher or lower scores are always preferred (Kirkwood, 1997). In order for the VFT process to work, the value functions created using it must be strategically equivalent. Strategic equivalence is a property that states that two value functions are strategically equivalent if they give the same rank ordering for any set of alternatives (Kirkwood, 1997). This property is what allows us to perform a monotonic transformation to obtain unitless values and then to score alternatives on a common scale. What is being said basically is that the monotonically transformed value function will score the alternatives in the exact same rank order as the original value function. Strategic equivalence is essential because it allows us to use several different types of SDVFs and transform them all in to a common scale for scoring purposes.

Finally the value function must be additive. In order for a value function to be additive, it must be strategically equivalent to a value function of the form:

$$v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i) \qquad (2.0)$$

For some function $v_i(x_i)$ and constants λ_i (Kirkwood, 1997). The terms $v_i(x_i)$ in equation 2.0 represent the SDVFs and the λ_i term represents the weights. The additive function utilized by VFT is normalized, meaning that the score on any single measure before weighting is between 0 and 1, which allows us to objectively rank the alternatives.

The two common functions utilized by SDVFs are the piecewise linear and the exponential functions. A discrete version of the piecewise linear function, called a categorical function is also used when a small range of scores is available for a measure. Figure 9 gives an example of one of our increasing exponential SDVFs and figure 10 displays an example of one of our decreasing exponential SDVFs. Both exhibit monotonicity because as you move along the x-axis the value either consistently increases or decreases.

The exponential SDVFs were created using the equation 3.1 for the increasing case and equation 3.2 for the decreasing case.

$$v_i(x_i) = \frac{(1 - \exp[-(x_i - x_i^l) / \rho_i])}{(1 - \exp[-(x_i^H - x_i^l) / \rho_i])} \quad \text{Where } \rho_i \neq 0 \qquad (3.1)$$

$$\frac{x_i - x_i^H}{x_i^H - x_i^L} \quad \text{Otherwise}$$

$$v_i(x_i) = \frac{(1 - \exp[-(x_i^H - x_i) / \rho_i])}{(1 - \exp[-(x_i^H - x_i^l) / \rho_i])} \quad \text{Where } \rho_i \neq 0 \qquad (3.2)$$

$$\frac{x_i^H - x_i}{x_i^H - x_i^L} \quad \text{Otherwise}$$

The SDVF for Successors was created by asking the decision maker to provide the specific number of successor projects that would garner 50% of the value for the Successors measure. As you can see in figure 9, a value of 0.50 is obtained when a recovery project has exactly three successor projects. After approximately 10 successor projects are identified for a given recovery project, the value increases a much slower rate. This represents the decision maker’s contention that after 10 successor projects have been identified for a given recovery project there is only a little increase in priority by adding another one.

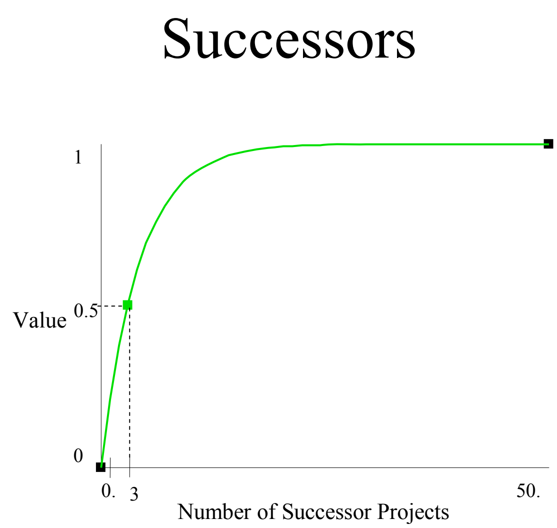


Figure 9. The SDVF for Successors

The SDVF for prevalence was created by asking the decision maker to provide the specific number of contractors available to complete a specific project that would garner 50% of the value for the Prevalence measure. As you can see in figure 10, a value of 0.50 is obtained when exactly five contractors are available on the market. After approximately 10 contractors are identified for a given recovery project, the value decreases a much slower rate. This represents the decision maker's contention that after 10 contractors have been identified for a given recovery project there is only a little decrease in priority by adding another one.

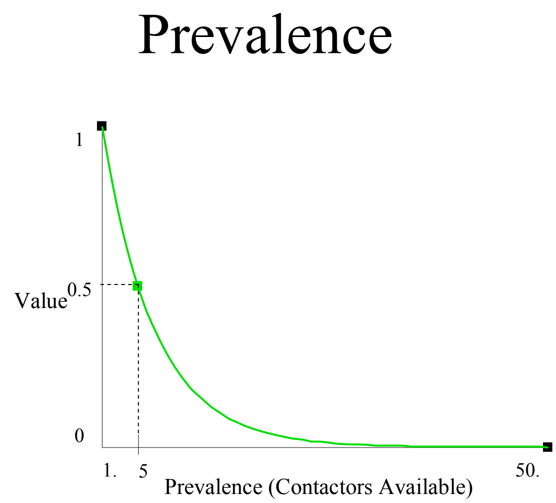


Figure 10. The SDVF for Prevalence

A piecewise linear SDVF must also be arranged so that the general trend of the function is monotonically increasing or decreasing. The procedure used for determining piecewise linear SDVFs are very similar to using the swing weighting system. Relative value increments are specified between each of the possible evaluation measure scores and this information is then used to specify the SDVF. The decision maker wanted to measure interior damage based on how serious the sustained damage was to the function of the facility. Originally, we thought that this would be categorical, but later decided on piecewise linear because it is a continuous function which allows us to measure in units of percent degraded. Based on the decision maker's expertise with evaluating interior damage, it was decided that half of the value for this measure would be obtained when the interior damage was reported to be exactly 25% degraded.

At a reported rate of 50% degradation the building is essentially rendered useless; therefore, at this level of degradation a value of 0.90 is obtained. See figure 11 for an example of our sole increasing piecewise linear SDVF of interior damage identified as Level.

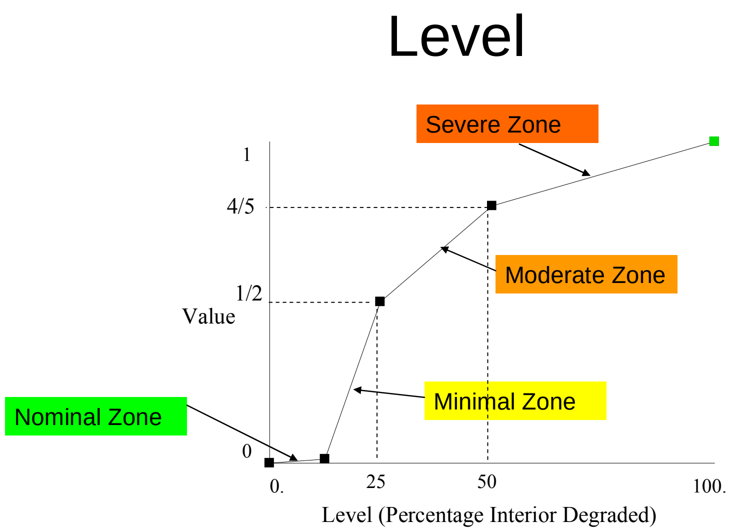


Figure 11. The SDVF for Level

The final type of SDVF used in this thesis is the categorical function which is basically a discrete version of the piecewise linear function. Our infrastructure damage measures all use the same categorical function with the following categories:

- **Systemic** – Infrastructure damage addressed by a particular project that results in the degradation of an entire system or network
- **Localized** – Infrastructure damage addressed by a particular project that is localized in nature
- **Temporarily Repaired** – Infrastructure damage addressed by a particular project that has been temporarily repaired and has rendered the system or network operational
- **Operational** – Infrastructure system for a particular project that remains operational

Figure 12 illustrates the categorical SDVF called Electrical Status.

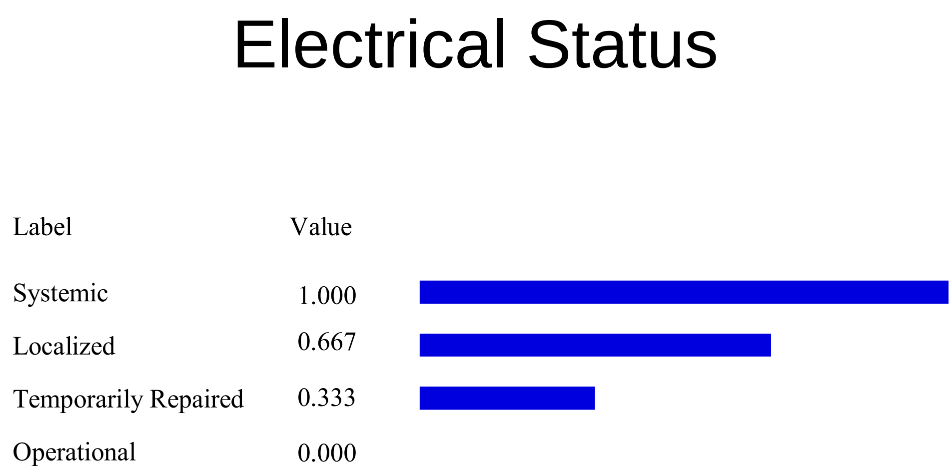
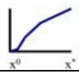
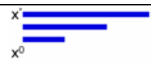
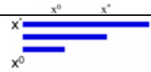
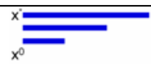
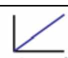
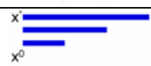
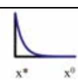
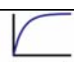
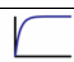
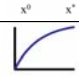


Figure 12. The SDVF for Electrical Status

Table 9 provides a summary of all of the measures used in the value hierarchy. A graphical representation of each SDVF is presented as well as the lowest possible score = x^0, the highest possible score = x^*, the global weight, and the units of measure. For a more detailed view of each measure see Appendix B.

Table 9. Synopsis of Evaluation Measures

Measure Name	SDVF	x^0	x^*	Global Weight	Units/Categories
Degree		0	100	.010	(Piecewise Continuous) Percentage of cosmetic components degraded
Electrical Status		Operational	Systemic	.020	(Categorical) Ranked highest to lowest: Systemic, Localized, Temporarily Repaired, and Operational
NG Status		Operational	Systemic	.005	(Categorical) Ranked highest to lowest: Systemic, Localized, Temporarily Repaired, and Operational
POL Status		Operational	Systemic	.010	Ranked highest to lowest: Systemic, Localized, Temporarily Repaired, and Operational
Sewage Status		Operational	Systemic	.005	Ranked highest to lowest: Systemic, Localized, Temporarily Repaired, and Operational
Transportation Status		Operational	Systemic	.007	Ranked highest to lowest: Systemic, Localized, Temporarily Repaired, and Operational
H_2O Status		Operational	Systemic	.020	Ranked highest to lowest: Systemic, Localized, Temporarily Repaired, and Operational
Level		0	100	.035	(Piecewise Continuous) Percentage of interior components degraded
Risk		0.33	1.00	.065	(Categorical) Ranked highest to lowest: High, Moderate, Low
Severity		No Structural Damage	Catastrophic	.075	(Categorical) Ranked highest to lowest: Catastrophic, Moderate, Nominal, No Structural Damage
Delta		0	100	.300	(Linear) Percentage of mission capability degraded
Rank		60	1	.300	(Exponential-Decreasing) The direct position on the Mission Priority List
Availability		3 or More	None	.100	(Categorical) Ranked highest to lowest: None, One, Two, 3 or More
Prevalence		1	50	.010	(Exponential-Decreasing) The number of contractors available on the market to complete work for a specific project
Delivery Time		0	52	.010	(Exponential-Increasing) Delivery time in weeks
Successors		0	50	.020	(Exponential-Increasing) Direct number of successor projects
ETC		0	730	.010	(Exponential-Increasing) Estimated time of completion in days

3.7 Alternative Generation

The alternatives for this model were based on a hypothetical USAF base called Base X. The background information was generated in consultation with the decision maker and included three sets of disaster event recovery programs for prioritization along with corresponding cost estimates. Each recovery program was based on a separate disaster event. The first program was based on a category 4 hurricane. The second program was based on an F-2 tornado, and the third event was based on a major flood. Hypothetical recovery projects were generated based on the type of damage associated with each specific event. Archives of the data generated for this research can be found in Appendix A.

3.8 Alternative Scoring

The scoring of the alternatives was conducted using the Logical Decisions Software suite. Each alternative was scored on all 17 measures and received a relative overall score which was then used to rank order the projects in each recovery program. The scoring done by Logical Decisions is based directly on the additive value function of equation 2.0. The prioritized recovery programs for all three disaster events, a hurricane, tornado, and flood as well as the relevant sensitivity analysis of each event are presented in detail in chapter 4.

IV. Results and Analysis

4.1 Overview

Chapter 4 contains the deterministic analysis and sensitivity analysis for the three hypothetical disaster recovery programs at Base X. Base X is assumed to be a medium sized Air Force special operations base located along the gulf coast of Florida. The base flying mission includes AC-130 gunship, MC-130 talons, and MH-53 helicopters. The deterministic and sensitivity outputs were obtained by inputting the project data created for each disaster event into the VFT model and then scoring each project based on the measures constructed in chapter 3. Also presented in this chapter are the results of a 0-1 knapsack integer program that determines which projects can be obligated based on maximizing a funding strategy objective while adhering to a fixed budget. The knapsack analysis was accomplished using hypothetical cost data based on similar real-world projects in conjunction with the deterministic ranking provided by the VFT model.

4.2 Deterministic Analysis

The deterministic analysis step of the VFT process ranks the alternatives based on their overall score determined using the additive value function presented in chapter 3. The additive value function is a product of the scaling weights for each measure and the resultant value obtained from that measure's SDVF (Kirkwood, 1997). Once the overall score has been determined for the alternatives, the alternatives are then listed in rank order depicting the highest valued alternatives at the top and the lowest valued alternatives at the bottom. In terms of this research, the deterministic output provides a prioritized list of reconstruction projects listed in order of highest to lowest priority. The deterministic output is displayed using a colored stacked bar graph.

Each color in the stacked bar graph displays the relative importance a measure has on the overall score of a particular alternative. Stacked bar graphs depicting the prioritized project sets for the three disaster events are presented in figures 13, 14, and 15.

4.3 Deterministic Analysis of Hurricane X

The first disaster event was based on a hypothetical CAT III hurricane. The reconstruction projects created for this disaster were based on historical project requirements and damage assessments at Hurlburt Field, Florida that resulted from Hurricane Ivan in 2004. The prioritized project set for Hurricane X can be found in figure 13.

Upon initial inspection, it appears that there is a general trend towards giving priority to the projects ranking highest on the facility priority list. However, after closer inspection of the raw scores, which can be found in Appendix A, it can be shown that this is not the case. For instance, the *Repair CDC Roof* project has a raw Rank measure score of (0.385), which is lower than ten other recovery projects based on the Rank measure. It should also be noted that the *Repair Fitness Center Roof* is prioritized below three projects that do not even rank on the facility priority list. Furthermore, the *Repair Fitness Center Interior* project is prioritized below four unranked projects. This further debunks the case for a trend towards prioritizing the projects that rank on the facility priority irregardless of all other measures.

There was a wide range of overall scores that resulted from the deterministic analysis of the Hurricane X project set. The highest scoring alternative was the *Repair Control Tower* projects (0.552) and the lowest scoring project was the *Repair Fitness Center Interior* project (0.114). This resulted in a range of scores was equal to 0.438 with a mean score of 0.314.

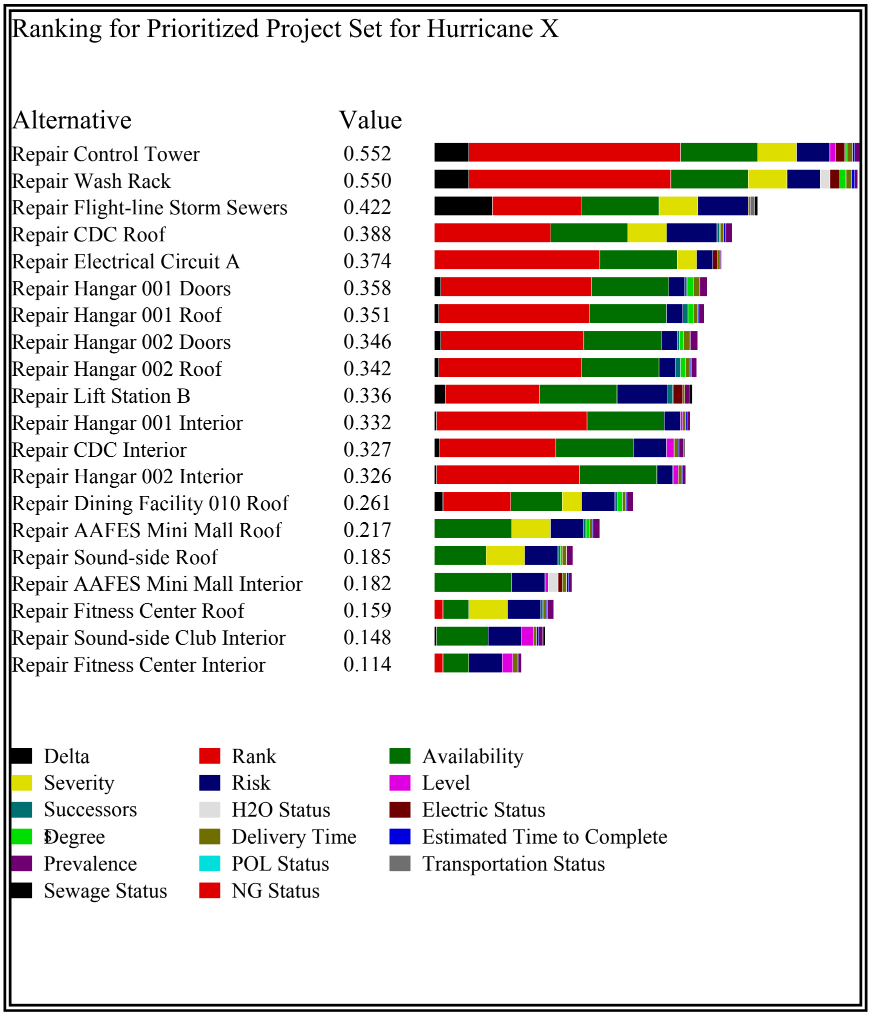


Figure 13. Deterministic Analysis of Hurricane X Recovery Projects

4.4 Deterministic Analysis of Tornado X

The second disaster event was based on a hypothetical F2 tornado. An F2 tornado is a Significant Tornado (112 - 157 mph) that can cause considerable damage including: Roofs torn off the frames of houses, mobile homes demolished, boxcars pushed over, large trees snapped or uprooted, and heavy cars lifted off ground and thrown (NOAA, 2006). The reconstruction projects for this event were created by the decision maker and myself using his experience and the information from NOAA correspond to the damage type and extent that is typical caused by a F2 tornado. The damage caused by a tornado generally will not be as widespread as that of a hurricane, but will generally be more severe in close proximity to the storms path. The prioritized project set for Tornado X can be found in figure 14.

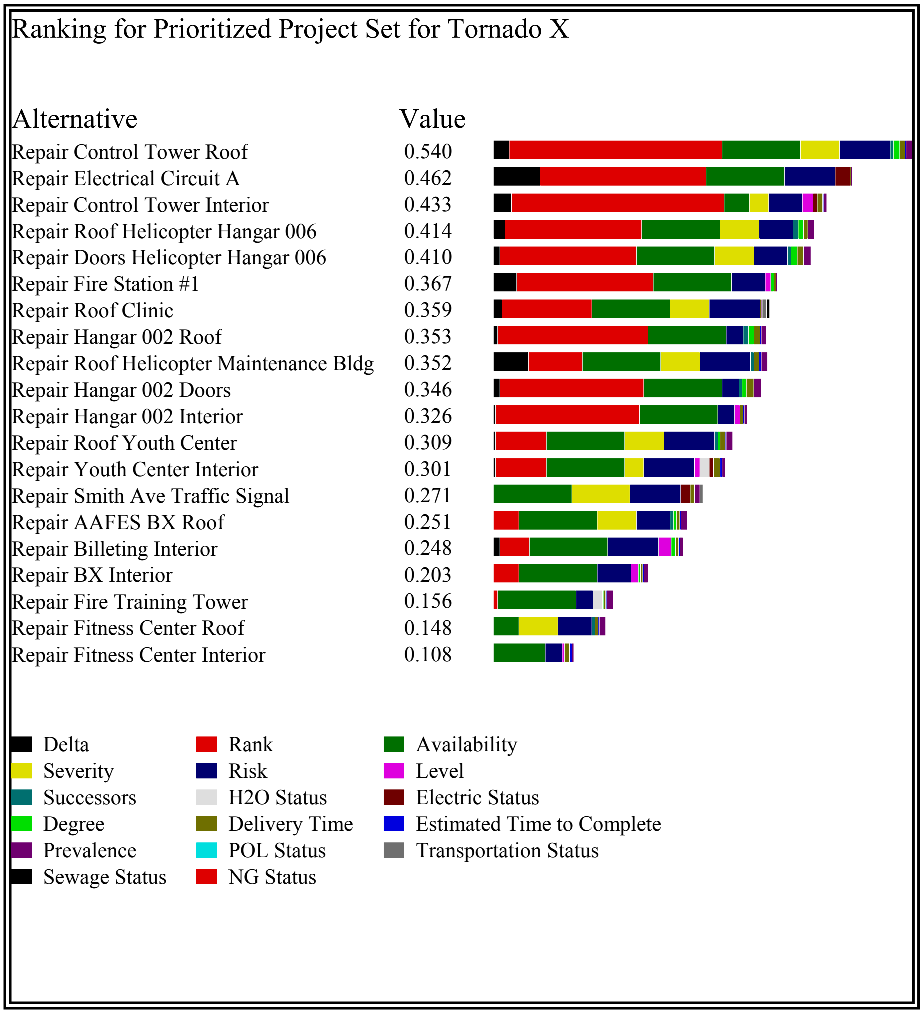


Figure 14. Deterministic Analysis of Tornado X Recovery Projects

Once again we see a wide range of scores for the projects. The highest priority project, *Repair Control Tower Roof*, is 0.423 higher than the lowest scoring project, *Repair Fitness Center Interior*. Again we see a fairly high variation in the alternative scores which may confirm the robustness of this hierarchy with respect to weighting sensitivity.

A particularly interesting observation with respect to the Delta measure can be made in this deterministic analysis. One might think that the Delta measure could determine the priority of the projects by itself by looking at the weights of the top tier values in the VFT hierarchy. However, this is not the case. Lets take a look the *Repair Roof Helicopter Maintenance Building* and *Repair Hangar 002 Roof* projects with respect to the delta measure raw scores (Appendix A). After closer inspection, we see that the *Repair Roof Helicopter Maintenance Building* project scores (0.150) and the *Repair Hangar 002* project scores (0.02) on the Delta measure. But from the deterministic output in figure 14 we see that the projects are not prioritized solely on there ability to restore the mission capabilities. This is because the decision maker is considering 16 other measures that contribute to the overall score. If any one measure was determined the outcome of the ranking there would be no need to construct a value hierarchy.

4.5 Deterministic Analysis of Flood X

The second disaster event was based on a hypothetical flood. The reconstruction projects created for this event correspond to the damage type and extent that is typical of a flood and were based on coastal flooding at Hurlburt Field, FL during Hurricane Ivan. The damage caused by a flood generally will not be as diverse as that of a hurricane or tornado. That is to say that the variety of damage type and extent is not as variable when compared to a hurricane or tornado. Prioritizing projects with homogenous damage can be even more difficult and naturally lends itself to the VFT process. The prioritized project set for Flood X can be found in figure 15.

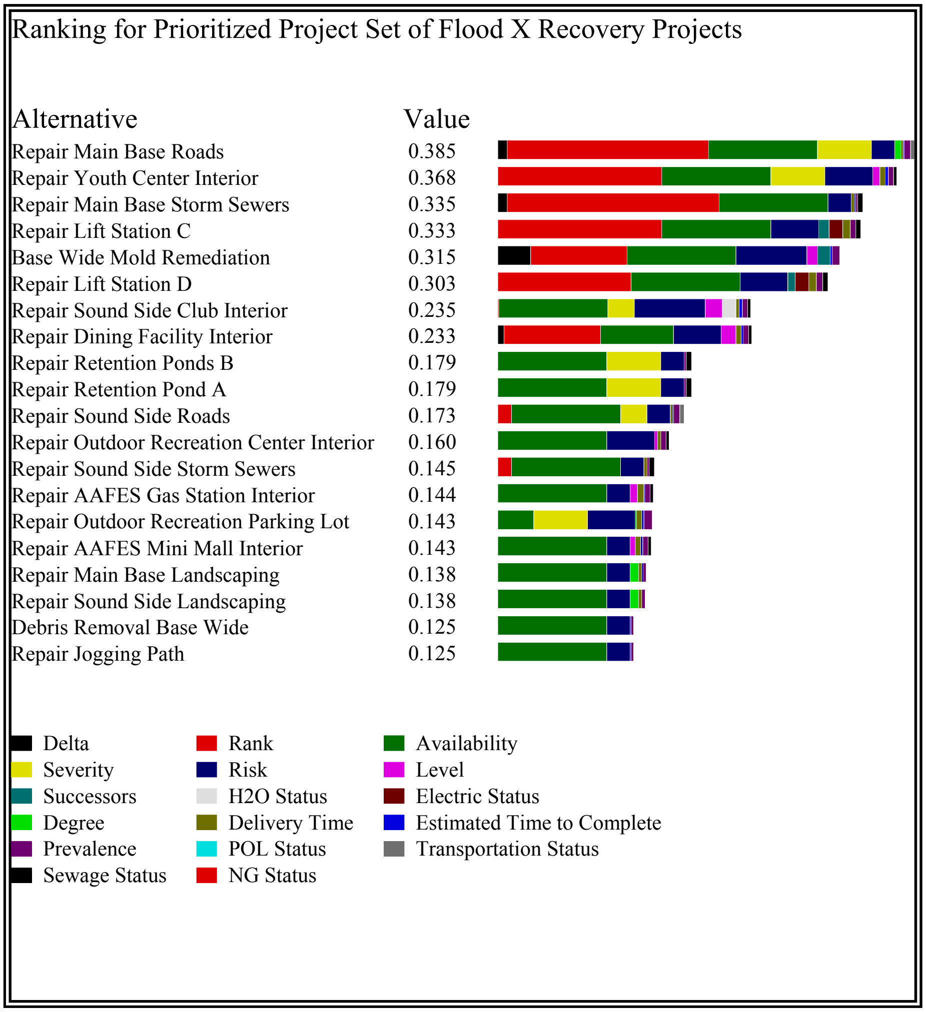


Figure 15. Deterministic Analysis of Flood X Recovery Projects

There are two significant observations with respect to the deterministic analysis of Flood X. First, due to the homogenous nature of damage caused by a flood event, several projects had the same overall ranking. Both retention pond repair projects scored the same as well as both landscaping projects. In these cases, it makes little difference from a value standpoint as to which project gets prioritized over the other and it then becomes the responsibility of the decision maker to decide on which project to fund first. The cost of each project may play an important role in deciding the final priority of closely valued projects and this will be addressed later through the knapsack programming analysis. You can also observe that the *Repair Outdoor Recreation Parking Lot* and *Repair AAFES Mini Mall Interior* projects are also equally ranked. In their case, it may also come down to the programmed cost of the project, but a decision to fund the project that generates the most funds for these non-appropriated funds (NAF) facilities may also come into play. The point being made is that the deterministic analysis does not fully remove the need for a decision maker but rather provides a prioritized set of projects that reflects the values of the decision maker. The second observation of the deterministic data refers back to the discussion of independence between the Rank and Delta measure. In that discussion, it was argued that a project need not be ranked on the facility priority list to have mission impact and that a project that ranks on the facility priority list does not necessarily impact the mission. Five projects on the prioritized list scored on the Rank measure but did not restore any mission capability and thus had no score on the Delta measure. This outcome is not unrealistic. In these cases, the base leadership did not perceive a mission impact due the damage addressed by these projects.

So, irregardless of the rank of the facilities addressed by these projects the mission capability was not impacted. A case where the mission capability was impacted by a facility that was not ranked is not illustrated in any of the output however; one could easily envision a case where a project that doesn't score on the Rank measure impacts the mission. For instance, if Base X had the potential of being fined tens of thousands of dollars a day for illegal sewage discharges into a nearby bay as a result of not funding a lift station repair project, the wing commander may decide that not accomplishing this project would cause a 5% degradation of the mission. The money spent on fines may be an opportunity that could have been applied to jet fuel. Even damage to a morale and welfare facility, such as the base enlisted club, could be perceived as mission degradation even though the facility itself may not rank on the facility priority list. This model utilizes both mission priority and mission capability values for these very reasons.

4.6 Sensitivity Analysis Overview

Sensitivity analysis is performed to provide additional insight on how changing the weights of values or measures will affect the ranking of alternatives. By examining the sensitivity graphs, the magnitude of the change in weighting needed before the ranking is altered can be determined. This analysis is particularly useful when there is conflict among stakeholders with respect to the weighting of certain goals or measures in the VFT hierarchy (Kirkwood, 1997).

For the purposes of this research, the determination of whether or not a measure or value is sensitive will be determined by analyzing several factors. One factor is the magnitude of the change required to alter the overall decision. Another factor that will be considered is the number of projects that are displaced by a change in weighting. For example, if only one or two projects are shuffled after reallocating the weights for a particular value or measure, it might not be considered sensitive regardless of what magnitude of a change in weighting was needed to cause the shuffle. The way that this analysis is conducted is by observing the intersection points where one project overtakes another project. The x-axis refers to the weighting range form 0 to 1 and the y-axis refers to the overall value score corresponding to a projects location on the priority list. When the weights are manipulated, you can observe the priority list on the y-axis with respect to weighting to determine if a measure is sensitive or insensitive to weighting. The current weight of measure is displayed using a thin vertical black line. It should be noted that traditionally VFT sensitivity analysis is primarily concerned with determining how sensitive the top few alternatives are to weighting because they represent the potential best decision. Sensitivity analysis for this research is concerned with sensitivity across the entire set of projects. Since a knapsack formulation will be used to define the set of projects by taking into account cost, the relative ranking of projects anywhere in the list can influence the final subset.

The following section covers the sensitivity analyses for all three disaster recovery programs but the majority of sensitivity graphs will come from the Hurricane X project set. The remainder of the sensitivity graphs can be found in Appendix C.

Each sensitivity graph depicts the 20 projects of the Hurricane X set. The graphs are to be viewed with the understanding that the sensitivity analysis is being conducted on a particular value or measure while holding all others proportionally equal.

4.7 Sensitivity Analysis

The sensitivity analysis conducted in this section covers several measures and values. Values that were only one tier above their respective measures were not considered in order to avoid duplication of effort. All three disaster events sensitivity analysis will be presented but not all of the sensitivity graphs will be presented in the text. The remainder of the sensitivity analysis graphs can be viewed in Appendix C.

The first measure to be analyzed for sensitivity was the Availability measure. This measure refers to the availability of redundant facilities for a facility that has a reconstruction project programmed. Currently, Availability has a global weight of 0.10. In order to affect a change in the outcome, only a 0.009 increase in the weighting is needed. However, this only changes the outcome of the list by moving one project, *Repair AAFES Mini-Mall Interior*, up one place in priority. It is not until the weighting is changed by 0.03, or a 33% increase in the original weight, that two out of the twenty projects change in priority. In each case, the result was to only climb one place in the priority list and both projects were relatively low priority projects. Additionally, one can see a general trend of insensitivity when viewing the similar endpoints when the weight is maximized to one. This is due to the categorical nature of the measure and is generally the case for categorical measures. Figure 16 illustrates the sensitivity analysis of the Availability measure for Hurricane X.

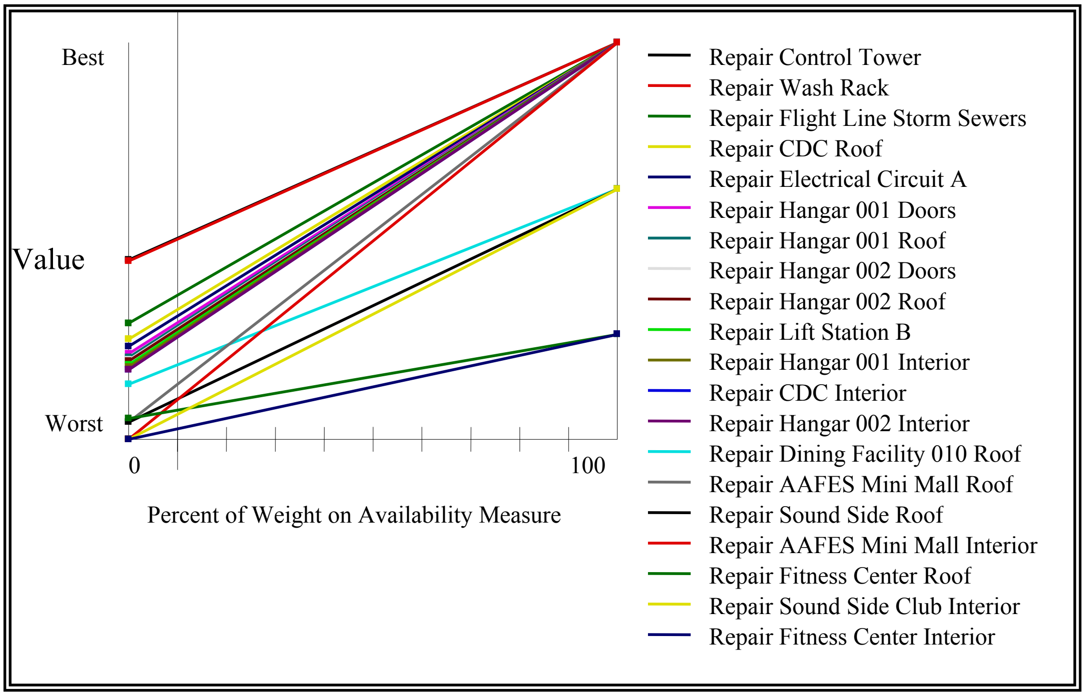


Figure 16. Sensitivity Analysis of Availability

The results of the sensitivity analysis of the Flood X and Tornado X recovery programs with respect to Availability were very similar. In all cases the same general trends toward insensitivity were observed with the changes in weighting only affecting the order of prioritization slightly. Furthermore, the weighting of this measure was reaffirmed by the decision maker on two occasions Therefore, it's concluded that the Availability measures is insensitive to weighting for the three disaster recovery programs with respect to prioritization.

The Delta measure accounts for the need to give priority to a project that restores a percentage of the mission capability of the base. Sensitivity analysis conducted on the Delta measure has shown it to be relatively insensitive both directions.

The weighting range of 0.20 to 0.48 is insensitive to weighting with respect to overall prioritized list for Hurricane X and Flood X. Tornado X was slightly more sensitive than the other two recovery project sets with a range of 0.25 to 0.35. However, relative to the overall outcome the Delta measure is insensitive to weighting. The decision maker's value for projects that restore the most mission capability is reflected in the high weight of 0.30. The results of the sensitivity analysis of the Delta measure for the Hurricane X project set are presented I figure 17.

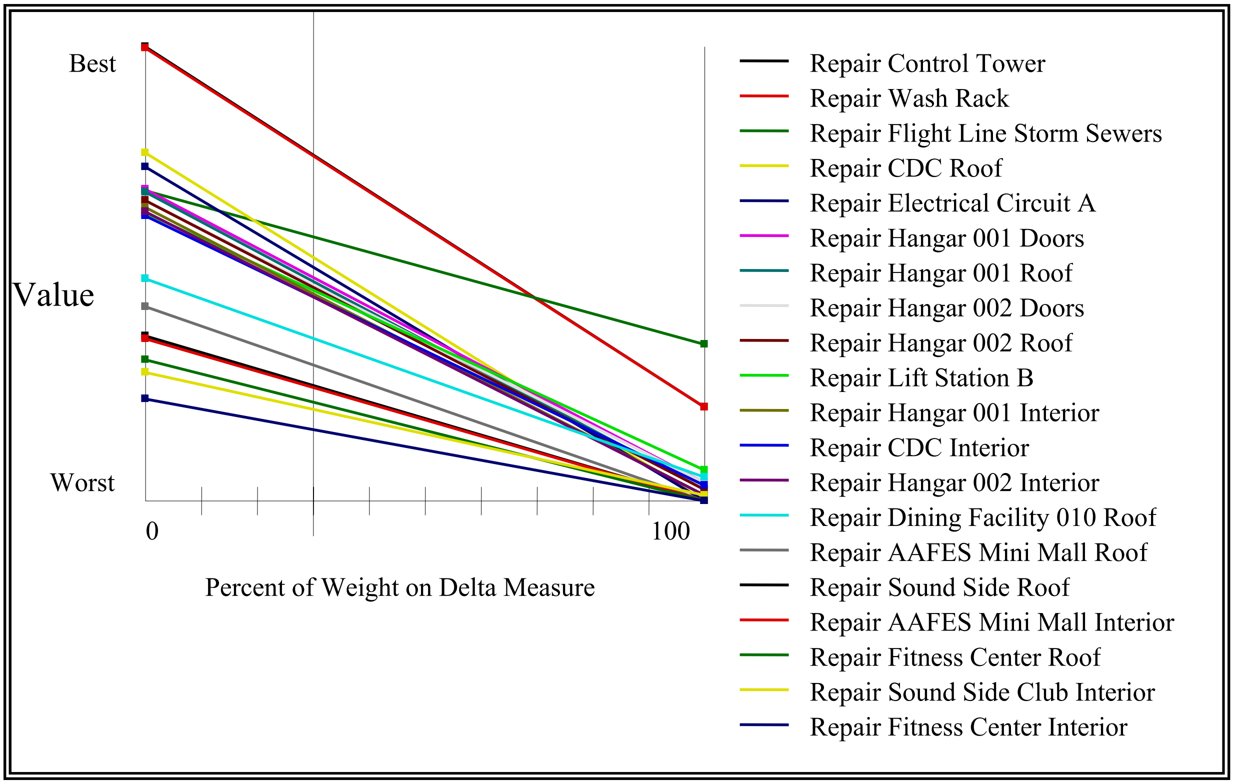


Figure 17. Sensitivity Analysis of Delta

The Rank measure is used to quantify the decision maker's value for projects that address facilities that appear on the facility priority list. These projects are valued because damage to these facilities is reportable to the Air Staff and subsequently the US Congress. This justifies high weight of 0.30 for this measure.

When analyzed for sensitivity to weighting changes, the Rank measure was sensitive throughout all ranges of weights but more so in the negative direction. If the weight was reduced from the 0.30 to 0.10 the outcome of the prioritized lists of all three storms would be dramatically impacted as can be seen in sensitivity graph displayed in figure 18.

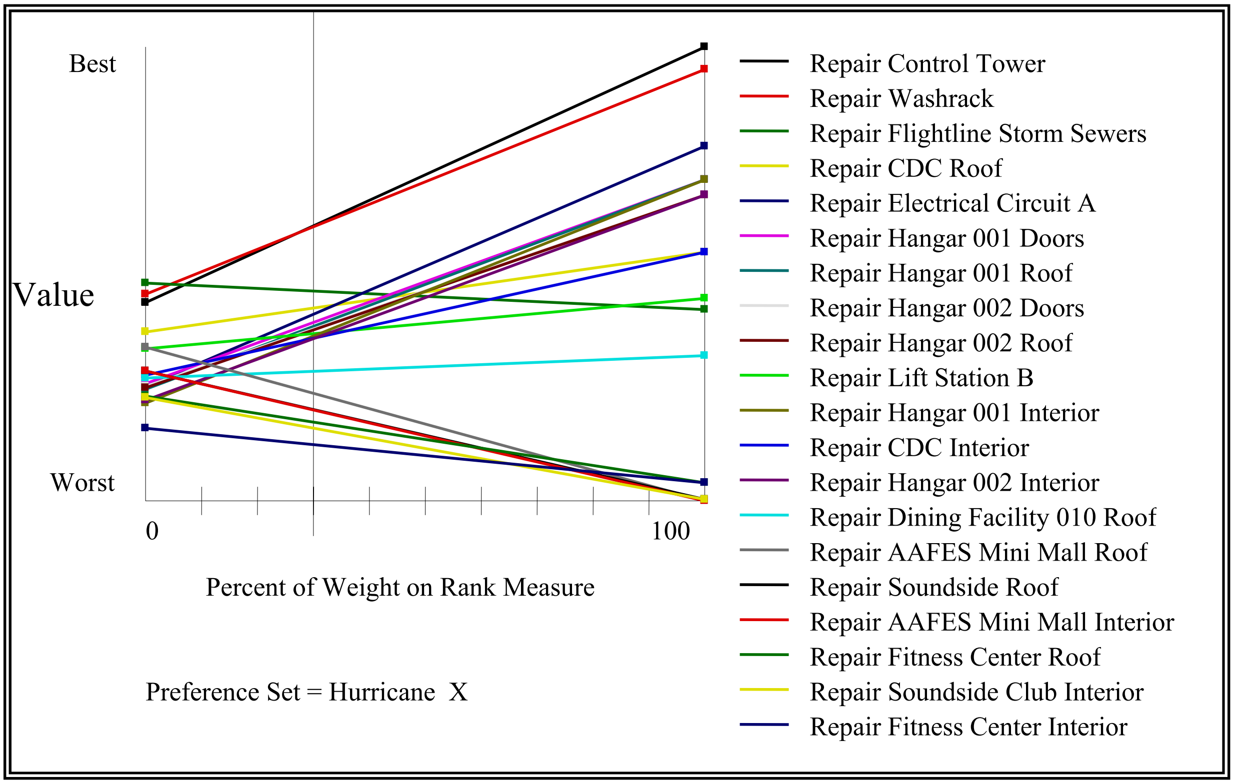


Figure 18. Sensitivity Analysis of Rank

Sensitivity analysis of the Damage value was performed next. The current global weight for Damage is 0.25. After conducting the dynamic sensitivity analysis, the Damage value is observed to be sensitive to weighting in both directions by either increasing or decreasing the current weight by as little as 0.002.

However, when you view the sensitivity graph illustrated in figure 19 it can be shown that the weight range from 0.23 to 0.27 for the Damage value currently resides in is the most stable area of the sensitivity graph. The decision maker may be inclined to adjust the weights within that range to fine tune the model, but this decision maker has determined that the Damage value should account for approximately one quarter of the overall score for a project. So, for the Hurricane X project set, the Damage value was fairly insensitive over the 0.23 to 0.27 range in which it currently resides. The 0.23 to 0.27 range of weights also appears to be the most stable range for the Tornado X and Flood X recovery project sets. The Damage value was most sensitive for the Flood X recovery project set. Overall, the Damage value appears to be very sensitive to weighting but there is high confidence that the range of 0.23 to 0.27 correctly reflects the values of the decision maker in all three instances.

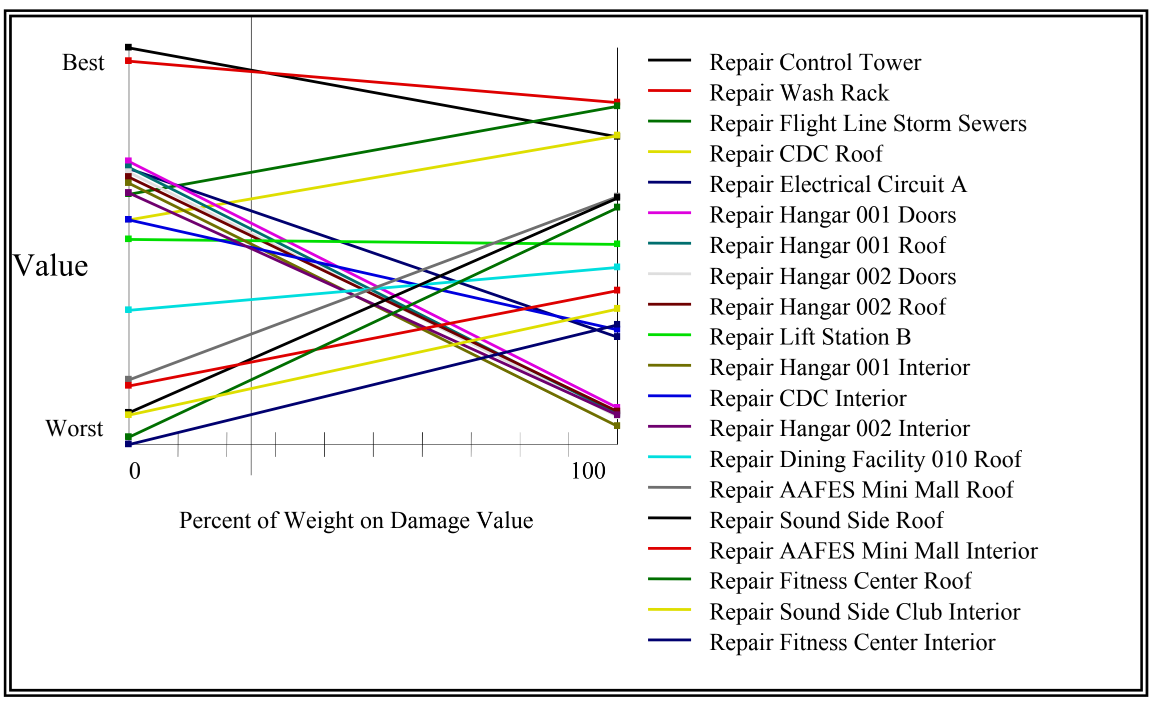
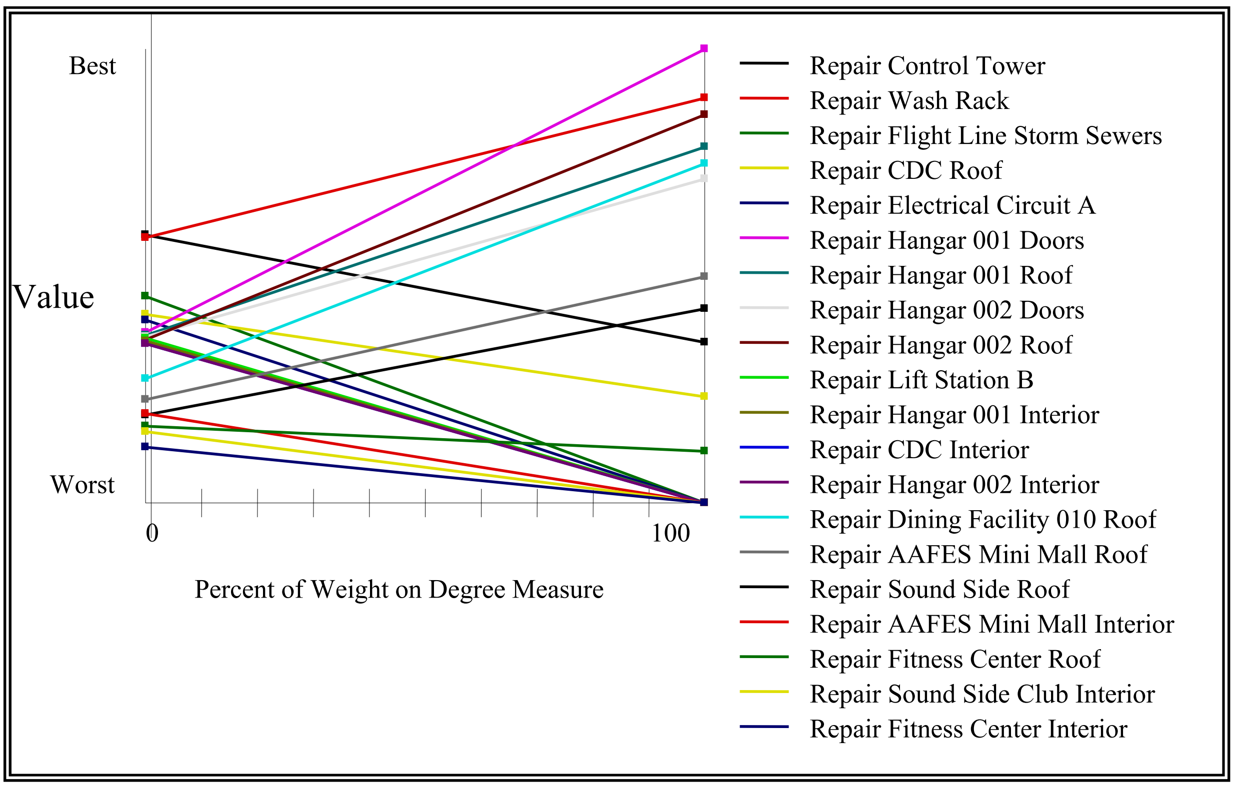


Figure 19. Sensitivity Analysis of Damage

The Degree measure was analyzed for sensitivity for weighting next. The Degree measure refers to the amount of exterior cosmetic damage that a particular project addresses. The current global weight was set at 0.01. After reviewing the sensitivity analysis graphs for all three disaster recovery project sets, some interesting trends were observed. First, a trend toward increasing sensitivity to weighting was observed as the diversity of recovery projects increased. For example, the sensitivity graph for the Hurricane X project set with respect to Degree shows a significant change in the prioritization when the weighting is increased to just 0.03. Also, the overall top priority project changes from *Repair Control Tower* to *Repair Wash Rack*. The sensitivity graph for Degree for Hurricane X can be viewed in figure 20.



. **Figure 20. Sensitivity Analysis of Degree (Hurricane X)**

Tornado X has damage that is less diverse in scope than Hurricane X due to the nature of the storm. In the case of Tornado X, Degree is sensitive to weighting because an increase from 0.01 to a weight of 0.02 would significantly change the rank of the recovery projects. The results of the sensitivity analysis of Degree for Tornado X can be viewed in figure 21.

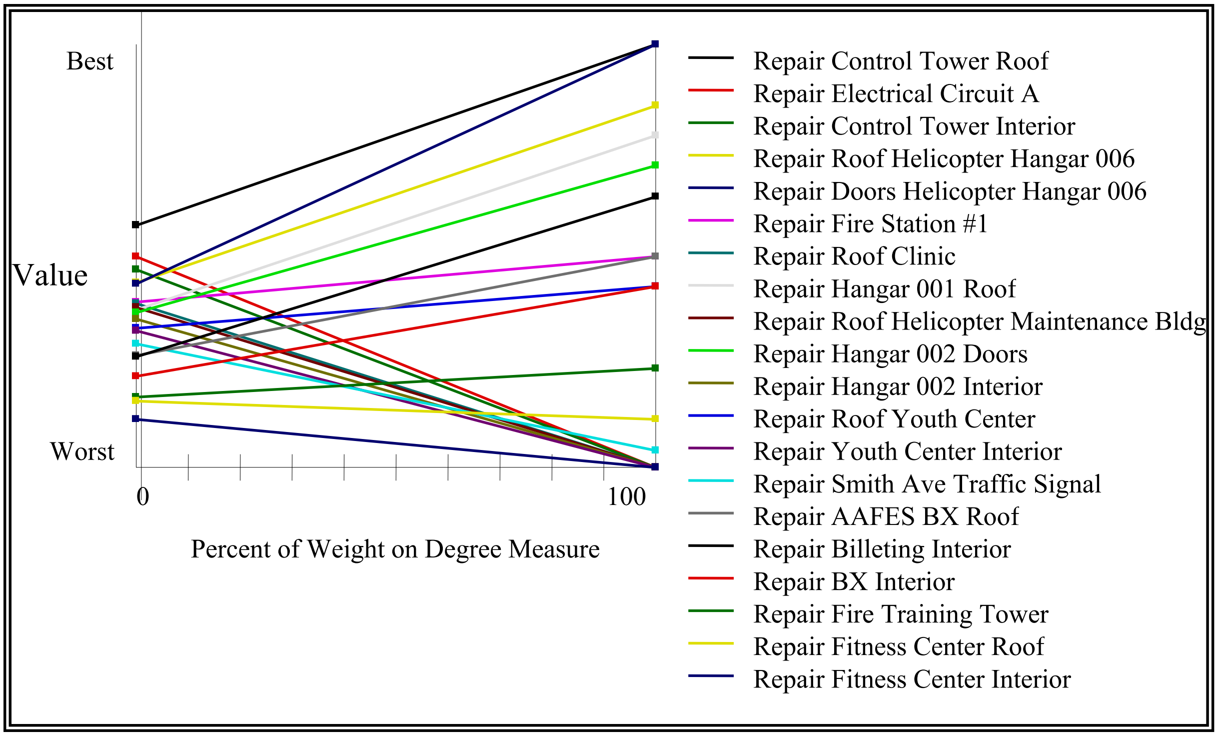


Figure 21. Sensitivity Analysis of Degree (Tornado X)

The sensitivity analysis of Degree with respect to the Flood X project set shows the same trend towards increased sensitivity around and a weight value of 0.02 but since only four projects address significant exterior cosmetic damage, the Degree measure appears to be less sensitive to weighting for Flood X in relation to the other two project sets.

Again, this is most likely due to the fact that the diversity in damage caused by a flood event is much lower than can be expected for either a tornado or hurricane. The results of the sensitivity analysis for Degree with respect to the Flood X project set can be found in figure 22.

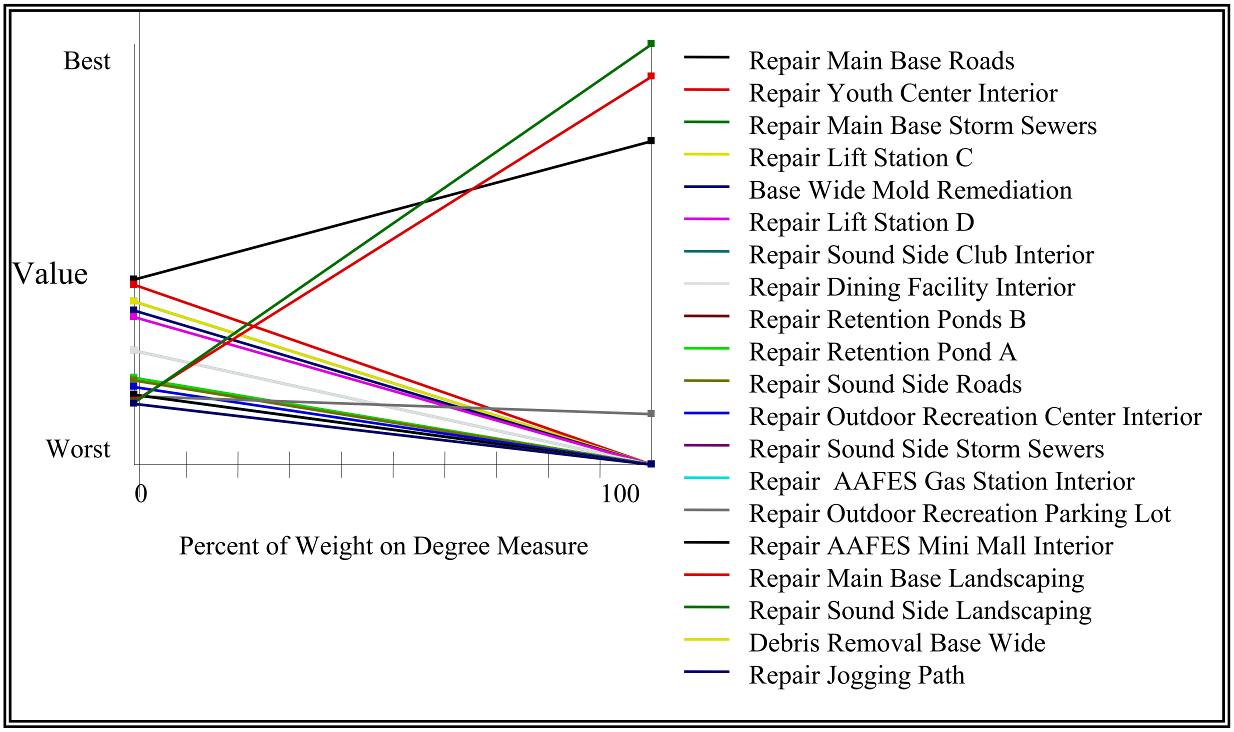


Figure 22. Sensitivity Analysis of Degree (Flood X)

Overall, the Degree measure has shown to be fairly sensitive to weighting and should be revisited with the decision maker if discrepancies arise in the final prioritization that are unacceptable. It will be shown that this is the case for almost every Damage value measure with the exception of the infrastructure damage measures which are in general insensitive to weighting.

The Level measure was the next Damage value tier measure analyzed for sensitivity. Level captures the amount of interior damage addressed by a particular recovery project. The current global weight is set at 0.035. After analyzing the sensitivity graph, a general trend toward increasing sensitivity to weighting in the positive direction can be observed. The two other disaster recovery project sets for the tornado and flood events exhibited the same trend toward sensitivity with increasing weights. The Tornado X set proved to be the most sensitive of the disaster recovery sets. Due to the sensitive nature of the Level measure, further investigation of the weighting might be considered if the VFT output was not consistent with the decision-maker's expectations. The sensitivity graph for the Level measure can be viewed in figure 23.

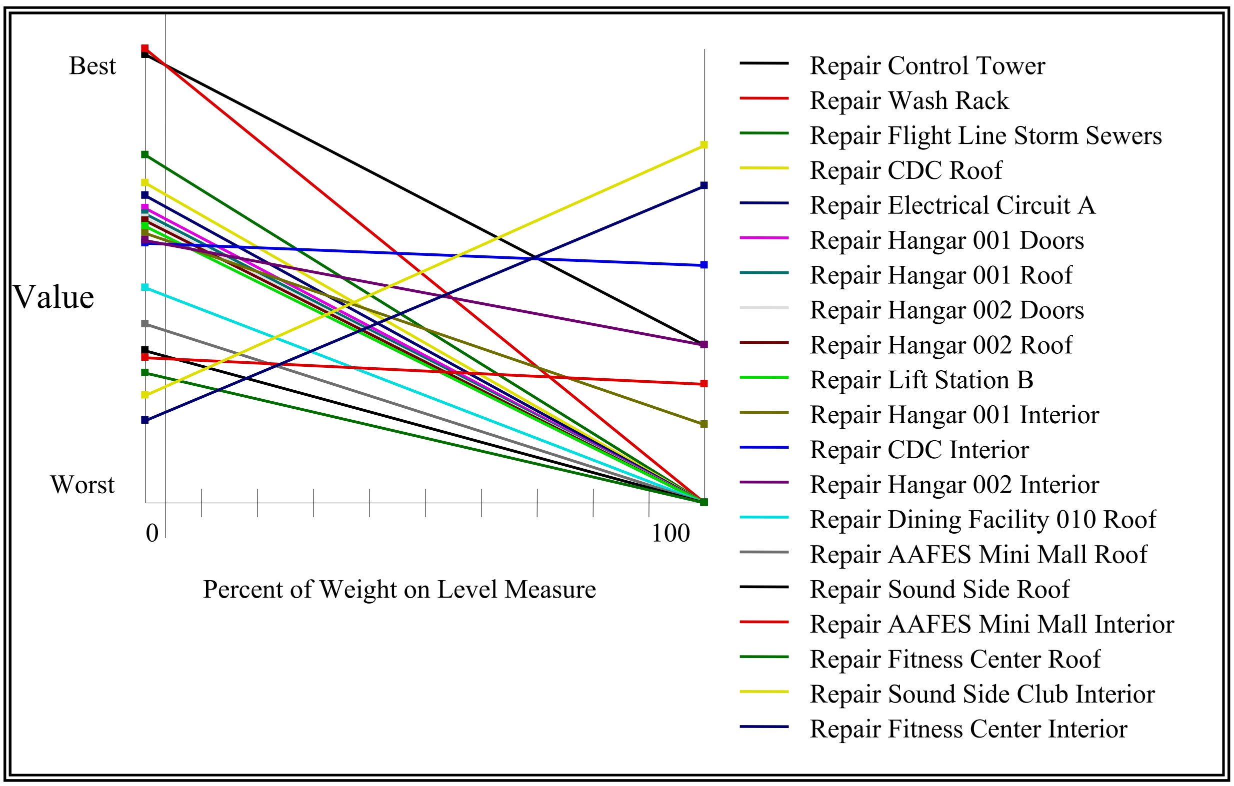


Figure 23. Sensitivity Analysis of Level

The Risk measure is used to account for the values the decision maker has with respect to the amount of safety deficiencies addressed by a recovery project. Currently the global weight for this measure is set at 0.065. This measure's sensitivity increases in the positive direction. In general, as the weight of Risk is increased the projects that address moderate to high risks eventually overcome all those projects with low risk. But, you can observe that several lower risk projects outrank several moderate and one high risk project. This is because of the cumulative effects of the other 16 measures and is to be expected. Figure 24 depicts the output of the sensitivity analysis conducted on the Risk measure.

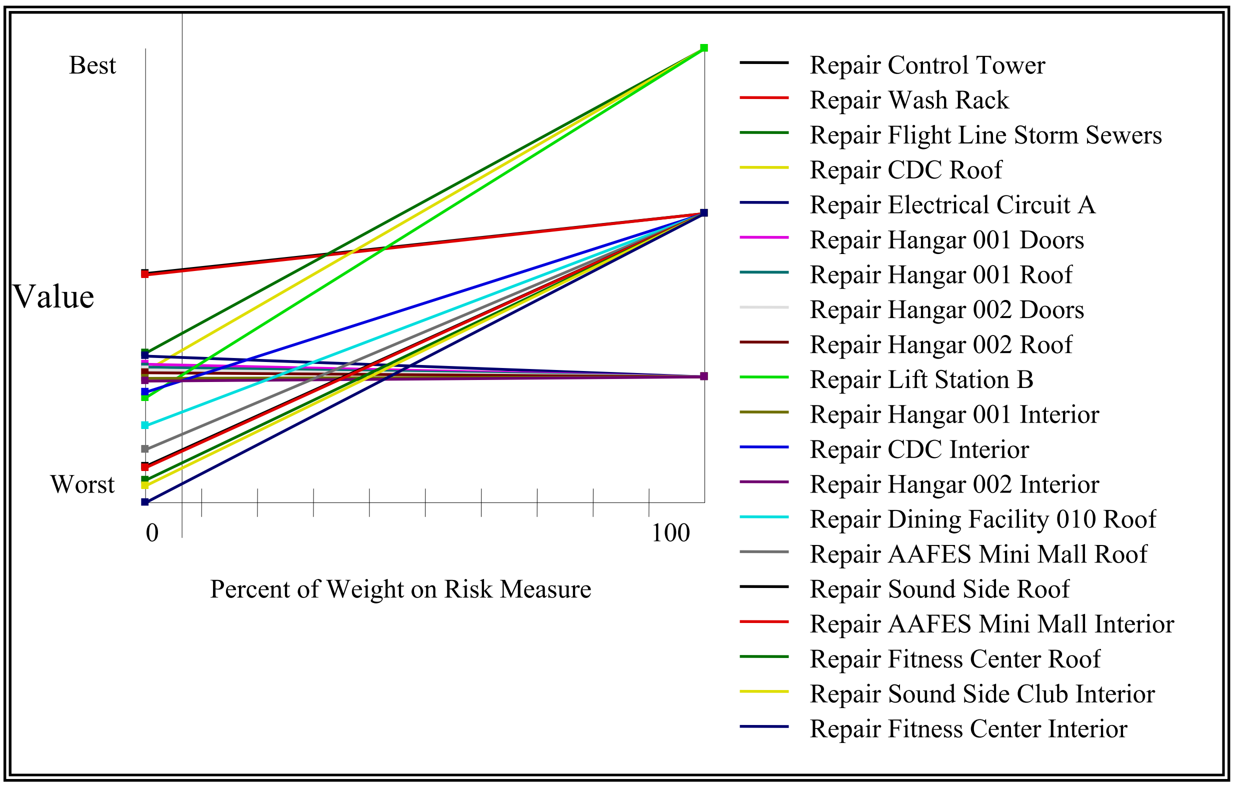


Figure 24. Sensitivity Analysis of Risk

The Risk measure is thoroughly understood by the leadership and the current level of importance placed on risk with the initial weighting has generated an acceptable prioritization of all three project sets. Risk to human health and safety issues must be carefully considered whenever considering the priority of a project. In a civilian setting this weight may be set at a much higher level than it is in this model. However, the requirement to restore the mission capabilities and to project the nation's air power from the weapon's platform, an Air Force Base, makes this setting unique when compared to the civilian world. Furthermore, military personnel routinely operate in a contingency environment where the risks are often elevated when compared with the civilian environment.

The sensitivity analysis of the Severity measure for the Hurricane X event reveals a general trend toward insensitivity to weighting over the range of 0.075 to 0.20. It is highly unlikely that the structural damage value weight would be significantly increased or decreased from it current weight because this measure already receives the most weight among the Damage value measures. Relative to the other damage measures it is insensitive. These observations hold true in general for the Flood X project set as well, although the range is much smaller (0.075-0.140). Tornado X's sensitivity analysis revealed that is the most sensitive to weighting on the Severity measure exhibiting sensitivity across the entire range of weights. An explanation for this may be that the Tornado X disaster produced a prioritized set in which the overall scores had less variance than the other two sets but more diversity in the level of structural damage sustained from the storm. Additionally, this was the only disaster event where a catastrophic structural failure occurred.

Changing the weight of the Severity measure is not recommended due to its relative insensitivity. Figure 25 gives the results of the sensitivity analysis of the Severity measure for the Hurricane X project set.

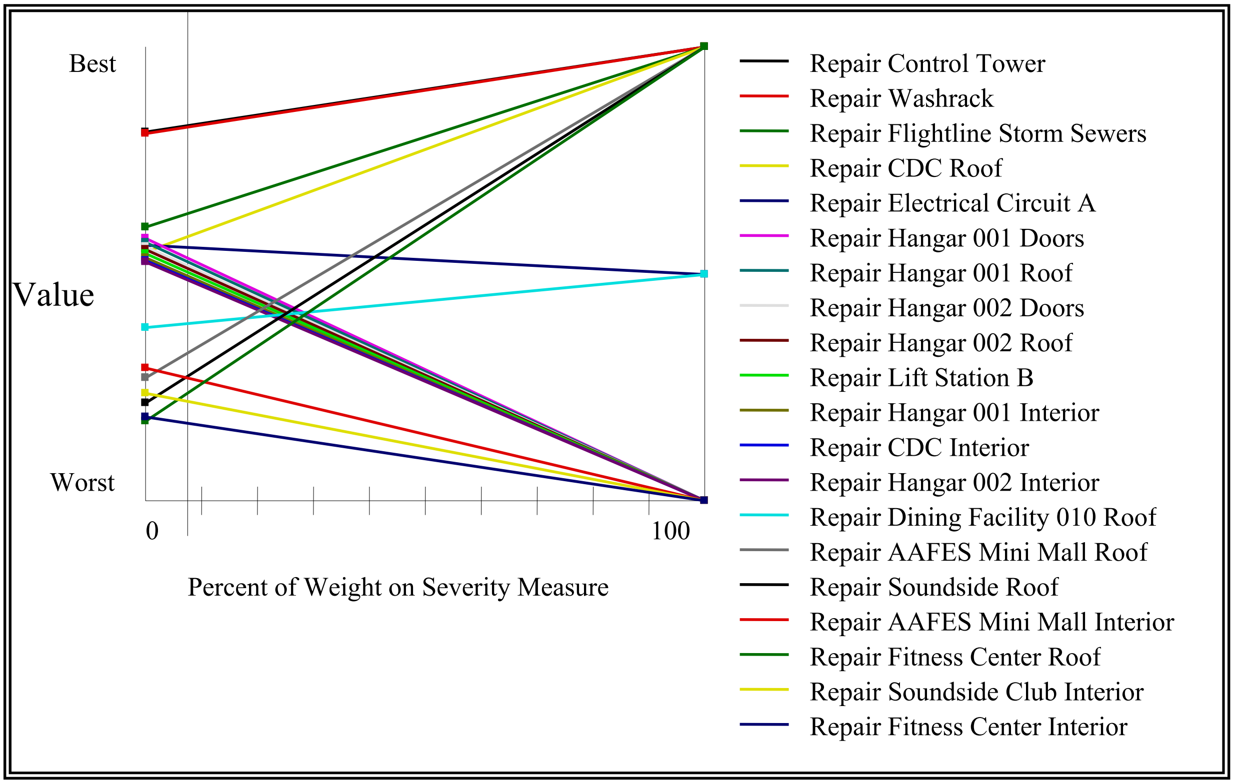


Figure 25. Sensitivity Analysis of Severity

The next step was to examine the sensitivity of the Infrastructure value. The measures that fall under Infrastructure value include: (1) electrical status, (2) natural gas (NG) status, (3) petroleum oil and lubricants (POL) status, (4) sewage status, (5) transportation status, and (6) H20 status. Theses measures were analyzed for sensitivity and the results concluded that the infrastructure measures were insensitive to weighting and on average would require individual increases of five to ten times their initial weights in order to significantly effect the outcome of the prioritized sets.

This observed insensitivity is a result of the lack of diversity and small overall extent of infrastructure damage caused by the three disaster events. Caution should be made before eliminating these measures though. If an earthquake, terrorist attack, or even the same type of disaster occurred at a later time, significant infrastructure damage may or may not occur. The infrastructure damage observed for the three hypothetical disasters in this research fell under the sewage, electrical, transportation, and water categories with no POL or NG damages being sustained. As would be expected from this data, the POL and NG sensitivity analyses showed no sensitivity to weighting. One suggestion that has been made to the decision maker is to combine the six measures currently under the infrastructure value in to one overall measure of infrastructure damage. However, this would amplify the effects of infrastructure damage because now all six measures would be combined into one with a global weight of 0.065 regardless if the damage occurred over all six categories. For these reasons, it was decided to leave the infrastructure measures as there were initially derived. When the Infrastructure value was analyzed for sensitivity to weighting alone, it was observed to be fairly sensitive over its entire range even though a majority of its measures were relatively insensitive.

The infrastructure tier of the VFT model should be analyzed further in order to be confident in its current weight and structure. This analysis would require testing more diverse sets of disaster recovery projects using a larger variety of disaster events. Figure 26 presents the sensitivity analysis for the Infrastructure value. The sensitivity graphs for the infrastructure measure are available in Appendix C.

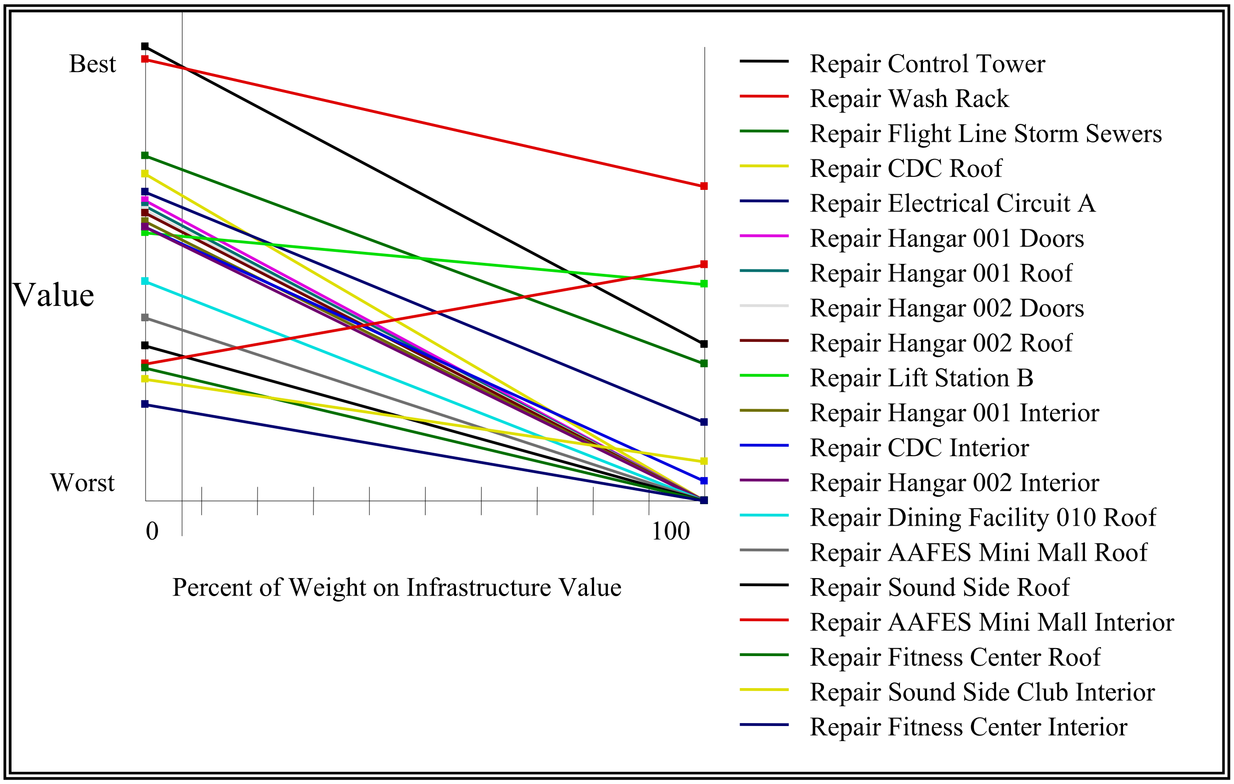


Figure 26. Sensitivity Analysis of the Infrastructure Value

The Time value proved to be the least sensitive. The current global weight is set at 0.05 and that weight would have to be doubled in order change the priority list by just one project. It is not until a weight of 0.17 that we see a dramatic difference in the outcome of the prioritized Hurricane X recovery project set. So, the range of weights between 0.05 and 0.17 are fairly insensitive to weighting for the Time value. Similarly, the same trends can be observed for both the Tornado X and Flood X project sets. The conclusion is that the 0.05 weight is appropriate for the Time value. Figure 27 presents the Time value sensitivity graph for Hurricane X.

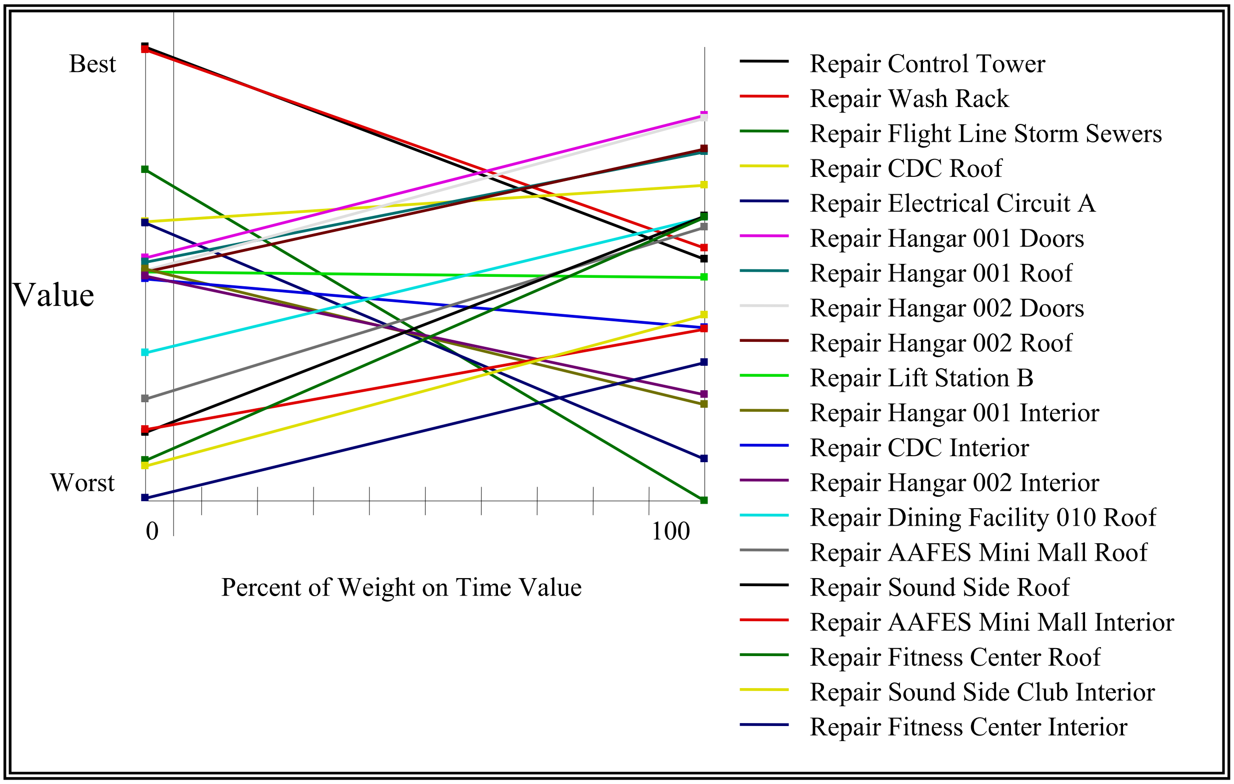


Figure 27. Sensitivity Analysis of the Time Value

The Delivery Time measure is included in the model because many times material availability is a limiting factor in post-disaster recovery. The Delivery Time measure is currently set at 0.01 and shows significant sensitivity when increased to 0.05. At 0.05 the weight change is observed to affect the ranking of 1/5th of the recovery projects in the Hurricane X set. The Delivery Time measure is highly sensitive in the positive direction for the other two recovery projects sets as well, but is most sensitive for the Tornado X project set. It is recommended that this measure be revisited by the decision maker to confirm the current weight if the results of the VFT model return unacceptable prioritization.

However, it should be noted that all three prioritized sets were accepted by the decision maker as acceptable straw men for further refinement using the integer knapsack program. Figure 28 displays the result of the sensitivity analysis for the Delivery Time measure for the Hurricane X projects set.

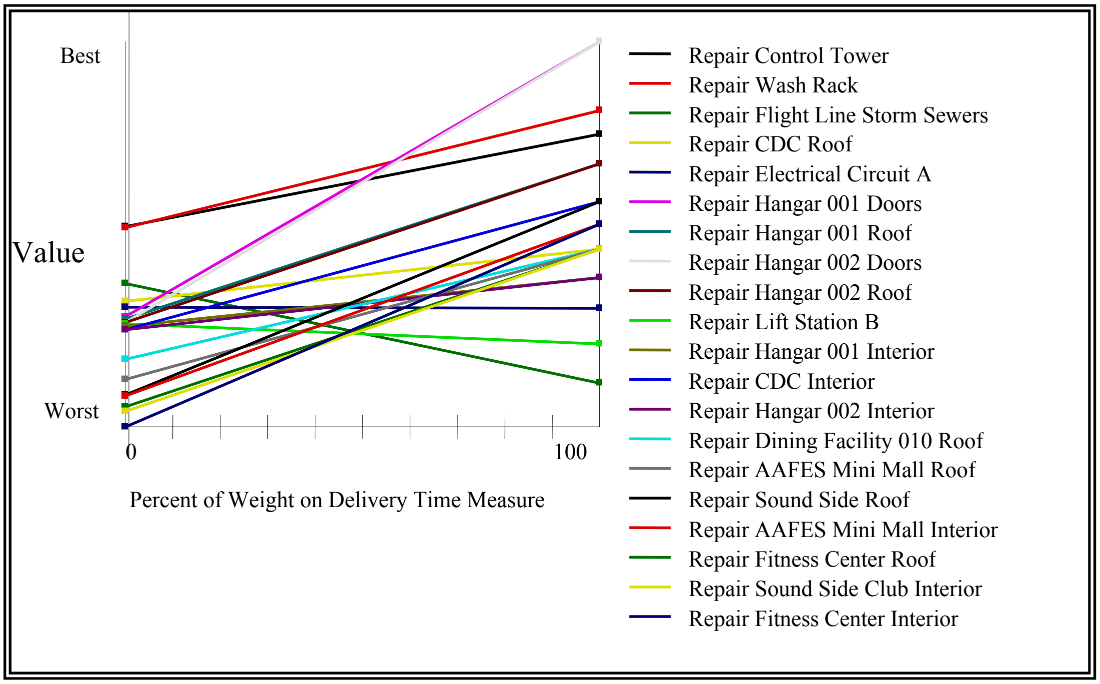


Figure 28. Sensitivity Analysis of the Delivery Time Measure

The Prevalence measure falls directly under the Time value in the hierarchy. Prevalence measures the availability of contractors on the market to perform a type of work specific to a particular reconstruction project with more priority being given to projects that have a lower supply of available contractors. The current global weight of Prevalence is 0.01. An increase of just 25% of the original prevalence weight is needed to affect a change in the priority list of two projects. The change has the net effect of raising each of these relatively low priority projects by one spot and changes their overall scores to within one ten thousandth of point of each other.

The weighting for Prevalence would need to be increased by a magnitude of approximately 5.3 in order to have a significant impact on the priority list. Similarly, the same general trends were observed for the other two disaster recovery programs. However, since it is unlikely that the decision maker values contractor availability five times more than he originally did, it is concluded that Prevalence measure, while sensitive to weighting, is acceptable at its current level. The results of the sensitivity analysis for the Prevalence measure are presented in figure 29.

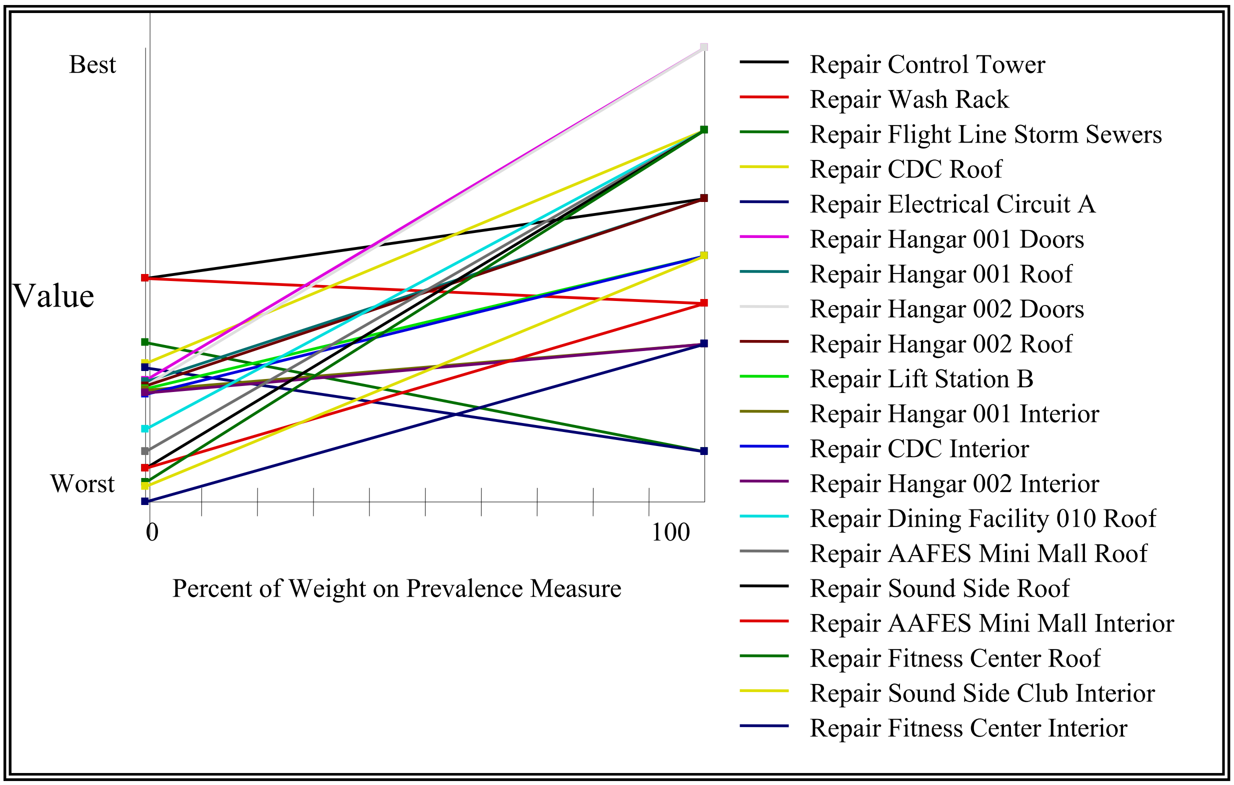


Figure 29. Sensitivity Analysis of Prevalence

The Successors measure is used to account for the value a decision maker places on a project that is the foundation of one or more successor projects. It is measured by the number of projects that directly depend on its completion. This measure's global weight was initially set at 0.02 and would need to be increased to 0.05 to influence the final prioritized list. This weight change would result in changing the rank of three projects, including interchanging the rank of the fourth and fifth projects. The Tornado X project set showed significant sensitivity between the 0.02 and 0.05 range and was the most sensitive set of the three. While there is only a relatively small change in weight needed to cause a significant shift in the overall priority list, the decision maker's confidence in the Time value's weight of 0.05 adds confidence to the current global weight of the successor measure at 0.01. Again, if the decision maker observed any unacceptable anomalies in the prioritized output of the VFT model, this measure's weight should be revisited. Figure 30 illustrates the results of the sensitivity analysis of Successors.

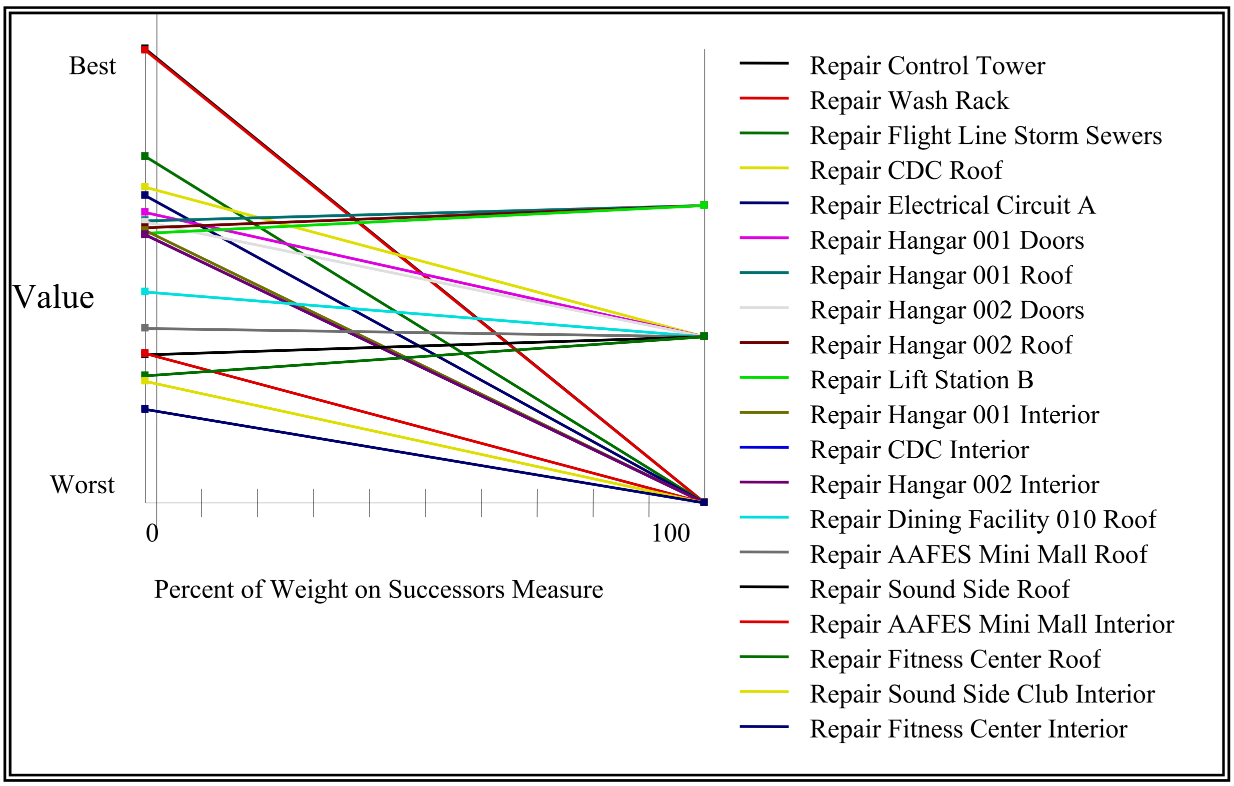


Figure 30. Sensitivity Analysis of the Successor Measure

Next the Estimated Time to Complete (ETC) measure was analyzed for weighting sensitivity. We observe sensitivity in the positive direction across the entire range of weighting possibilities. However, since we are dealing with one of four measures that represent the Time value of the hierarchy, we would be hard pressed to adjust the current weight of 0.01 because of the confidence in the global weight of the Time value.

It should be noted that if this were a traditional analysis of a VFT measure we would probably conclude that the measure is fairly insensitive to weighting since the top five alternatives would not change until the weighting for ETC was increased by a factor of ten. The sensitivity graph for the ETC measure of the Hurricane X recovery set is presented in figure 31. Figure 32 is a synopsis of the sensitivity analysis.

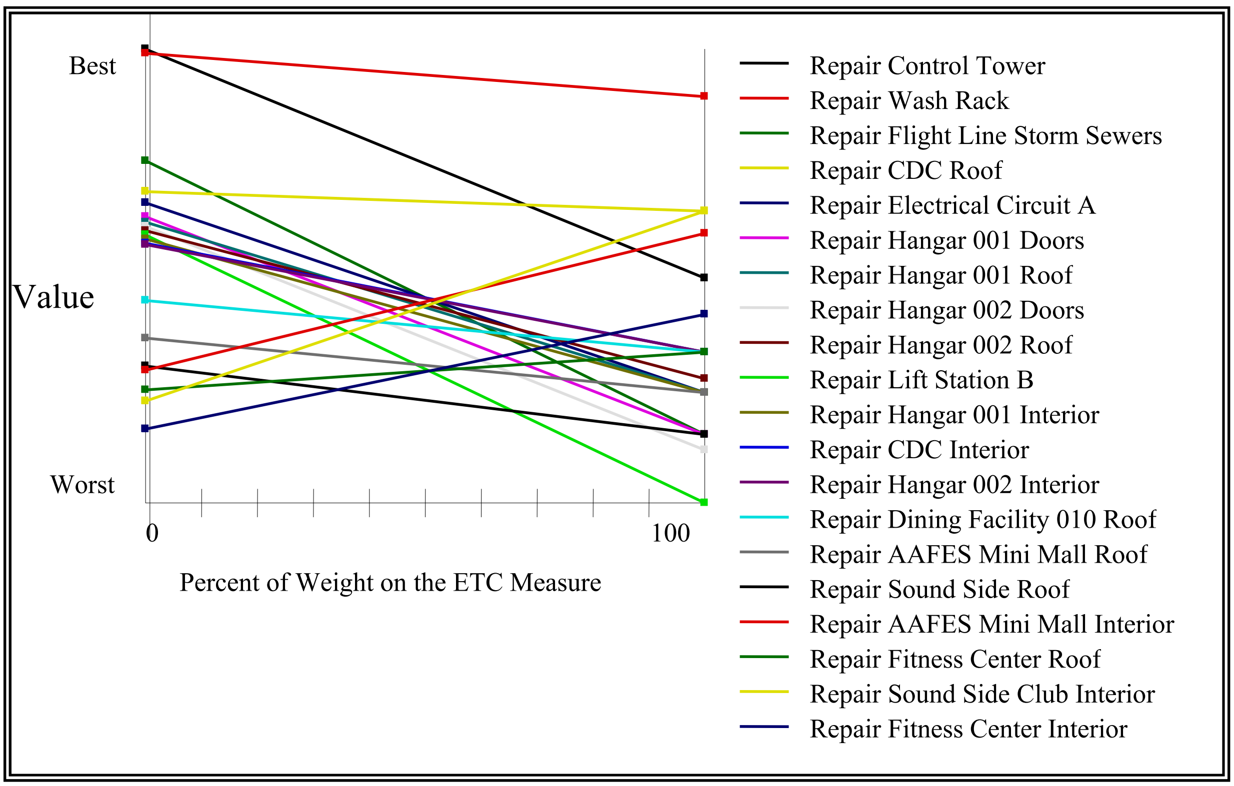


Figure 31. Sensitivity Analysis of the ETC Measure

Table 10. Synopsis of Sensitivity Analysis for Hurricane X

Value/Measure	Figure	Current Global Weight	Sensitive Weight Range	Insensitive Weight Range
Availability	16	0.10	0.00-0.09 & 0.14-1.00	0.10-0.13
Delta	17	0.30	0.00-0.19 & 0.49-1.00	0.20-0.48
Rank	18	0.30	0.00 – 1.00	N/A
Damage	19	0.25	0.00-0.22 & 0.27-1.00	0.23-0.27
Degree	20	0.01	0.00-1.00	N/A
Level	23	0.035	0.00-1.00	N/A
Risk	24	0.065	0.00-1.00	N/A
Severity	25	0.075	0.000-0.074 & 0.201-1.000	0.075-0.200
Infrastructure	26	0.065	0.00-1.00	N/A
Time	27	0.05	0.00-0.04 & 0.18-1.00	0.05-0.17
Delivery Time	28	0.01	0.00-1.00	N/A
Prevalence	29	0.01	0.00-1.00	N/A
Successors	30	0.02	0.00-1.00	N/A
ETC	31	0.01	0.00-1.00	N/A

4.8 Knapsack Program Analysis Overview

The integer programming 0-1 knapsack formulation utilized in this research is aimed at solving the problem of resource allocation and project selection. A 0-1 knapsack problem is one that restricts number of each item, in our case a particular project, to zero or one by using a binary decision variable while maximizing the objective function. For this research, the three objective functions are: (1) to maximize value, (2) to maximize value/cost, and finally (3) to maximize spending without taking into account value. For the purposes of this thesis, the "Solver" add-in function of Microsoft Excel will be utilized exclusively. The typical maximize form of a knapsack problem has its single constraint enforcing a budget. When there are budget limits over more than one time period, or multiple limited resources, a more general capital budgeting or multi-dimensional knapsack model is utilized (Rardin, 2000). Solving the resource allocation problem directly addresses the real-world situation where funding for a recovery program is released in phases over multiple time periods rather than in one lump sum. The practice of releasing funds in a series of drops is done to provide oversight, but more importantly to hold back money in the event of a more pressing contingency.

4.9 Knapsack Formulation that Maximizes Value

The first iteration of the 0-1 knapsack formulation focuses on maximizing the value that can be obtained from funding the optimal or near optimal set of projects while adhering to budget constraints. This allows the decision maker to see what set of recovery projects would provide that greatest value possible at the current funding level.

By maximizing value, we are taking into consideration only the combination of projects that maximizes value without violating the constraints of funding, nonnegativity, and the binary properties which allows us to either fund or not fund a project. The 0-1 knapsack problem was formulated to maximize value as follows:

Maximize

$$\sum_{j=1}^{n} v_j x_j$$

Subject to:

$$\sum_{j=1}^{n} c_j x_j \leq F$$

$x_j = 0$ or 1 $\quad j = 1,...,n$

Where n= number of item projects, x_1 through x_n. Each item x_j has a value v_j = the value score and a dollar value c_j. The maximum dollar value that we can fund is

F =construction budget.

Table 11 shows the MS Excel spreadsheet used to run the 0-1 knapsack for the value maximization of value as well as the results. The total damage sustained by Base X from Hurricane X was $6,760,944.00 and the funding limit for the first allocation of funds was set at $4,500,000.00. The costs, values, and value/cost ratios are provided for each corresponding project. It should be noted that the value/cost ratio has been normalized by a factor of 10^7 to make the output more pleasing to the decision maker. The results of this knapsack analysis concluded that 17 projects should be funded for a total of $4,486,260.00.

The total value added by this funding strategy was 5.39 which was the highest of the three funding strategies. The projects that were not funded were *Repair Electrical Circuit A, Repair Hangar 001 Doors, and Repair Sound Side Club Interior*. The project to repair the electrical circuit is currently temporarily repaired, only has a 4 week material delivery time, 0% mission impact, and a 45-day ETC and is therefore a good candidate for exclusion for this round of funding. Since the Sound Side Club roof has been addressed, the potential for further damage to the interior of the club will be mitigated and it to could be realistically excluded from the initial funding list as well. Since the Hangar 001 roof and interior projects address the main functions of the hangar, the work space and offices, the door project, while important, could be delayed a few months until more funding is available.

Table 11. Knapsack Formulation that Maximizes Value

Project	Fund	Cost	Value	Value/Cost
Repair Control Tower	1	$927,900.00	0.552	0.595
Repair Wash Rack	1	$950,000.00	0.55	0.579
Repair Flight Line Storm Sewers	1	$530,000.00	0.422	0.796
Repair CDC Roof	1	$178,500.00	0.388	2.174
Repair Electrical Circuit A	0	$1,554,900.00	0.374	0.241
Repair Hangar 001 Doors	0	$675,784.00	0.358	0.530
Repair Hangar 001 Roof	1	$380,000.00	0.351	0.924
Repair Hangar 002 Doors	1	$600,010.00	0.346	0.577
Repair Hangar 002 Roof	1	$420,000.00	0.342	0.814
Repair Lift Station B	1	$15,000.00	0.336	22.400
Repair Hangar 001 Interior	1	$90,000.00	0.332	3.689
Repair CDC Interior	1	$103,000.00	0.327	3.175
Repair Hangar 002 Interior	1	$75,000.00	0.326	4.347
Repair Dining Facility 010 Roof	1	$120,000.00	0.261	2.175
Repair AAFES Mini Mall Roof	1	$17,000.00	0.217	12.765
Repair Sound Side Roof	1	$11,000.00	0.185	16.818
Repair AAFES Mini Mall Interior	1	$32,000.00	0.182	5.688
Repair Fitness Center Roof	1	$15,500.00	0.159	10.258
Repair Sound Side Club Interior	0	$44,000.00	0.148	3.364
Repair Fitness Center Interior	1	$21,350.00	0.114	5.340
Totals for Hurricane X	**17**	**$6,760,944.00**		

Funding Limit	**$4,500,000.00**
Total Value	**5.39**
Objective: Max Value	**5.39**

SUBJECT TO:

	LS		RS	
Total Amount Funded	**$4,486,260.00**	**<=**	**$4,500,000.00**	**Fund Limit**

4.10 Knapsack Formulation that Maximizes the Value/Cost Ratio

The second iteration of the 0-1 knapsack program focuses on maximizing the value/cost ratio, or benefit to cost ratio, that can be obtained by funding the optimal or near optimal set of projects while adhering to budget constraints. This allows the decision maker to see what set of recovery projects would provide that greatest value/cost ratio possible at the current funding level. By maximizing the value/ cost ratio, we are taking into consideration the combination of projects that maximizes value per dollar added without violating the constraints of funding, nonnegativity, and the binary properties which allows us to either fund or not fund a project. The 0-1 knapsack problem was formulated to maximize the value/cost ratio as follows:

Maximize

$$\sum_{j=1}^{n} v_j x_j$$

Subject to:

$$\sum_{j=1}^{n} c_j x_j \leq F$$

$$x_j = 0 \text{ or } 1 \qquad j = 1,\ldots,n$$

Where n= number of item projects, x_1 through x_n. Each item x_j has a value v_j = the value/cost ratio and a dollar value c_j. The maximum dollar value that we can fund is *F =construction budget*.

Table 12 shows the MS Excel spreadsheet used to run the 0-1 knapsack for the value/cost maximization iteration as well as the results. The total damage sustained by Base X from Hurricane X and the amount initially funded are the same as in the last iteration. The costs, values, and value/cost ratios are provided for each corresponding project. The results of this knapsack analysis concluded that 18 projects should be funded for a total of $4,256,044.00. The total value added by this funding strategy was 5.35. The strategy to maximize the value/cost ratio resulted in funding the greatest number of projects, providing the second highest added value, but allocating the least monetary resources. The two projects that were not funded were *Repair Wash Rack and Repair Electrical Circuit A*. These projects would need to be funded with the next funding installment. The project to repair the electrical circuit is currently temporarily repaired and was discussed in the previous analysis. The decision to delete the wash rack project may be very difficult to for the decision maker due to its high overall rank and 15% mission capability delta. The decision maker may choose to accept this funding strategy or promote a work-around. Also, he or she may be inclined to alter the strategy by deleting other projects from the list in order to fully fund the wash rack. The point being that the results of these knapsack analyses do not totally remove the decision maker from the decision. However, they do provide an informed strategy where one may have been previously unavailable.

Table 12. Knapsack Formulation that Maximizes the Value/Cost Ratio

Project	Fund	Cost	Value	Value/Cost
Repair Control Tower	1	$927,900.00	0.552	0.595
Repair Wash Rack	0	$950,000.00	0.55	0.579
Repair Flight Line Storm Sewers	1	$530,000.00	0.422	0.796
Repair CDC Roof	1	$178,500.00	0.388	2.174
Repair Electrical Circuit A	0	$1,554,900.00	0.374	0.241
Repair Hangar 001 Doors	1	$675,784.00	0.358	0.530
Repair Hangar 001 Roof	1	$380,000.00	0.351	0.924
Repair Hangar 002 Doors	1	$600,010.00	0.346	0.577
Repair Hangar 002 Roof	1	$420,000.00	0.342	0.814
Repair Lift Station B	1	$15,000.00	0.336	22.400
Repair Hangar 001 Interior	1	$90,000.00	0.332	3.689
Repair CDC Interior	1	$103,000.00	0.327	3.175
Repair Hangar 002 Interior	1	$75,000.00	0.326	4.347
Repair Dining Facility 010 Roof	1	$120,000.00	0.261	2.175
Repair AAFES Mini Mall Roof	1	$17,000.00	0.217	12.765
Repair Sound Side Roof	1	$11,000.00	0.185	16.818
Repair AAFES Mini Mall Interior	1	$32,000.00	0.182	5.688
Repair Fitness Center Roof	1	$15,500.00	0.159	10.258
Repair Sound Side Club Interior	1	$44,000.00	0.148	3.364
Repair Fitness Center Interior	1	$21,350.00	0.114	5.340
Totals for Hurricane X	**18**	**$6,760,944.00**		

Funding Limit	**$4,500,000.00**
Total Value	**5.346**
Objective: Max Value/Cost	**96.4261495**

SUBJECT TO:	**LS**		**RS**	
Total Amount Funded	**$4,256,044.00**	**<=**	**$4,500,000.00**	**Fund Limit**

4.11 Knapsack Formulation that Maximizes Spending

The second iteration of the 0-1 knapsack formulation focuses on maximizing the total dollars spent on the recovery program by funding the optimal or near optimal set of projects while adhering to budget constraints. This allows the decision maker to see what set of recovery projects would provide that greatest value/cost ratio possible at the current funding level.

Conversely, by maximizing spending, we are taking into consideration the combination of projects that maximizes dollars spent with no consideration for value added. This is done without violating the constraints of funding, nonnegativity, and the binary properties which allows us to either fund or not fund a project. The 0-1 knapsack problem was formulated to maximize spending is as follows:

Maximize

$$\sum_{j=1}^{n} c_j x_j$$

Subject to:

$$\sum_{j=1}^{n} c_j x_j \le F$$

$$x_j = 0 \text{ or } 1 \qquad j = 1,...,n$$

Where n= number of item projects, x_1 through x_n. Each item x_j has a dollar value c_j. The maximum dollar value that we can fund is

F =construction budget.

Table 13 shows the MS Excel spreadsheet used to run the 0-1 knapsack for the spending maximization iteration as well as the results. The total damage sustained by Base X from Hurricane X was $6,760,944.00 and the funding limit for the first allocation of funds was set at $4,500,000.00. The results of this knapsack analysis concluded that 12 projects should be funded for a total of $4,498,044.00. The total value added by this funding strategy was only 3.42.

The strategy to maximize the value/cost ratio resulted in funding the least number of projects, providing the lowest added value, and allocating the most monetary resources, but by only $11,784. Under this strategy, four out of the top ten valued projects including the top two prioritized projects do not get funded. Additionally, since the value of the decision maker has not been considered, several projects are funded that do not stand the test of reason. For instance, this strategy funds the interior repair of the Child Development Center without funding the roof repair on the same building. This same error occurs on the Sound Side Club facility as well.

Table 13. Knapsack Formulation that Maximizes Spending

Project	Fund	Cost	Value	Value/Cost
Repair Control Tower	0	$927,900.00	0.552	0.595
Repair Wash Rack	0	$950,000.00	0.55	0.579
Repair Flight Line Storm Sewers	1	$530,000.00	0.422	0.796
Repair CDC Roof	0	$178,500.00	0.388	2.174
Repair Electrical Circuit A	1	$1,554,900.00	0.374	0.241
Repair Hangar 001 Doors	1	$675,784.00	0.358	0.530
Repair Hangar 001 Roof	1	$380,000.00	0.351	0.924
Repair Hangar 002 Doors	1	$600,010.00	0.346	0.577
Repair Hangar 002 Roof	1	$420,000.00	0.342	0.814
Repair Lift Station B	0	$15,000.00	0.336	22.400
Repair Hangar 001 Interior	0	$90,000.00	0.332	3.689
Repair CDC Interior	1	$103,000.00	0.327	3.175
Repair Hangar 002 Interior	0	$75,000.00	0.326	4.347
Repair Dining Facility 010 Roof	1	$120,000.00	0.261	2.175
Repair AAFES Mini Mall Roof	1	$17,000.00	0.217	12.765
Repair Sound Side Roof	0	$11,000.00	0.185	16.818
Repair AAFES Mini Mall Interior	1	$32,000.00	0.182	5.688
Repair Fitness Center Roof	0	$15,500.00	0.159	10.258
Repair Sound Side Club Interior	1	$44,000.00	0.148	3.364
Repair Fitness Center Interior	1	$21,350.00	0.114	5.340
Totals for Hurricane X	**12**	**$6,760,944.00**		

Funding Limit	**$4,500,000.00**
Total Value	**3.442**
Objective: Spending	**$4,498,044.00**

SUBJECT TO:	**LS**		**RS**	
Total Amount Funded	**$4,498,044.00**	**<=**	**$4,500,000.00**	**Fund Limit**

Chapter 5 provides the conclusions to this research. The areas discussed in chapter 5 include: conclusions, limitations, reflection on research questions, and suggestions for future areas of research.

V. Conclusions and Recommendations

5.1 Overview

Chapter five provides a review of this thesis by addressing the research questions postulated in chapter 1. The development of a VFT decision-making tool for prioritizing disaster recovery projects is discussed in relation to its strengths and limitations. Finally, recommendations for future research are presented.

5.2 Review of Research Questions

1. What does the Air force value in identifying the priorities of a natural disaster reconstruction program?

The process of identifying the values AF leaders have with regard to a natural disaster recovery program has been described and presented in detail by completing steps one and two of the VFT process. The VFT hierarchy was formed from a collaboration of technical experts and AF leaders and was ultimately ratified by the decision maker. This value hierarchy illustrates the values of our AF decision maker with respect to prioritizing a disaster recovery program. The importance that each value has in prioritizing a recovery project is conveyed by it relative position in the hierarchy and by its global weight. The measures developed to score alternatives on the value hierarchy were created based on Air Force Instructions, current practices, and most importantly the experience and prerogative of the decision maker.

Research question one has been answered using the VFT approach for one hypothetical AF base. The value hierarchy would need to be adjusted and then ratified by the responsible decision makers at each base before implementation.

2. How can the Air Force optimally allocate its resources during a recovery effort?

The answer to this question is addressed through the use of the 0-1 Knapsack analyses that were presented in chapter 4. The problem of what project set to fund was attacked by using three different funding strategies. First, a strategy that maximized the value obtained by funding a specific set of recovery projects was examined. Then a benefit to cost funding strategy was analyzed to identify the set of recovery projects that maximized the value per dollar allocated. Finally, a method based purely on maximizing the allocation of funds was compared to the previous two methods. By utilizing these 0-1 knapsack formulations, the Air Force will be able to choose a strategy that is optimal or near optimal with respect to disaster recovery project funds allocation. Based on this research, it is recommended that the objective function should be to maximize either value or the value/cost ratio to achieve the near optimal set of recovery projects.

3. What are the advantages and disadvantages of the new prioritization tool versus the current method*?*

The literature review in chapter 2, as well as the review of the AFIs and AFPAMs in chapter 1, exhaustively searched for a current disaster recovery prioritization method but none were found. The USAF has made an effort to standardize its disaster preparation and initial response through the creation of the Contingency Response Plan (CRP) which is described in AFI 10-211 with additional guidance available in AFPAM 10-219 Volumes 1-3. However, these AFIs and pamphlets provide only general recommendations for post-disaster recovery and are primarily concerned with the initial response. The remaining task of reconstructing or repairing damaged buildings and infrastructure was not specifically addressed by these or any other AFI or AFPAM. However, this is not to imply that there are no standardized practices in place at any of the Air Force's bases. The literature review findings were that no official formalized method for prioritizing recovery projects after disasters has be put forth to date. The fruits of this research effort include the creation of a formalized strategy for disaster recovery through the implementation of a VFT based decision tool. This work is a significant departure from the reactionary alternative based approaches that are currently employed. The following section details the strengths and limitations of the VFT approach to disaster recovery project prioritization.

5.3 Model Strengths

The VFT model and 0-1 knapsack formulations developed in this thesis have several inherent strengths for assisting the decision maker in tackling prioritization and resource allocation issues. Many of these strengths are related to the VFT process itself. Improving communication is a strength that is readily apparent in the VFT process. The output produced including the stacked bar ranking charts and the VFT hierarchy dramatically improves the decision maker's ability to explain the reasons for his or her decision. This transparency of the process also improves the feedback loops with those involved in the reconstruction effort by empowering them with the knowledge of how the decision-making process is structured. The fact that this VFT process utilizes the experience and expertise of personnel from diverse backgrounds and participatory roles in the recovery process increases the interconnectivity of the decision-making process. Because the parties vital to the outcome of the recovery program were involved in the initial brainstorming process they have in effect been included in the decision. Another strength of this VFT process is that it guides strategic thinking by requiring the leadership to think in terms of the decision's objectives and values rather than of the available alternatives. This strength is particular useful for this research because of the uncertain nature of the problem and the resulting alternatives that ensue. The measures used in the VFT hierarchy are easy to understand and were created to involve as many of our highly qualified civil engineer squadron personnel as possible. By simplifying the measures, the job of collecting data can be allocated more efficiently and because the measures are understood by all in advance of the disaster a plan to guide the collection of information can be created.

Increasing participation in the recovery process and improving the decision maker's ability to evaluate alternatives are two assets of the VFT process shown in this research.

The strength of the 0-1 knapsack analysis lies in its ability to combine the results of the ranked priority list, the corresponding value scores, and the recovery project cost data to analyze decisions based on funding strategies. As a result, the decision maker can make a more informed decision by quickly and accurately considering multiple funding strategies.

5.4 Model Limitations

The main limitation of this research is that it was not tested on real-world disaster events at a real AF base, but rather on three hypothetical disasters at a hypothetical base. Furthermore, the recovery projects were hypothetical as well. Each project's data was based on historical and manufactured recovery projects based on similar disaster events experienced by the modeler and decision maker. Subsequently, the associated cost data is also hypothetical. For the purposes of this research these limitations were acceptable. However, in order to implement this model further, sensitivity analysis and knapsack evaluations based on real-world data should be conducted. Another limitation of this research is a need to refine the data collection procedures. For this thesis, the data needed to score the alternatives was created not collected. In a post-disaster contingency environment, the procedures and methods for collecting the measure data for recovery projects would need to be expressly documented and the personnel charged with this collection would need to be properly trained.

The importance of obtaining standardized data is a key component of being able to provide an objective analysis. If this work could be tested during a real disaster event more knowledge of its applicability could be gleaned.

5.5 Conclusions

The purpose of this research was to create a decision-making tool to objectively prioritize disaster recovery projects and then to determine the optimal allocation of funds given a fixed budget. The VFT process combined with the 0-1 knapsack formulation achieved these objectives. This combination of a VFT approach and a knapsack integer program will empower the decision maker with an improved insight into the strategic decision-making process for prioritizing and funding disaster recovery construction programs.

5.6 Recommendations for Future Work

Future work need to be conducted on creating adequate procedures and techniques for evaluating the measures created in this thesis. For example, mission capability is measured by the percentage of the mission capability that is degraded by damage addressed by a recovery project. However, this research has not identified the procedure for obtaining the mission capability data. The composition of the team used during the brainstorming session also needs to be considered. This research included only civil engineer personnel whereas this model would need to be vetted by a more diverse team. Finally, future research based on integrating this decision tool into the Air Forces geographical information system and project databases should be examined.

Appendix A: Project Data and Raw Scores

Table 14. Project Data for Hurricane X

	Availability	Degree	Delivery Time	Delta	Successors	Electric Status	ETC	H2O Status	Level	NG Status	POL Status	Prevalence	Rank	Risk	Severity	Sewage Status	Transportation Status
Repair AAFES Mini Mall Interior	None	0.0%	7	0.0%	0	Temporarily Repaired	110	Localized	15.0%	Operational	Operational	5	60	Moderate	No Structural Damage	Operational	Operational
Repair AAFES Mini Mall Roof	None	35.0%	6	0.0%	1	Operational	45	Operational	0.0%	Operational	Operational	2	60	Moderate	Moderate	Operational	Operational
Repair CDC Interior	None	0.0%	8	2.5%	0	Operational	60	Operational	30.0%	Operational	Operational	4	15	Moderate	No Structural Damage	Temporarily Repaired	Operational
Repair CDC Roof	None	20.0%	6	0.0%	1	Operational	120	Operational	0.0%	Operational	Operational	2	15	High	Moderate	Operational	Operational
Repair Control Tower	None	25.0%	12	15.0%	0	Localized	90	Operational	20.0%	Operational	Operational	3	3	Moderate	Moderate	Operational	Operational
Repair Dining Facility 010 Roof	One	55.0%	6	4.0%	1	Operational	60	Operational	0.0%	Operational	Operational	2	25	Moderate	Nominal	Operational	Operational
Repair Electrical Circuit A	None	0.0%	4	0.0%	0	Temporarily Repaired	45	Operational	0.0%	Operational	Operational	10	8	Low	Nominal	Operational	Operational
Repair Fitness Center Interior	Two	0.0%	7	0.0%	0	Operational	75	Operational	40.0%	Operational	Operational	6	51	Moderate	No Structural Damage	Operational	Operational
Repair Fitness Center Roof	Two	15.0%	6	0.0%	1	Operational	60	Operational	0.0%	Operational	Operational	2	51	Moderate	Moderate	Operational	Operational
Repair Flight Line Storm Sewers	None	0.0%	2	25.0%	0	Operational	30	Operational	0.0%	Operational	Operational	10	20	High	Moderate	Systemic	Systemic
Repair Hangar 001 Doors	None	90.0%	26	3.0%	1	Operational	30	Operational	0.0%	Operational	Operational	1	10	Low	No Structural Damage	Operational	Operational
Repair Hangar 001 Interior	None	0.0%	5	1.0%	0	Operational	45	Operational	10.0%	Operational	Operational	6	10	Low	No Structural Damage	Operational	Operational
Repair Hangar 001 Roof	None	60.0%	10	2.0%	2	Operational	45	Operational	0.0%	Operational	Operational	3	10	Low	No Structural Damage	Operational	Operational
Repair Hangar 002 Doors	None	50.0%	26	3.0%	1	Operational	25	Operational	0.0%	Operational	Operational	1	11	Low	No Structural Damage	Operational	Operational
Repair Hangar 002 Interior	None	0.0%	5	2.0%	0	Operational	60	Operational	20.0%	Operational	Operational	6	11	Low	No Structural Damage	Operational	Operational
Repair Hangar 002 Roof	None	70.0%	10	2.0%	2	Operational	50	Operational	0.0%	Operational	Operational	3	11	Low	No Structural Damage	Operational	Operational
Repair Lift Station B	None	0.0%	3	5.0%	3	Localized	7	Operational	0.0%	Operational	Operational	4	15	High	No Structural Damage	Systemic	Operational
Repair Sound Side Club Interior	One	0.0%	6	1.0%	0	Operational	120	Operational	45.0%	Operational	Operational	4	59	Moderate	No Structural Damage	Localized	Operational
Repair Sound Side Roof	One	30.0%	8	0.0%	1	Operational	30	Operational	0.0%	Operational	Operational	2	59	Moderate	Moderate	Operational	Operational
Repair Wash Rack	None	75.0%	14	15.0%	0	Localized	180	Localized	0.0%	Operational	Operational	5	4	Moderate	Moderate	Operational	Operational

Table 15. Project Data for Tornado X

	Availability	Degree	Delivery Time	Delta	Successors	Electric Status	ETC	H2O Status	Level	NG Status	POL Status	Prevalence	Rank	Risk	Severity	Sewage Status	Transportation Status
Repair AAFES BX Roof	None	35%	6	0%	1	Operational	40	Operational	0%	Operational	Operational	2	40	Moderate	Moderate	Operational	Operational
Repair Billeting Interior	None	45%	6	3%	0	Operational	60	Operational	50%	Operational	Operational	5	38	High	No Structural Damage	Operational	Operational
Repair BX Interior	None	30%	4	0%	0	Operational	60	Operational	30%	Operational	Operational	4	40	Moderate	No Structural Damage	Operational	Operational
Repair Control Tower Interior	Two	0%	14	8%	0	Temporarily Repaired	75	Operational	40%	Operational	Operational	6	3	Moderate	Nominal	Operational	Operational
Repair Control Tower Roof	None	90%	12	7%	1	Operational	60	Operational	0%	Operational	Operational	2	3	High	Moderate	Operational	Operational
Repair Doors Helicopter Hangar 006	None	90%	20	3%	1	Operational	20	Operational	0%	Operational	Operational	1	12	Moderate	Moderate	Operational	Operational
Repair Electrical Circuit A	None	0%	2	20%	0	Systemic	10	Operational	0%	Operational	Operational	10	8	High	No Structural Damage	Operational	Operational
Repair Fire Station #1	None	35%	4	10%	0	Operational	30	Operational	20%	Operational	Operational	10	12	Moderate	No Structural Damage	Operational	Operational
Repair Fire Training Tower	None	20%	3	0%	0	Operational	60	Localized	0%	Operational	Operational	2	55	Low	No Structural Damage	Operational	Operational
Repair Fitness Center Interior	One	0%	13	0%	0	Operational	120	Operational	10%	Operational	Operational	7	59	Low	No Structural Damage	Operational	Operational
Repair Fitness Center Roof	Two	15%	6	0%	1	Operational	60	Operational	0%	Operational	Operational	2	59	Moderate	Moderate	Operational	Operational
Repair Hangar 002 Roof	None	60%	16	2%	2	Operational	45	Operational	0%	Operational	Operational	3	10	Low	No Structural Damage	Operational	Operational
Repair Hangar 002 Doors	None	50%	26	3%	1	Operational	25	Operational	0%	Operational	Operational	1	11	Low	No Structural Damage	Operational	Operational
Repair Hangar 002 Interior	None	0%	5	1%	0	Operational	60	Operational	20%	Operational	Operational	6	11	Low	No Structural Damage	Operational	Operational
Repair Roof Clinic	None	0%	2	4%	0	Operational	30	Operational	0%	Operational	Operational	10	20	High	Moderate	Systemic	Systemic
Repair Roof Helicopter Hangar 006	None	70%	8	5%	2	Operational	30	Operational	0%	Operational	Operational	2	12	Moderate	Moderate	Operational	Operational
Repair Roof Helicopter Maintenance Bldg	None	0%	10	15%	1	Operational	90	Operational	0%	Operational	Operational	2	29	High	Moderate	Operational	Operational
Repair Roof Youth Center	None	30%	12	1%	1	Operational	40	Operational	0%	Operational	Operational	2	30	High	Moderate	Operational	Operational
Repair Smith Ave Traffic Signal	None	10%	8	0%	0	Localized	3	Operational	0%	Operational	Operational	3	60	High	Catastrophic	Operational	Localized
Repair Youth Center Interior	None	0%	16	1%	0	Temporarily Repaired	90	Localized	20%	Operational	Operational	6	30	High	Nominal	Operational	Operational

Table 16. Project Data for Flood X

	Availability	Degree	Delivery Time	Delta	Successors	Electric Status	ETC	H2O Status	Level	NG Status	POL Status	Prevalence	Rank	Risk	Severity	Sewage Status	Transportation Status
Base Wide Mold Remediation	None	0%	0	10%	4	Operational	90	Operational	30%	Operational	Operational	3	25	High	No Structural Damage	Operational	Operational
Debris Removal Base Wide	None	0%	0	0%	0	Operational	45	Operational	0%	Operational	Operational	10	60	Low	No Structural Damage	Operational	Operational
Repair AAFES Gas Station Interior	None	0%	8	0%	0	Operational	45	Operational	20%	Operational	Operational	5	60	Low	No Structural Damage	Localized	Operational
Repair Retention Pond A	None	0%	0	0%	0	Operational	14	Operational	0%	Operational	Operational	10	60	Low	Moderate	Systemic	Operational
Repair AAFES Mini Mall Interior	None	0%	7	0%	0	Operational	60	Operational	15%	Operational	Operational	5	60	Low	No Structural Damage	Localized	Operational
Repair Dining Facility Interior	One	0%	6	2%	0	Operational	75	Operational	40%	Operational	Operational	5	25	Moderate	No Structural Damage	Localized	Operational
Repair Jogging Path	None	0%	0	0%	0	Operational	30	Operational	0%	Operational	Operational	10	60	Low	No Structural Damage	Operational	Operational
Repair Lift Station C	None	0%	10	0%	3	Localized	7	Operational	0%	Operational	Operational	5	15	Moderate	No Structural Damage	Systemic	Operational
Repair Lift Station D	None	0%	10	0%	2	Localized	7	Operational	0%	Operational	Operational	4	19	Moderate	No Structural Damage	Systemic	Operational
Repair Main Base Landscaping	None	70%	4	0%	0	Operational	50	Operational	0%	Operational	Operational	8	60	Low	No Structural Damage	Operational	Operational
Repair Main Base Roads	None	50%	2	3%	0	Operational	45	Operational	0%	Operational	Operational	4	11	Low	Moderate	Operational	Localized
Repair Main Base Storm Sewers	None	0%	3	3%	0	Operational	30	Operational	0%	Operational	Operational	10	10	Low	No Structural Damage	Systemic	Operational
Repair Outdoor Recreation Center Interior	None	0%	4	0%	0	Operational	25	Operational	10%	Operational	Operational	5	60	Moderate	No Structural Damage	Localized	Operational
Repair Outdoor Recreation Parking Lot	Two	15%	6	0%	0	Operational	60	Operational	0%	Operational	Operational	2	60	Moderate	Moderate	Operational	Operational
Repair Retention Ponds B	None	0%	0	0%	0	Operational	21	Operational	0%	Operational	Operational	10	60	Low	Moderate	Systemic	Operational
Repair Sound Side Club Interior	None	0%	3	0%	0	Operational	120	Localized	45%	Operational	Operational	5	59	High	Nominal	Localized	Operational
Repair Sound Side Landscaping	None	80%	4	0%	0	Operational	20	Operational	0%	Operational	Operational	8	60	Low	No Structural Damage	Operational	Operational
Repair Sound Side Storm Sewers	None	0%	3	0%	0	Operational	15	Operational	0%	Operational	Operational	10	50	Low	No Structural Damage	Systemic	Operational
Repair Sound Side Roads	None	0%	2	0%	0	Operational	30	Operational	0%	Operational	Operational	4	50	Low	Nominal	Operational	Localized
Repair Youth Center Interior	None	0%	6	0%	0	Operational	120	Operational	22%	Operational	Operational	5	15	Moderate	Moderate	Localized	Operational

Table 17. Raw Scores for Hurricane X

	Prioritized Project List Value	Mission Priority Value	Mission Capability Value	Delta Measure	Rank Measure	Damage Value	Redundancy Value	Availability Measure	Severity Measure	Structural Value	Safety Value	Infrastructure Value	Risk Measure	Time Value	Interior Value	Level Measure	Successors Measure	Predecessor Projects Value	Electric Status Measure	H2O Status Measure
Weight	1	0.3	0.3	0.3	0.3	0.25	0.1	0.1	0.075	0.075	0.065	0.065	0.065	0.05	0.035	0.035	0.02	0.02	0.02	0.02
Repair Control Tower	0.552	0.908	0.15	0.15	0.908	0.467	1	1	0.667	0.667	0.667	0.2	0.667	0.349	0.2	0.2	0	0	0.667	0
Repair Washrack	0.55	0.865	0.15	0.15	0.865	0.511	1	1	0.667	0.667	0.667	0.4	0.667	0.36	0	0	0	0	0.667	0.667
Repair Flightline Storm Sewers	0.422	0.385	0.25	0.25	0.385	0.506	1	1	0.667	0.667	1	0.175	1	0.104	0	0	0	0	0	0
Repair CDC Roof	0.388	0.5	0	0	0.5	0.469	1	1	0.667	0.667	1	0	1	0.424	0	0	0.206	0.206	0	0
Repair Electrical Circuit A	0.374	0.711	0	0	0.711	0.213	1	1	0.333	0.333	0.333	0.1	0.333	0.147	0	0	0	0	0.333	0
Repair Hangar 001 Doors	0.358	0.644	0.03	0.03	0.644	0.124	1	1	0	0	0.333	0	0.333	0.494	0	0	0.206	0.206	0	0
Repair Hangar 001 Roof	0.351	0.644	0.02	0.02	0.644	0.116	1	1	0	0	0.333	0	0.333	0.458	0	0	0.37	0.37	0	0
Repair Hangar 002 Doors	0.346	0.613	0.03	0.03	0.613	0.113	1	1	0	0	0.333	0	0.333	0.491	0	0	0.206	0.206	0	0
Repair Hangar 002 Roof	0.342	0.613	0.02	0.02	0.613	0.119	1	1	0	0	0.333	0	0.333	0.461	0	0	0.37	0.37	0	0
Repair Lift Station B	0.336	0.406	0.05	0.05	0.406	0.332	1	1	0	0	1	0.275	1	0.331	0	0	0.37	0.37	0.667	0
Repair Hangar 001 Interior	0.332	0.644	0.01	0.01	0.644	0.101	1	1	0	0	0.333	0	0.333	0.203	0.1	0.1	0	0	0	0
Repair CDC Interior	0.327	0.5	0.025	0.025	0.5	0.222	1	1	0	0	0.667	0.025	0.667	0.28	0.3	0.3	0	0	0	0
Repair Hangar 002 Interior	0.326	0.613	0.01	0.01	0.613	0.115	1	1	0	0	0.333	0	0.333	0.212	0.2	0.2	0	0	0	0
Repair Dining Facility 010 Roof	0.261	0.292	0.04	0.04	0.292	0.301	0.667	0.667	0.333	0.333	0.667	0	0.667	0.391	0	0	0.206	0.206	0	0
Repair AAFES Mini Mall Roof	0.217	0	0	0	0	0.392	1	1	0.667	0.667	0.667	0	0.667	0.382	0	0	0.206	0.206	0	0
Repair Soundside Roof	0.185	0.004	0	0	0.004	0.389	0.667	0.667	0.667	0.667	0.667	0	0.667	0.393	0	0	0.206	0.206	0	0
Repair AAFES Mini Mall Interior	0.182	0	0	0	0	0.272	1	1	0	0	0.667	0.3	0.667	0.279	0.15	0.15	0	0	0.333	0.667
Repair Fitness Center Roof	0.159	0.038	0	0	0.038	0.378	0.333	0.333	0.667	0.667	0.667	0	0.667	0.391	0	0	0.206	0.206	0	0
Repair Soundside Club Interior	0.148	0.004	0.01	0.01	0.004	0.249	0.667	0.667	0	0	0.667	0.05	0.667	0.292	0.45	0.45	0	0	0	0
Repair Fitness Center Interior	0.114	0.038	0	0	0.038	0.229	0.333	0.333	0	0	0.667	0	0.667	0.244	0.4	0.4	0	0	0	0

Table 17. Raw Scores for Hurricane X (Continued)

	Prioritized Project List Value	Water Value	Electric Value	Cosmetic Value	Degree Measure	Project Duration Value	Prevalence Measure	Estimated Time to Complete Measure	Delivery Time Measure	Material Availability Value	Contractor Availabilty Value	POL Value	POL Status Measure	Transportation Value	Transportation Status Measure	Sewage Value	Sewage Status Measure	NG Status Measure	Natural Gas Value
Weight	1	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.007	0.007	0.005	0.005	0.005	0.005
Repair Control Tower	0.552	0	0.667	0.333	0.333	0.288	0.707	0.288	0.751	0.751	0.707	0	0	0	0	0	0	0	0
Repair Washrack	0.55	0.667	0.667	0.834	0.834	0.5	0.5	0.5	0.802	0.802	0.5	0	0	0	0	0	0	0	0
Repair Flightline Storm Sewers	0.422	0	0	0	0	0.106	0.21	0.106	0.206	0.206	0.21	0	0	1	1	1	1	0	0
Repair CDC Roof	0.388	0	0	0.22	0.22	0.366	0.841	0.366	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair Electrical Circuit A	0.374	0	0.333	0	0	0.155	0.21	0.155	0.37	0.37	0.21	0	0	0	0	0	0	0	0
Repair Hangar 001 Doors	0.358	0	0	0.933	0.933	0.106	1	0.106	0.952	0.952	1	0	0	0	0	0	0	0	0
Repair Hangar 001 Roof	0.351	0	0	0.734	0.734	0.155	0.707	0.155	0.685	0.685	0.707	0	0	0	0	0	0	0	0
Repair Hangar 002 Doors	0.346	0	0	0.667	0.667	0.089	1	0.089	0.952	0.952	1	0	0	0	0	0	0	0	0
Repair Hangar 002 Roof	0.342	0	0	0.8	0.8	0.171	0.707	0.171	0.685	0.685	0.707	0	0	0	0	0	0	0	0
Repair Lift Station B	0.336	0	0.667	0	0	0.026	0.595	0.026	0.293	0.293	0.595	0	0	0	0	1	1	0	0
Repair Hangar 001 Interior	0.332	0	0	0	0	0.155	0.42	0.155	0.439	0.439	0.42	0	0	0	0	0	0	0	0
Repair CDC Interior	0.327	0	0	0	0	0.202	0.595	0.202	0.603	0.603	0.595	0	0	0	0	0.333	0.333	0	0
Repair Hangar 002 Interior	0.326	0	0	0	0	0.202	0.42	0.202	0.439	0.439	0.42	0	0	0	0	0	0	0	0
Repair Dining Facility 010 Roof	0.261	0	0	0.7	0.7	0.202	0.841	0.202	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair AAFES Mini Mall Roof	0.217	0	0	0.467	0.467	0.155	0.841	0.155	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair Soundside Roof	0.185	0	0	0.4	0.4	0.106	0.841	0.106	0.603	0.603	0.841	0	0	0	0	0	0	0	0
Repair AAFES Mini Mall Interior	0.182	0.667	0.333	0	0	0.341	0.5	0.341	0.555	0.555	0.5	0	0	0	0	0	0	0	0
Repair Fitness Center Roof	0.159	0	0	0.107	0.107	0.202	0.841	0.202	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair Soundside Club Interior	0.148	0	0	0	0	0.366	0.595	0.366	0.5	0.5	0.595	0	0	0	0	0.667	0.667	0	0
Repair Fitness Center Interior	0.114	0	0	0	0	0.246	0.42	0.246	0.555	0.555	0.42	0	0	0	0	0	0	0	0

Table 18. Raw Scores for Tornado X

	Prioritized Project List Value	Mission Priority Value	Mission Capability Value	Delta Measure	Rank Measure	Damage Value	Redundancy Value	Availability Measure	Severity Measure	Structural Value	Safety Value	Infrastructure Value	Risk Measure	Time Value	Interior Value	Level Measure	Dependencies Measure	Predecessor Projects Value	Electric Status Measure	H2O Status Measure
Weight	1	0.3	0.3	0.3	0.3	0.25	0.1	0.1	0.075	0.075	0.065	0.065	0.065	0.05	0.035	0.035	0.02	0.02	0.02	0.02
Repair Control Tower Roof	0.54	0.908	0.07	0.07	0.908	0.497	1	1	0.667	0.667	1	0	1	0.441	0	0	0.206	0.206	0	0
Repair Electrical Circuit A	0.462	0.711	0.2	0.2	0.711	0.338	1	1	0	0	1	0.3	1	0.091	0	0	0	0	1	0
Repair Control Tower Interior	0.433	0.908	0.08	0.08	0.908	0.355	0.333	0.333	0.333	0.333	0.667	0.1	0.667	0.294	0.4	0.4	0	0	0.333	0
Repair Roof Helicopter Hangar 006	0.414	0.583	0.05	0.05	0.583	0.405	1	1	0.667	0.667	0.667	0	0.667	0.458	0	0	0.37	0.37	0	0
Repair Doors Helicopter Hangar 006	0.41	0.583	0.03	0.03	0.583	0.411	1	1	0.667	0.667	0.667	0	0.667	0.477	0	0	0.206	0.206	0	0
Repair Fire Station #1	0.367	0.583	0.1	0.1	0.583	0.22	1	1	0	0	0.667	0	0.667	0.137	0.2	0.2	0	0	0	0
Repair Roof Clinic	0.359	0.385	0.04	0.04	0.385	0.506	1	1	0.667	0.667	1	0.175	1	0.104	0	0	0	0	0	0
Repair Hangar 001 Roof	0.353	0.644	0.02	0.02	0.644	0.116	1	1	0	0	0.333	0	0.333	0.489	0	0	0.37	0.37	0	0
Repair Roof Helicopter Maintenace Bldg	0.352	0.232	0.15	0.15	0.232	0.46	1	1	0.667	0.667	1	0	1	0.445	0	0	0.206	0.206	0	0
Repair Hangar 002 Doors	0.346	0.613	0.03	0.03	0.613	0.113	1	1	0	0	0.333	0	0.333	0.491	0	0	0.206	0.206	0	0
Repair Hangar 002 Interior	0.326	0.613	0.01	0.01	0.613	0.115	1	1	0	0	0.333	0	0.333	0.212	0.2	0.2	0	0	0	0
Repair Roof Youth Center	0.309	0.218	0.01	0.01	0.218	0.476	1	1	0.667	0.667	1	0	1	0.429	0	0	0.206	0.206	0	0
Repair Youth Center Interior	0.301	0.218	0.01	0.01	0.218	0.466	1	1	0.333	0.333	1	0.3	1	0.31	0.2	0.2	0	0	0.333	0.667
Repair Smith Ave Traffic Signal	0.271	0	0	0	0	0.631	1	1	1	1	1	0.267	1	0.264	0	0	0	0	0.667	0
Repair AAFES BX Roof	0.251	0.112	0	0	0.112	0.392	1	1	0.667	0.667	0.667	0	0.667	0.378	0	0	0.206	0.206	0	0
Repair Billeting Interior	0.248	0.13	0.03	0.03	0.13	0.354	1	1	0	0	1	0	1	0.24	0.5	0.5	0	0	0	0
Repair BX Interior	0.203	0.112	0	0	0.112	0.231	1	1	0	0	0.667	0	0.667	0.233	0.3	0.3	0	0	0	0
Repair Fire Training Tower	0.156	0.019	0	0	0.019	0.147	1	1	0	0	0.333	0.2	0.333	0.267	0	0	0	0	0	0.667
Repair Fitness Center Roof	0.148	0.004	0	0	0.004	0.378	0.333	0.333	0.667	0.667	0.667	0	0.667	0.391	0	0	0.206	0.206	0	0
Repair Fitness Center Interior	0.108	0.004	0	0	0.004	0.101	0.667	0.667	0	0	0.333	0	0.333	0.3	0.1	0.1	0	0	0	0

Table 18. Raw Scores for Tornado X (Continued)

	Prioritized Project List Value	Water Value	Electric Value	Cosmetic Value	Degree Measure	Project Duration Value	Prevalence Measure	Estimated Time to Complete Measure	Delivery Time Measure	Material Availability Value	Contractor Availabilty Value	POL Value	POL Status Measure	Transportation Value	Transportation Status Measure	Sewage Value	Sewage Status Measure	NG Status Measure	Natural Gas Value
Weight	1	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.007	0.007	0.005	0.005	0.005	0.005
Repair Control Tower Roof	0.54	0	0	0.933	0.933	0.202	0.841	0.202	0.751	0.751	0.841	0	0	0	0	0	0	0	0
Repair Electrical Circuit A	0.462	0	1	0	0	0.037	0.21	0.037	0.206	0.206	0.21	0	0	0	0	0	0	0	0
Repair Control Tower Interior	0.433	0	0.333	0	0	0.246	0.42	0.246	0.802	0.802	0.42	0	0	0	0	0	0	0	0
Repair Roof Helicopter Hangar 006	0.414	0	0	0.8	0.8	0.106	0.841	0.106	0.603	0.603	0.841	0	0	0	0	0	0	0	0
Repair Doors Helicopter Hangar 006	0.41	0	0	0.933	0.933	0.072	1	0.072	0.902	0.902	1	0	0	0	0	0	0	0	0
Repair Fire Station #1	0.367	0	0	0.467	0.467	0.106	0.21	0.106	0.37	0.37	0.21	0	0	0	0	0	0	0	0
Repair Roof Clinic	0.359	0	0	0	0	0.106	0.21	0.106	0.206	0.206	0.21	0	0	1	1	1	1	0	0
Repair Hangar 001 Roof	0.353	0	0	0.734	0.734	0.155	0.707	0.155	0.844	0.844	0.707	0	0	0	0	0	0	0	0
Repair Roof Helicopter Maintenace Bldg	0.352	0	0	0	0	0.288	0.841	0.288	0.685	0.685	0.841	0	0	0	0	0	0	0	0
Repair Hangar 002 Doors	0.346	0	0	0.667	0.667	0.089	1	0.089	0.952	0.952	1	0	0	0	0	0	0	0	0
Repair Hangar 002 Interior	0.326	0	0	0	0	0.202	0.42	0.202	0.439	0.439	0.42	0	0	0	0	0	0	0	0
Repair Roof Youth Center	0.309	0	0	0.4	0.4	0.139	0.841	0.139	0.751	0.751	0.841	0	0	0	0	0	0	0	0
Repair Youth Center Interior	0.301	0.667	0.333	0	0	0.288	0.42	0.288	0.844	0.844	0.42	0	0	0	0	0	0	0	0
Repair Smith Ave Traffic Signal	0.271	0	0.667	0.04	0.04	0.011	0.707	0.011	0.603	0.603	0.707	0	0	0.667	0.667	0	0	0	0
Repair AAFES BX Roof	0.251	0	0	0.467	0.467	0.139	0.841	0.139	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair Billeting Interior	0.248	0	0	0.6	0.6	0.202	0.5	0.202	0.5	0.5	0.5	0	0	0	0	0	0	0	0
Repair BX Interior	0.203	0	0	0.4	0.4	0.202	0.595	0.202	0.37	0.37	0.595	0	0	0	0	0	0	0	0
Repair Fire Training Tower	0.156	0.667	0	0.22	0.22	0.202	0.841	0.202	0.293	0.293	0.841	0	0	0	0	0	0	0	0
Repair Fitness Center Roof	0.148	0	0	0.107	0.107	0.202	0.841	0.202	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair Fitness Center Interior	0.108	0	0	0	0	0.366	0.354	0.366	0.778	0.778	0.354	0	0	0	0	0	0	0	0

Table 19. Raw Scores for Flood X

	Prioritized Project List Value	Mission Priority Value	Mission Capability Value	Delta Measure	Rank Measure	Damage Value	Redundancy Value	Availability Measure	Severity Measure	Structural Value	Safety Value	Infrastructure Value	Risk Measure	Time Value	Interior Value	Level Measure	Dependencies Measure	Predecessor Projects Value	Electric Status Measure	H2O Status Measure
Weight	1	0.3	0.3	0.3	0.3	0.25	0.1	0.1	0.075	0.075	0.065	0.065	0.065	0.05	0.035	0.035	0.02	0.02	0.02	0.02
Repair Main Base Roads	0.385	0.613	0.03	0.03	0.613	0.331	1	1	0.667	0.667	0.333	0.067	0.333	0.191	0	0	0	0	0	0
Repair Youth Center Interior	0.368	0.5	0	0	0.5	0.417	1	1	0.667	0.667	0.667	0.05	0.667	0.273	0.22	0.22	0	0	0	0
Repair Main Base Storm Sewers	0.335	0.644	0.03	0.03	0.644	0.106	1	1	0	0	0.333	0.075	0.333	0.122	0	0	0	0	0	0
Repair Lift Station C	0.333	0.5	0	0	0.5	0.245	1	1	0	0	0.667	0.275	0.667	0.442	0	0	0.5	0.5	0.667	0
Basewide Mold Remediation	0.315	0.292	0.1	0.1	0.292	0.302	1	1	0	0	1	0	1	0.44	0.3	0.3	0.603	0.603	0	0
Repair Lift Station D	0.303	0.406	0	0	0.406	0.245	1	1	0	0	0.667	0.275	0.667	0.409	0	0	0.37	0.37	0.667	0
Repair Soundside Club Interior	0.235	0.004	0	0	0.004	0.488	1	1	0.333	0.333	1	0.25	1	0.232	0.45	0.45	0	0	0	0.667
Repair Dining Facility Interior	0.233	0.292	0.02	0.02	0.292	0.242	0.667	0.667	0	0	0.667	0.05	0.667	0.249	0.4	0.4	0	0	0	0
Repair Retention Ponds B	0.179	0	0	0	0	0.306	1	1	0.667	0.667	0.333	0.075	0.333	0.057	0	0	0	0	0	0
Repair Retention Pond A	0.179	0	0	0	0	0.306	1	1	0.667	0.667	0.333	0.075	0.333	0.052	0	0	0	0	0	0
Repair Sounside Roads	0.173	0.044	0	0	0.044	0.204	1	1	0.333	0.333	0.333	0.067	0.333	0.181	0	0	0	0	0	0
Repair Outdoor Recreation Center Interior	0.16	0	0	0	0	0.2	1	1	0	0	0.667	0.05	0.667	0.192	0.1	0.1	0	0	0	0
Repair Soundside Storm Sewers	0.145	0.044	0	0	0.044	0.106	1	1	0	0	0.333	0.075	0.333	0.111	0	0	0	0	0	0
Repair AAFES Gas Station Interior	0.144	0	0	0	0	0.128	1	1	0	0	0.333	0.05	0.333	0.252	0.2	0.2	0	0	0	0
Repair Outdoor Recreation Parking Lot	0.143	0	0	0	0	0.378	0.333	0.333	0.667	0.667	0.667	0	0.667	0.309	0	0	0	0	0	0
Repair AAFES Mini Mall Interior	0.143	0	0	0	0	0.121	1	1	0	0	0.333	0.05	0.333	0.251	0.15	0.15	0	0	0	0
Repair Main Base Landscaping	0.138	0	0	0	0	0.119	1	1	0	0	0.333	0	0.333	0.168	0	0	0	0	0	0
Repair Soundside Landscaping	0.138	0	0	0	0	0.121	1	1	0	0	0.333	0	0.333	0.148	0	0	0	0	0	0
Debris Removal Basewide	0.125	0	0	0	0	0.087	1	1	0	0	0.333	0	0.333	0.073	0	0	0	0	0	0
Repair Jogging Path	0.125	0	0	0	0	0.087	1	1	0	0	0.333	0	0.333	0.063	0	0	0	0	0	0

Table 19. Raw Scores for Flood X (Continued)

	Prioritized Project List Value	Water Value	Electric Value	Cosmetic Value	Degree Measure	Project Duration Value	Prevalence Measure	Estimated Time to Complete	Delivery Time Measure	Material Availability Value	Contractor Availabilty Value	POL Value	POL Status Measure	Transportation Value	Transportation Status Measure	Sewage Value	Sewage Status Measure	NG Status Measure	Natural Gas Value
Weight	1	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.007	0.007	0.005	0.005	0.005	0.005
Repair Main Base Roads	0.385	0	0	0.667	0.667	0.155	0.595	0.155	0.206	0.206	0.595	0	0	0.667	0.667	0	0	0	0
Repair Youth Center Interior	0.368	0	0	0	0	0.366	0.5	0.366	0.5	0.5	0.5	0	0	0	0	0.667	0.667	0	0
Repair Main Base Storm Sewers	0.335	0	0	0	0	0.106	0.21	0.106	0.293	0.293	0.21	0	0	0	0	1	1	0	0
Repair Lift Station C	0.333	0	0.667	0	0	0.026	0.5	0.026	0.685	0.685	0.5	0	0	0	0	1	1	0	0
Basewide Mold Remediation	0.315	0	0	0	0	0.288	0.707	0.288	0	0	0.707	0	0	0	0	0	0	0	0
Repair Lift Station D	0.303	0	0.667	0	0	0.026	0.595	0.026	0.685	0.685	0.595	0	0	0	0	1	1	0	0
Repair Soundside Club Interior	0.235	0.667	0	0	0	0.366	0.5	0.366	0.293	0.293	0.5	0	0	0	0	0.667	0.667	0	0
Repair Dining Facility Interior	0.233	0	0	0	0	0.246	0.5	0.246	0.5	0.5	0.5	0	0	0	0	0.667	0.667	0	0
Repair Retention Ponds B	0.179	0	0	0	0	0.075	0.21	0.075	0	0	0.21	0	0	0	0	1	1	0	0
Repair Retention Pond A	0.179	0	0	0	0	0.051	0.21	0.051	0	0	0.21	0	0	0	0	1	1	0	0
Repair Sounside Roads	0.173	0	0	0	0	0.106	0.595	0.106	0.206	0.206	0.595	0	0	0.667	0.667	0	0	0	0
Repair Outdoor Recreation Center Interior	0.16	0	0	0	0	0.089	0.5	0.089	0.37	0.37	0.5	0	0	0	0	0.667	0.667	0	0
Repair Soundside Storm Sewers	0.145	0	0	0	0	0.054	0.21	0.054	0.293	0.293	0.21	0	0	0	0	1	1	0	0
Repair AAFES Gas Station Interior	0.144	0	0	0	0	0.155	0.5	0.155	0.603	0.603	0.5	0	0	0	0	0.667	0.667	0	0
Repair Outdoor Recreation Parking Lot	0.143	0	0	0.107	0.107	0.202	0.841	0.202	0.5	0.5	0.841	0	0	0	0	0	0	0	0
Repair AAFES Mini Mall Interior	0.143	0	0	0	0	0.202	0.5	0.202	0.555	0.555	0.5	0	0	0	0	0.667	0.667	0	0
Repair Main Base Landscaping	0.138	0	0	0.8	0.8	0.171	0.297	0.171	0.37	0.37	0.297	0	0	0	0	0	0	0	0
Repair Soundside Landscaping	0.138	0	0	0.867	0.867	0.072	0.297	0.072	0.37	0.37	0.297	0	0	0	0	0	0	0	0
Debris Removal Basewide	0.125	0	0	0	0	0.155	0.21	0.155	0	0	0.21	0	0	0	0	0	0	0	0
Repair Jogging Path	0.125	0	0	0	0	0.106	0.21	0.106	0	0	0.21	0	0	0	0	0	0	0	0

Appendix B: Evaluation Measures

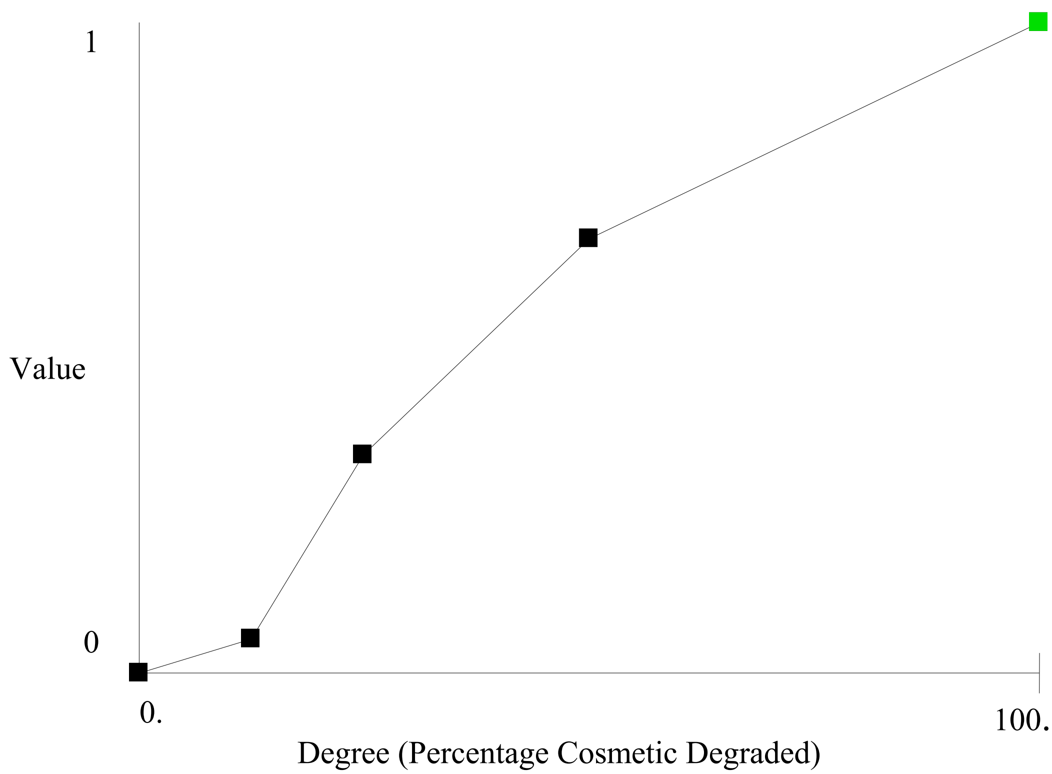


Figure 32. SDVF of Degree

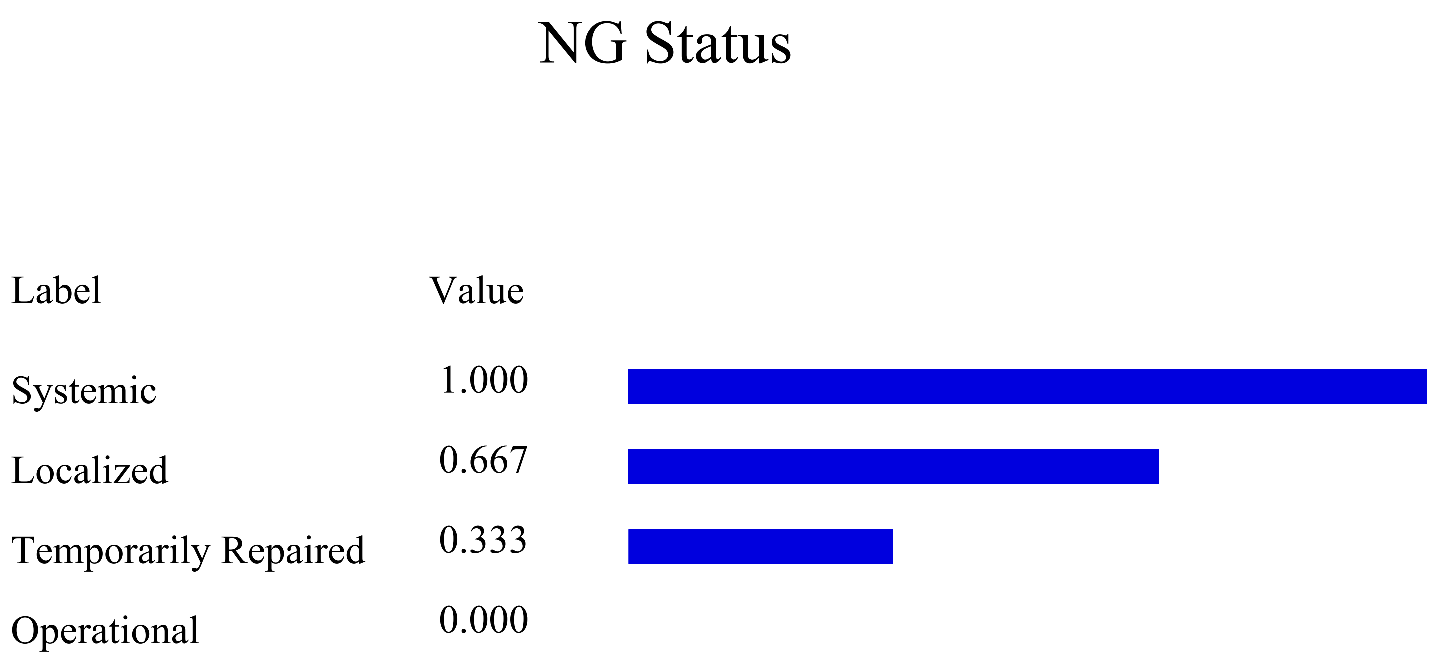


Figure 33. SDVF for NG Status

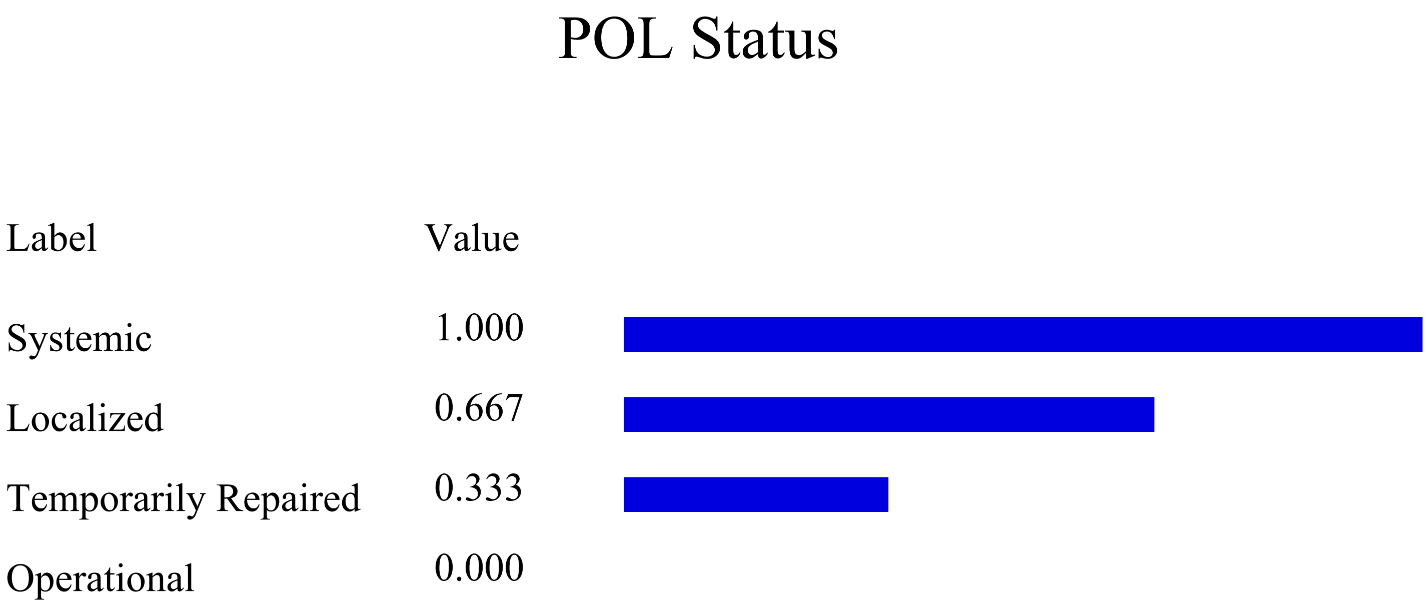


Figure 34. SDVF for POL Status

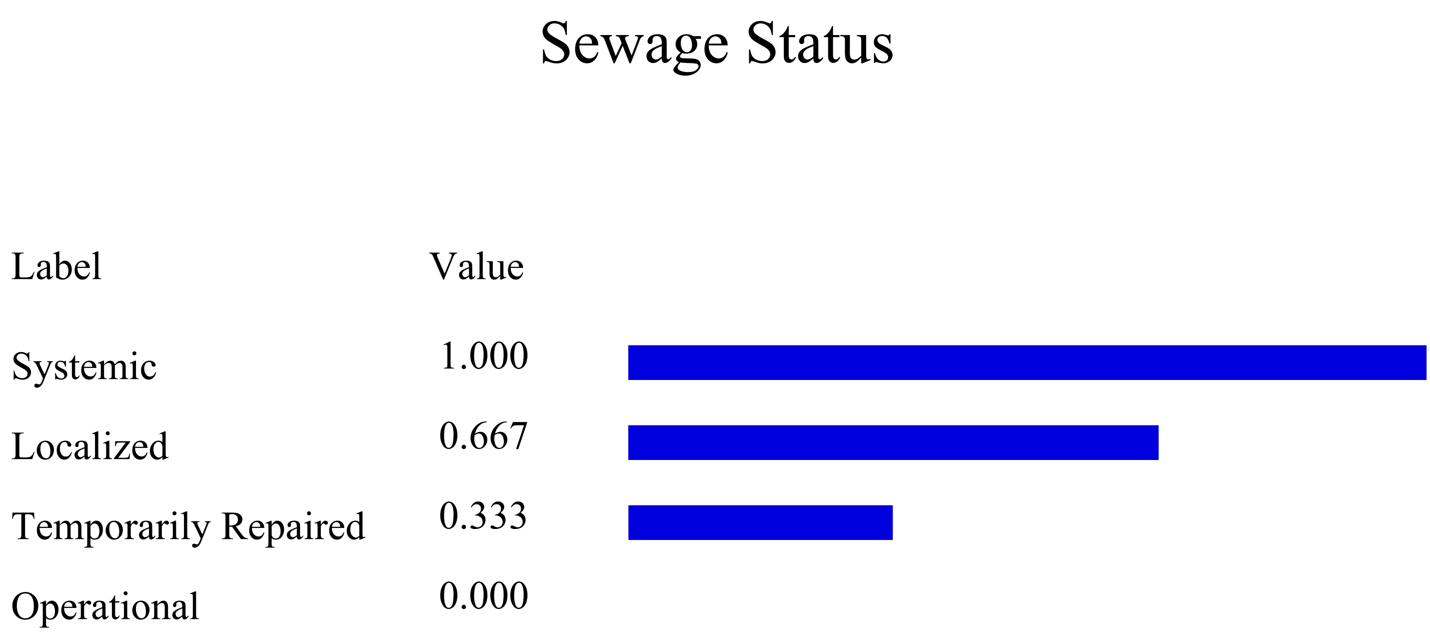


Figure 35. SDVF for Sewage Status

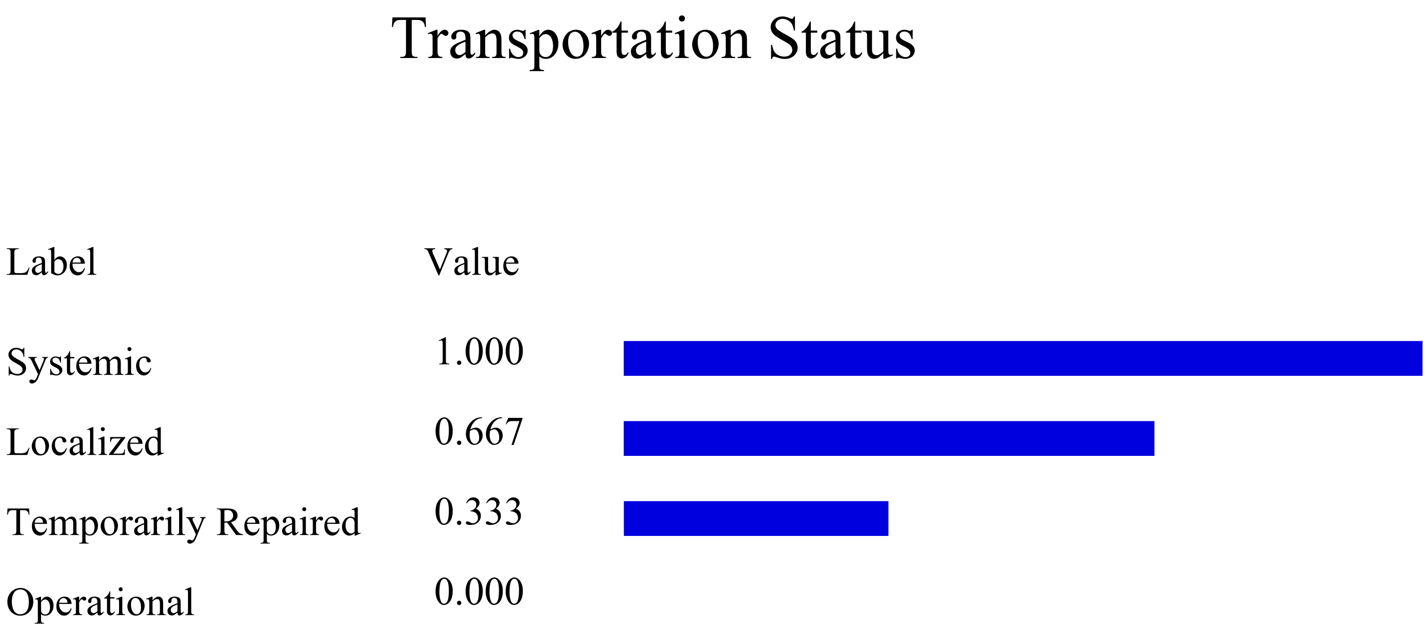


Figure 36. SDVF for Transportation Status

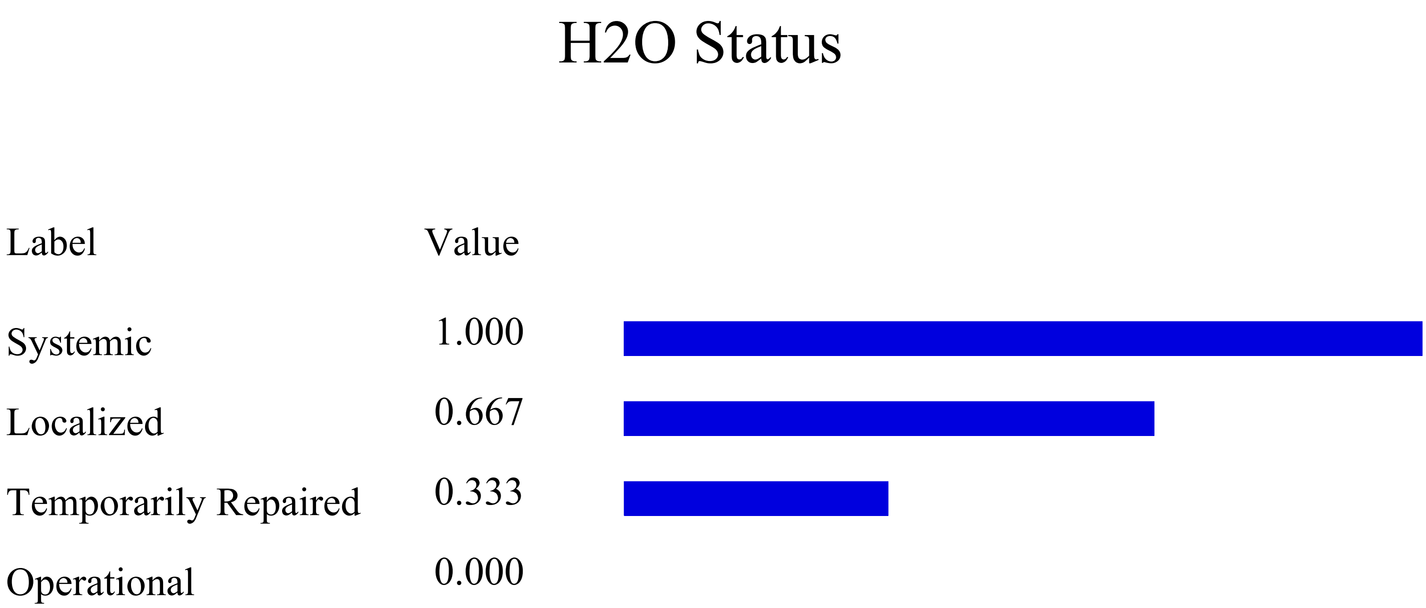


Figure 37. SDVF for H20 Status

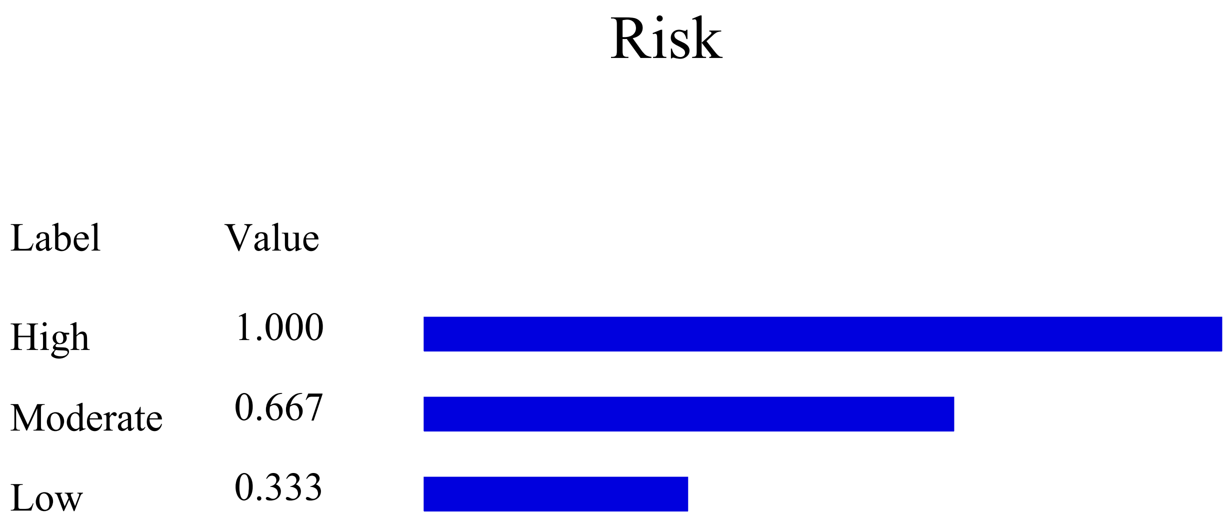


Figure 38. SDVF for Risk

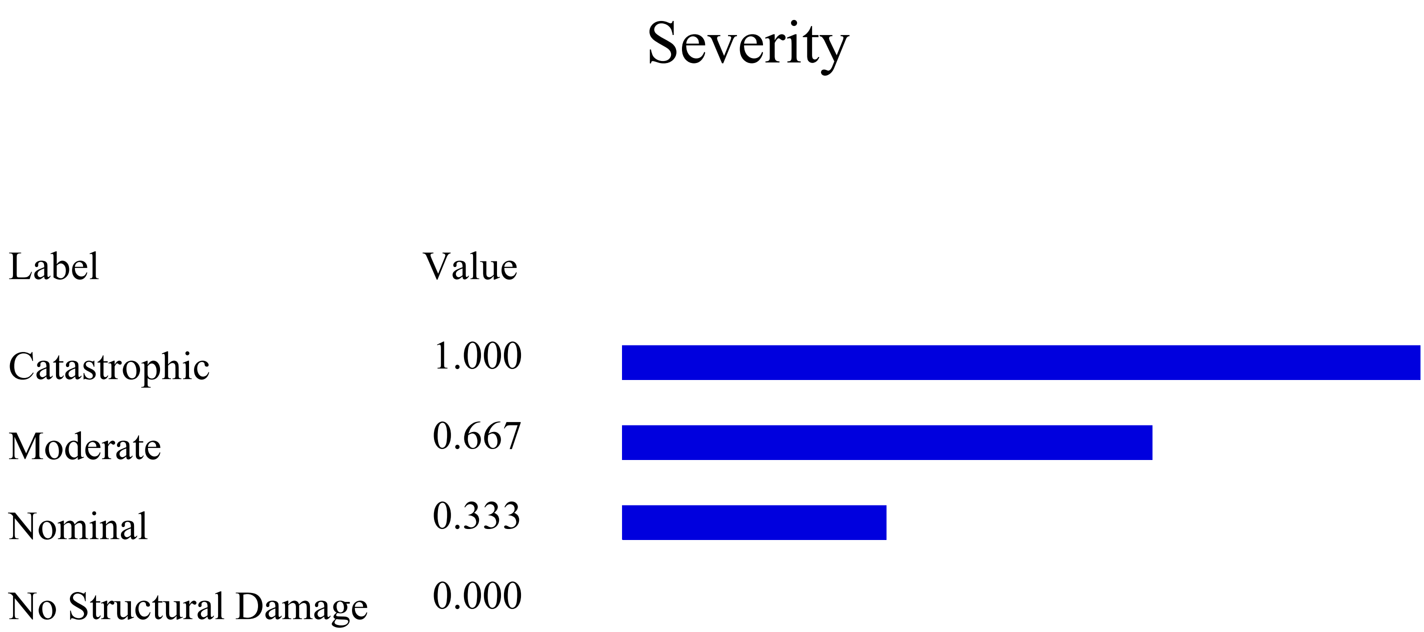


Figure 39. SDVF of Severity

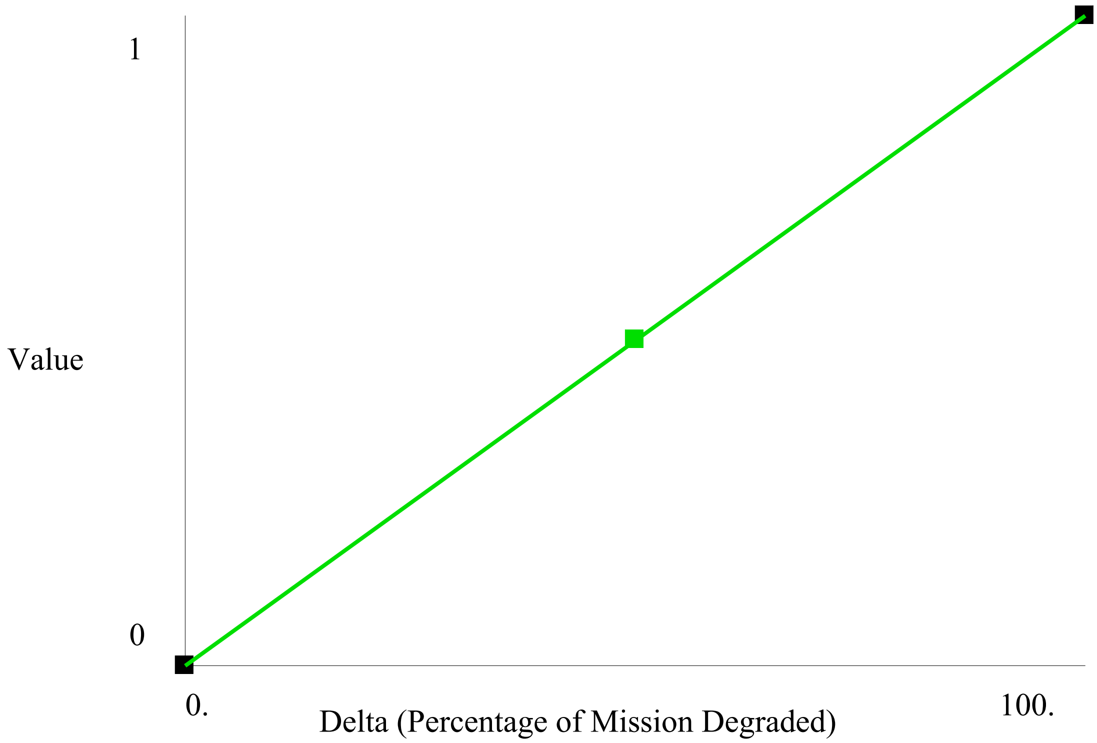


Figure 40. SDVF of Delta

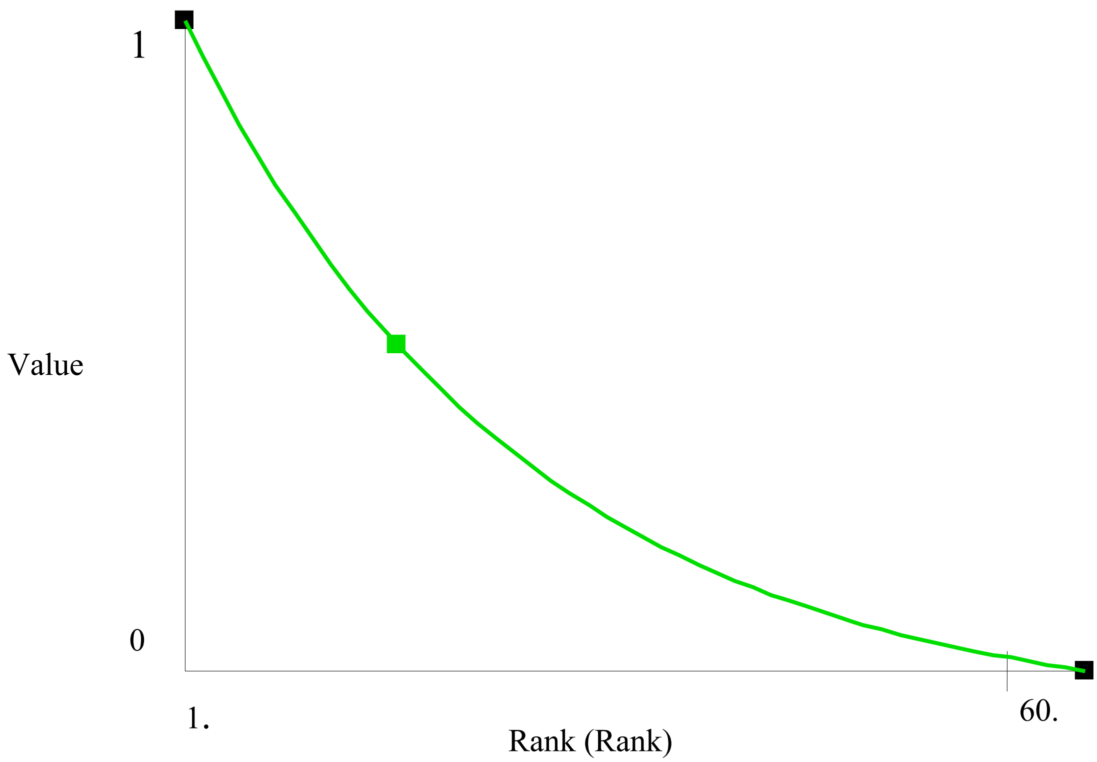


Figure 41. SDVF of Rank

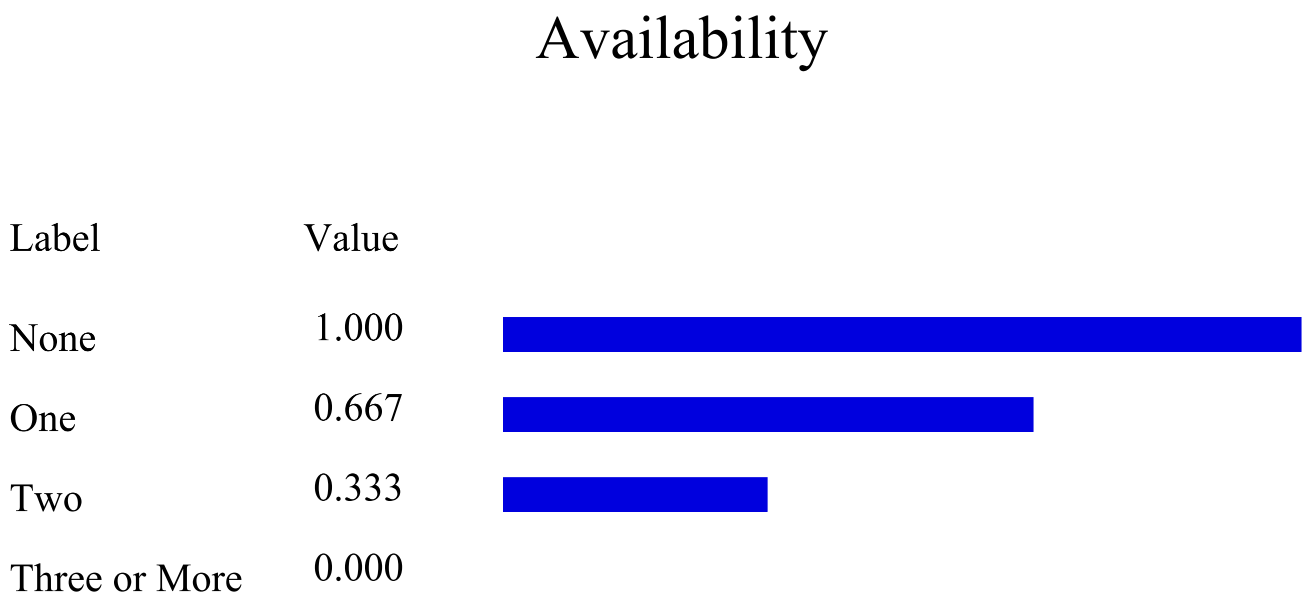


Figure 42. SDVF for Availability

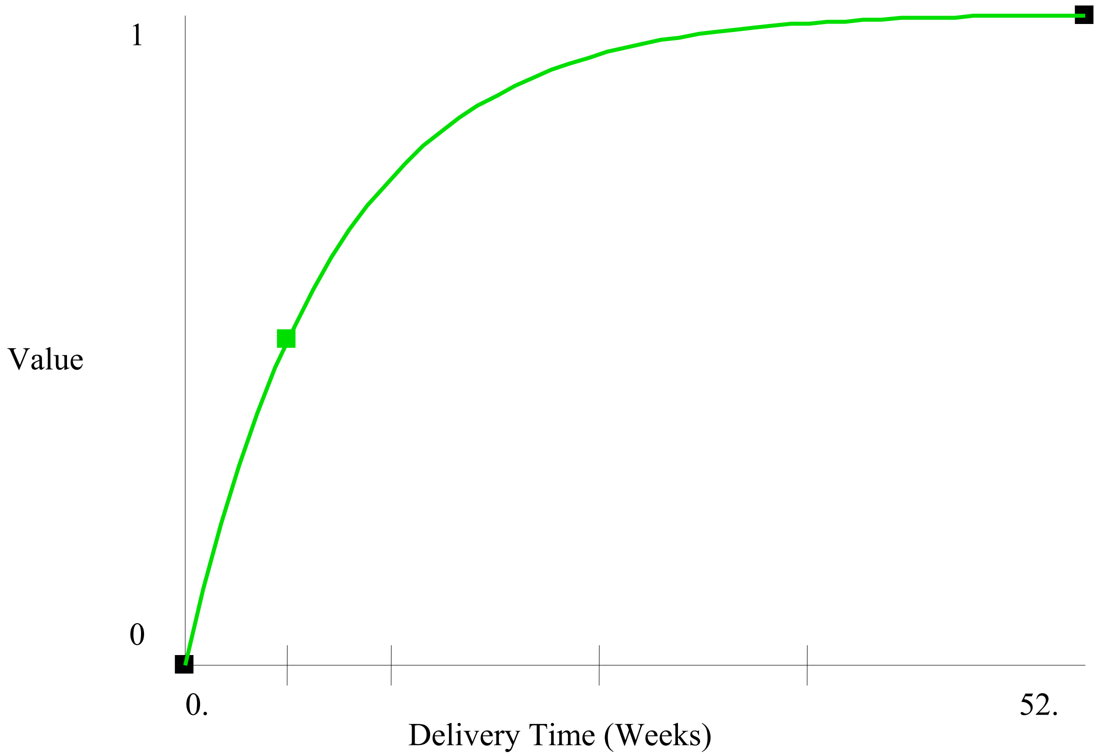


Figure 43. SDVF of Delivery Time

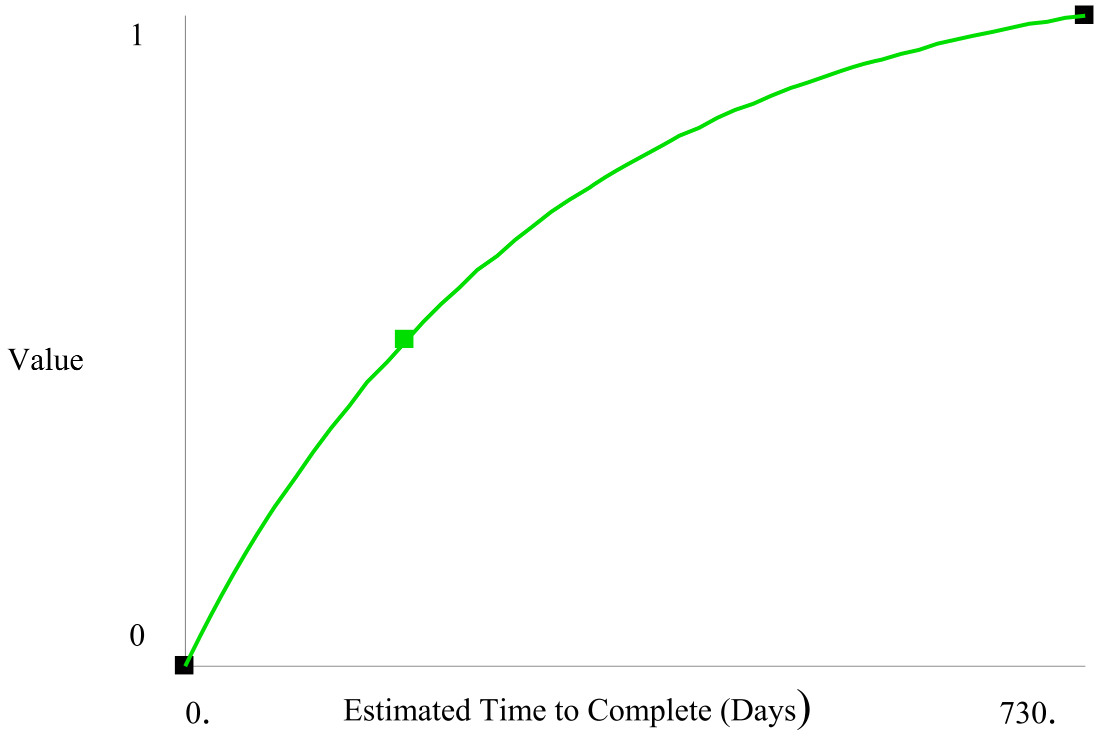
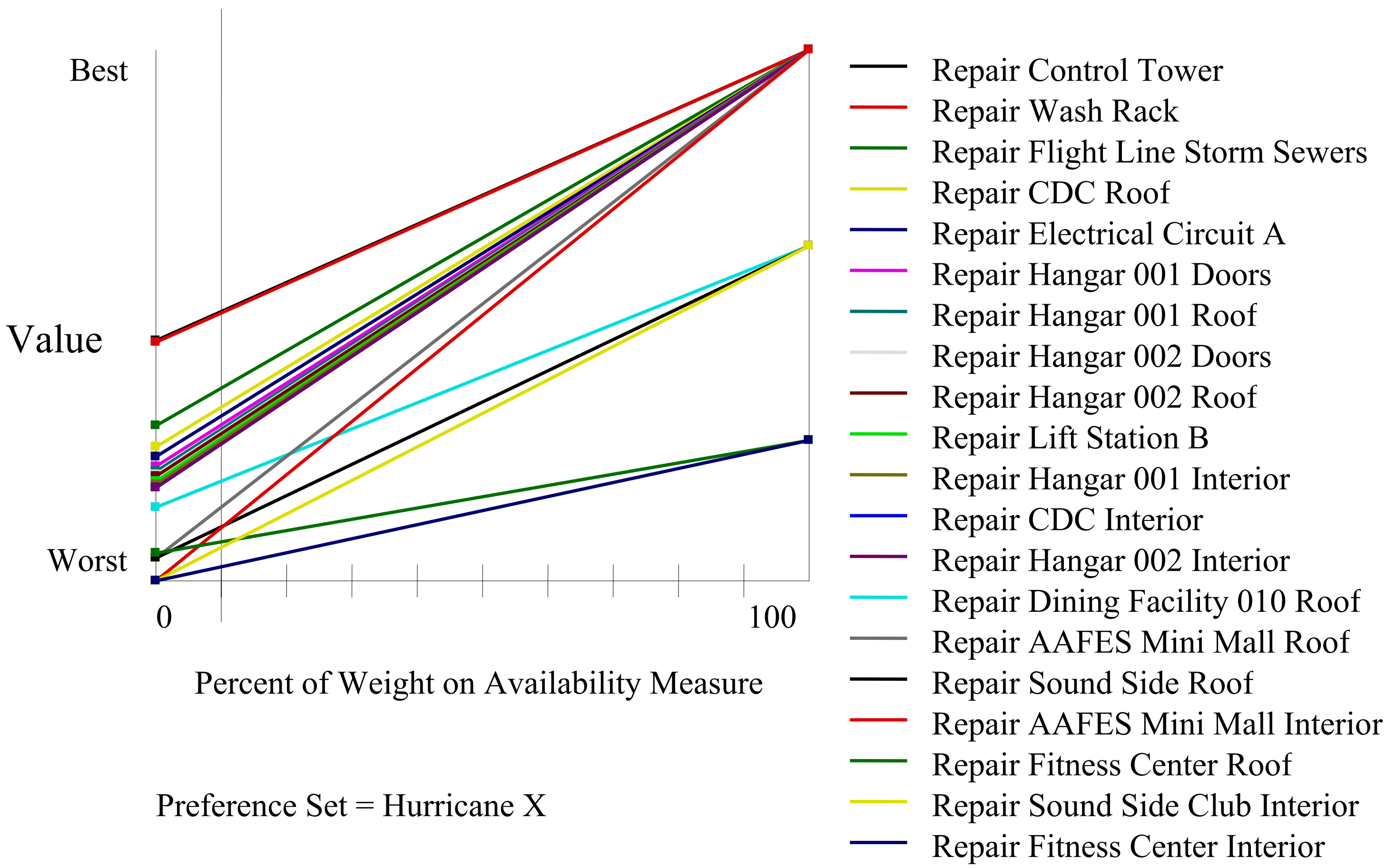
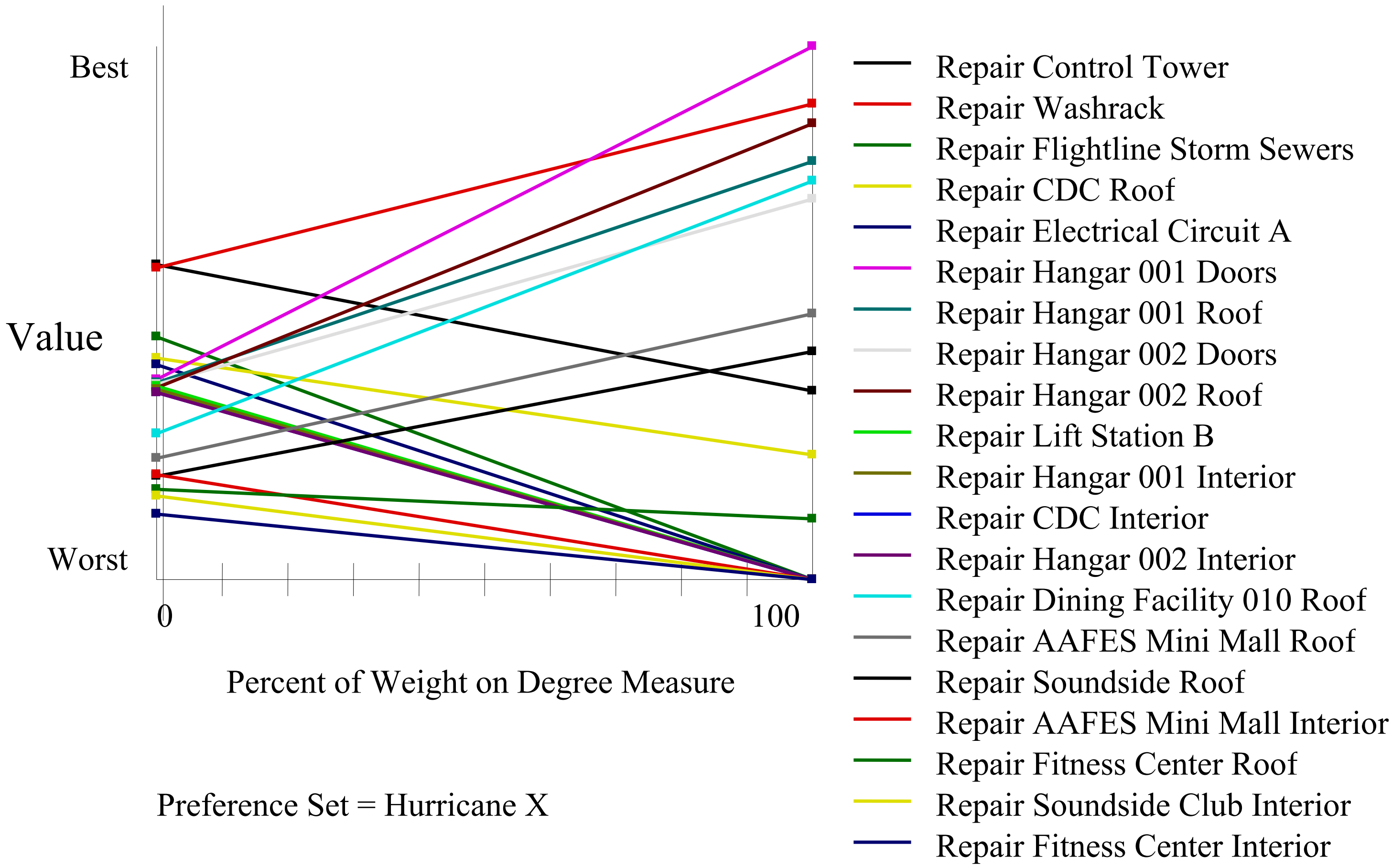
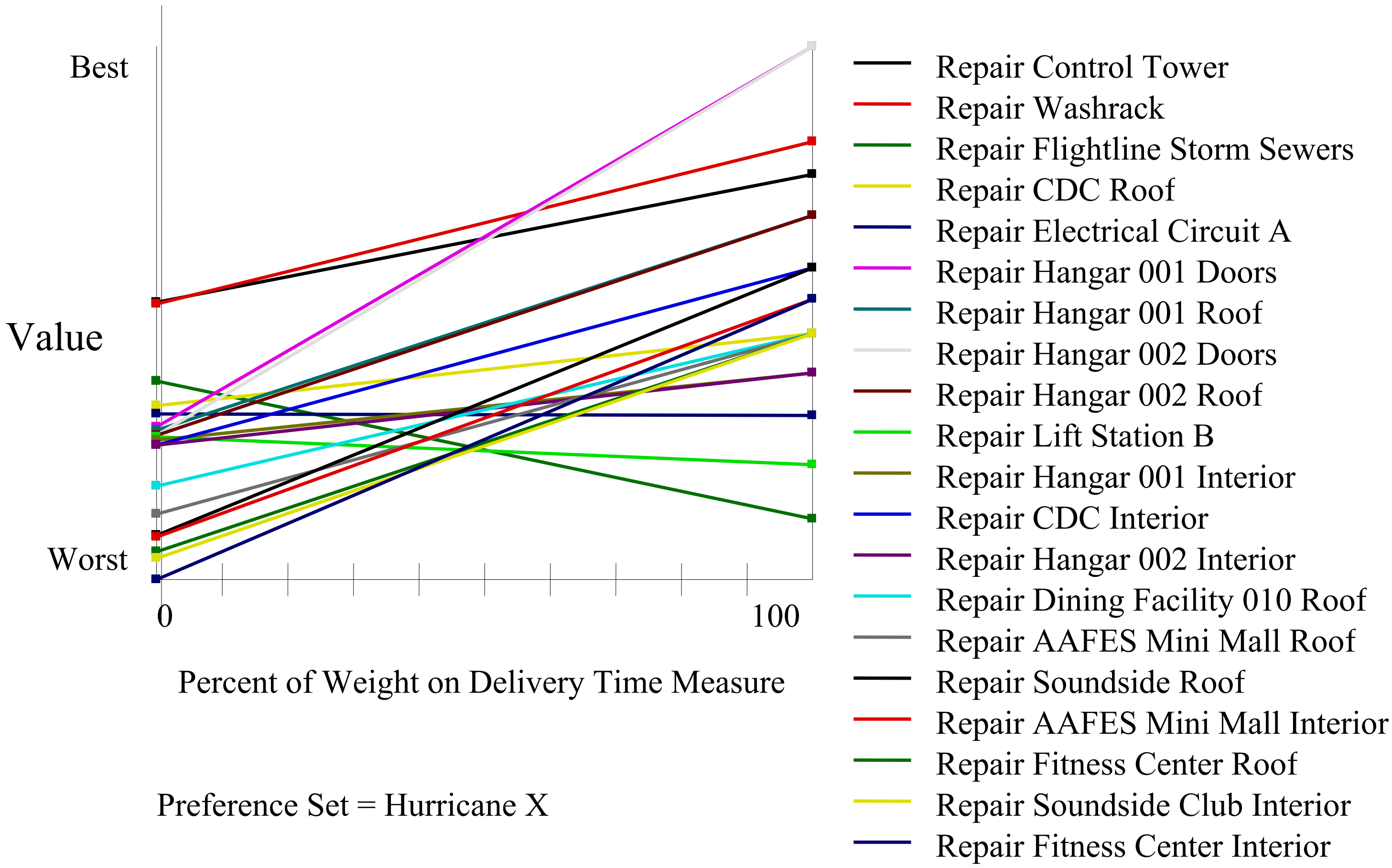


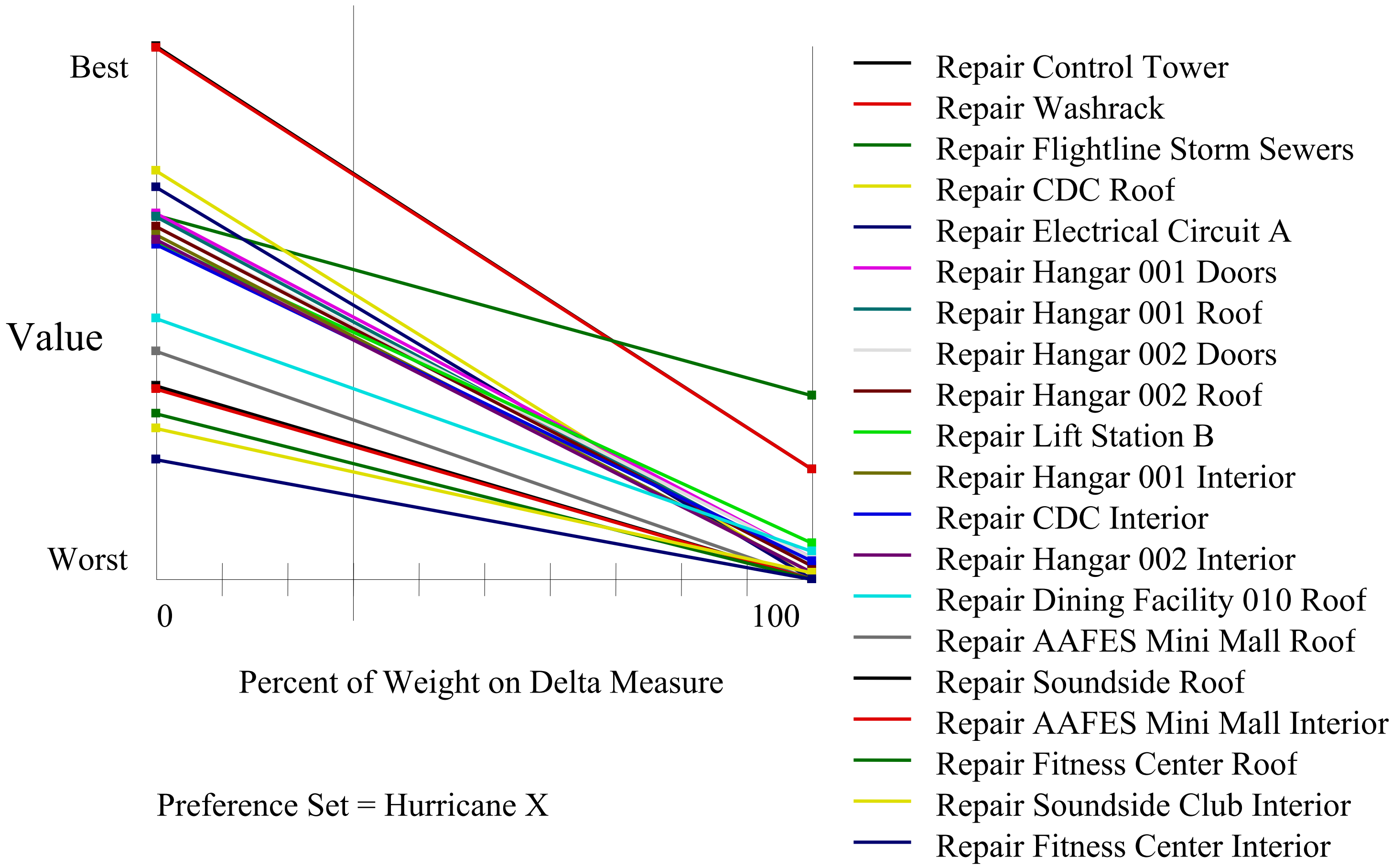
Figure 44. SDVF for ETC

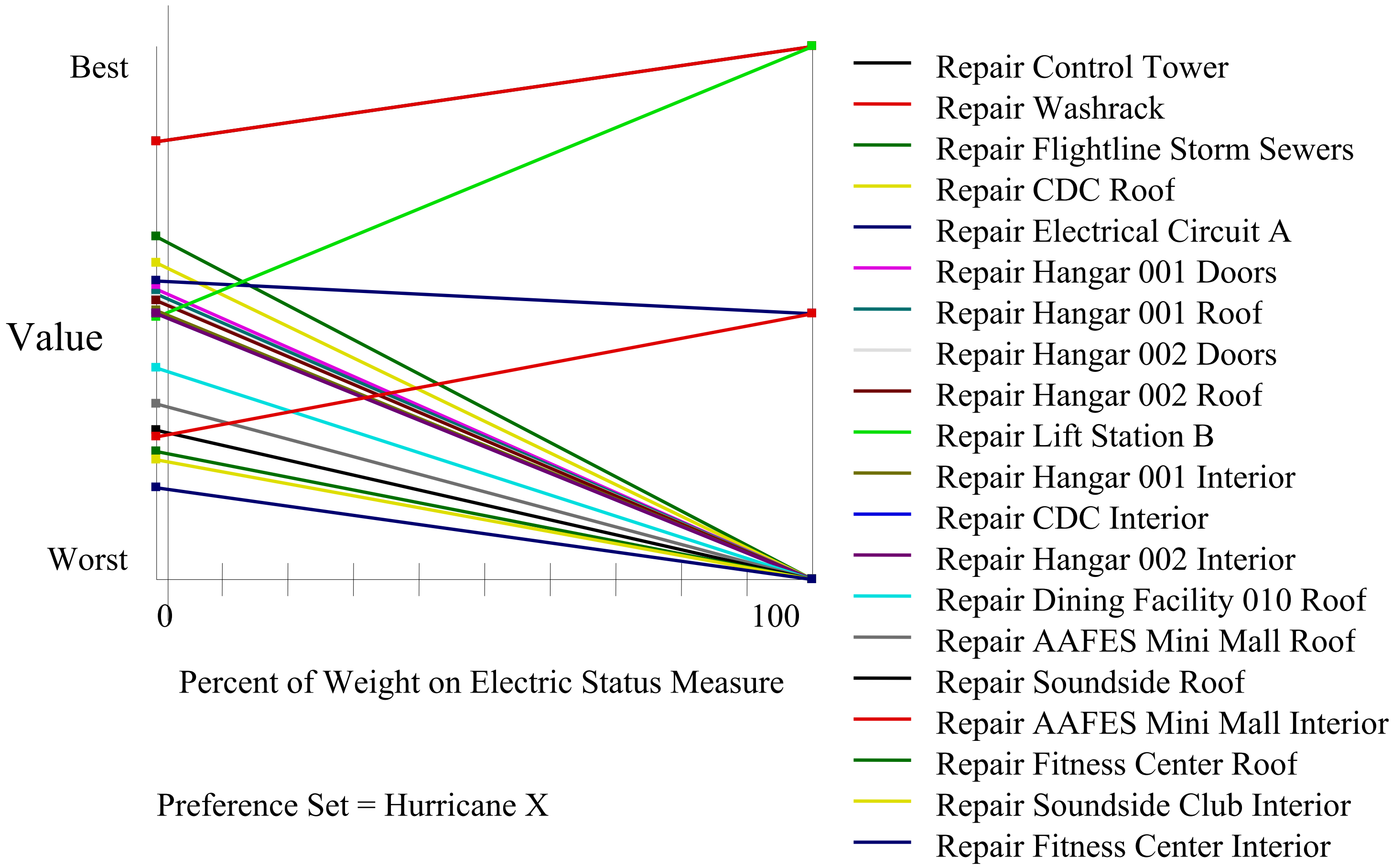
Appendix C: Sensitivity Analysis Graphs (Hurricane X)

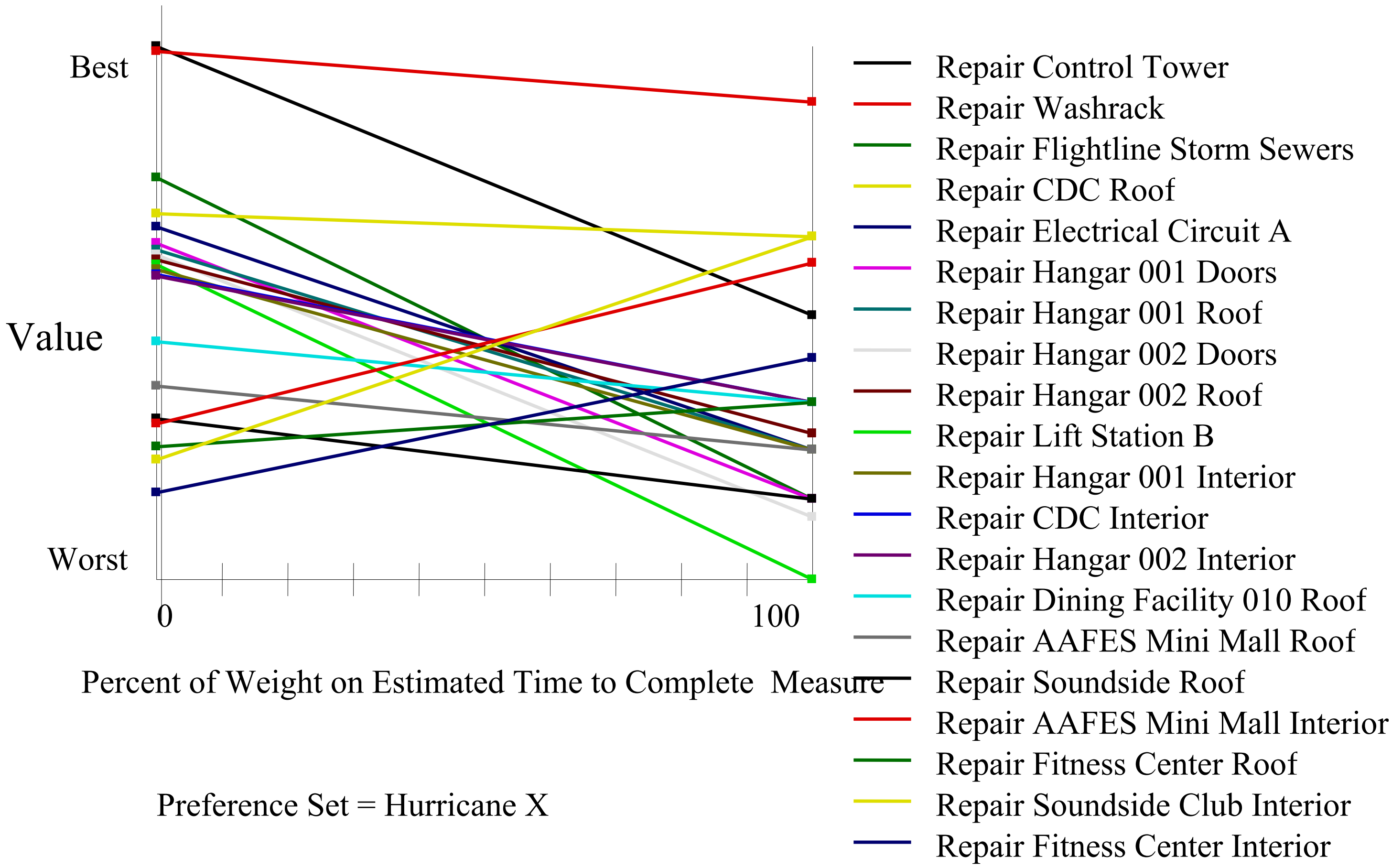


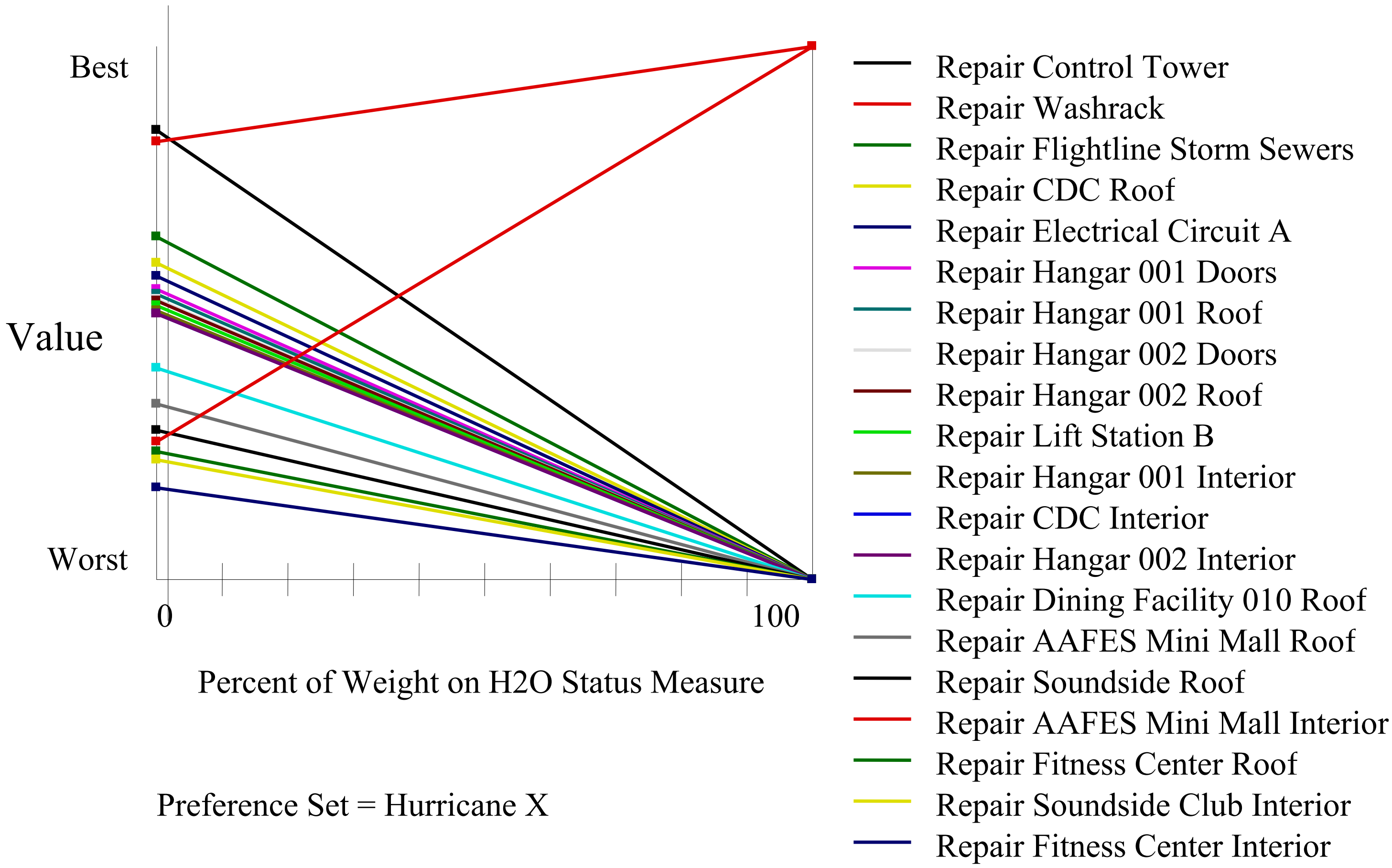

Best
Value
Worst
0
100
Percent of Weight on Degree Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

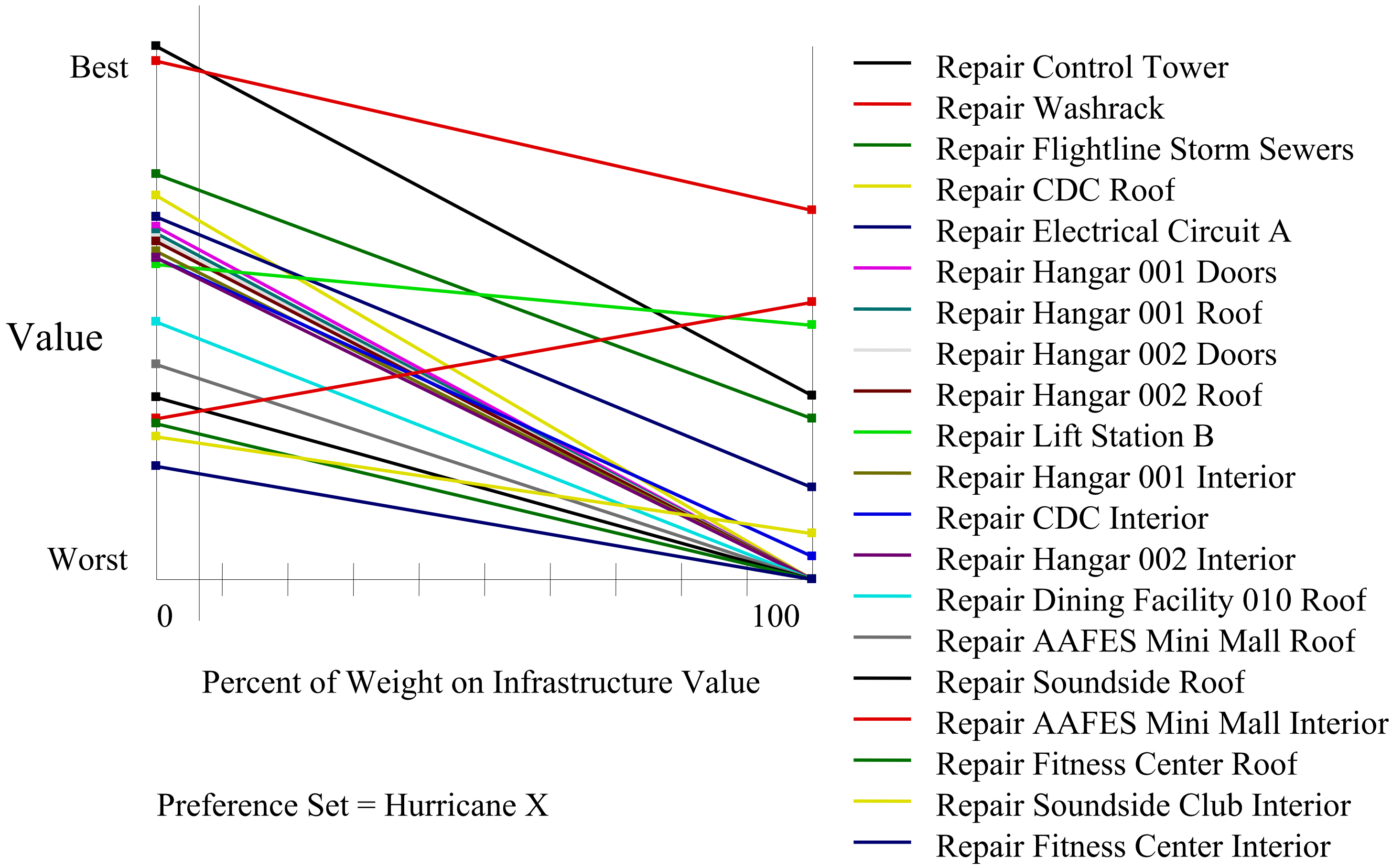

Best
Value
Worst
0
100
Percent of Weight on Delivery Time Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior


Best
Value
Worst
0
100
Percent of Weight on Delta Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

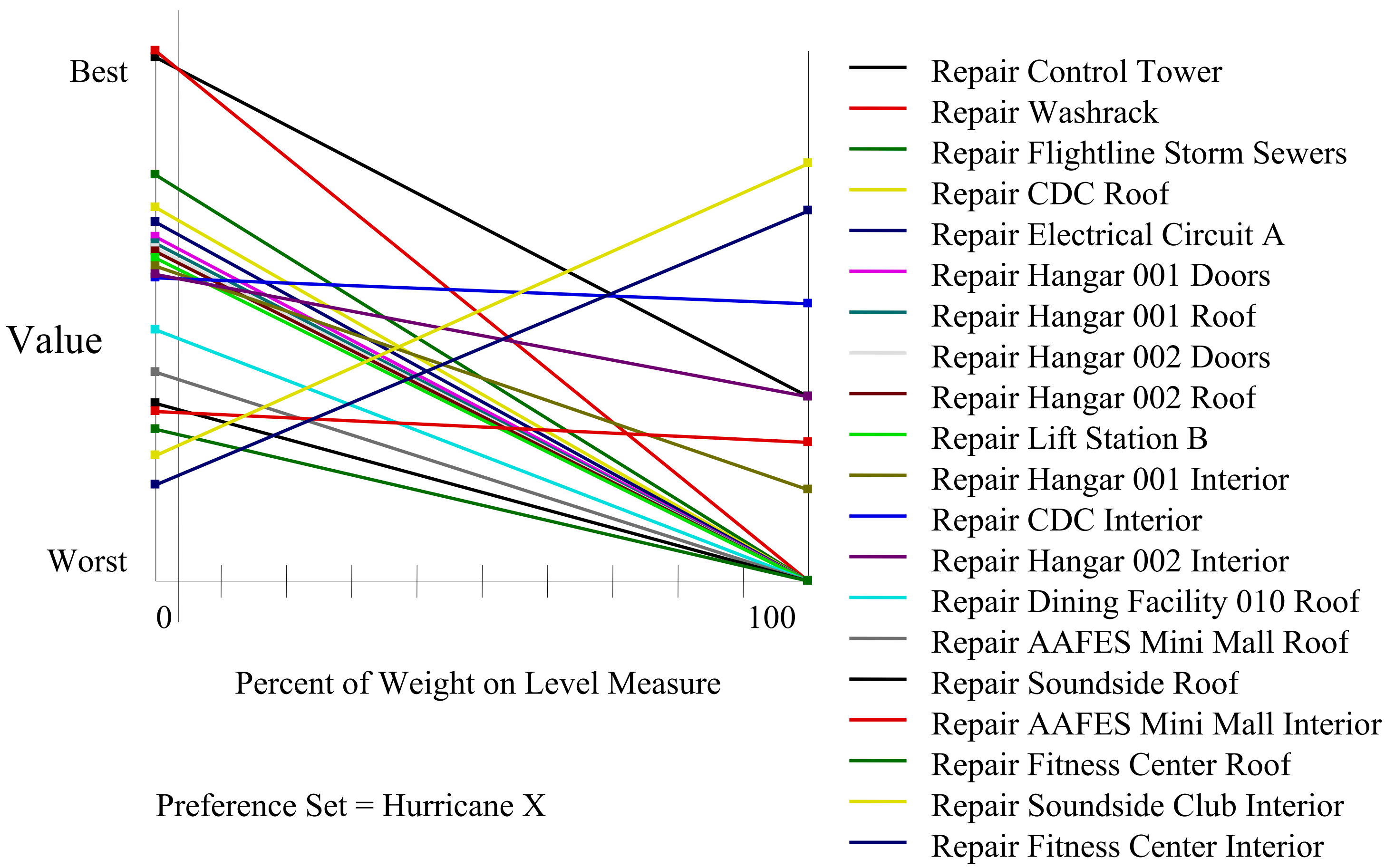

Best
Value
Worst
0
100
Percent of Weight on Electric Status Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

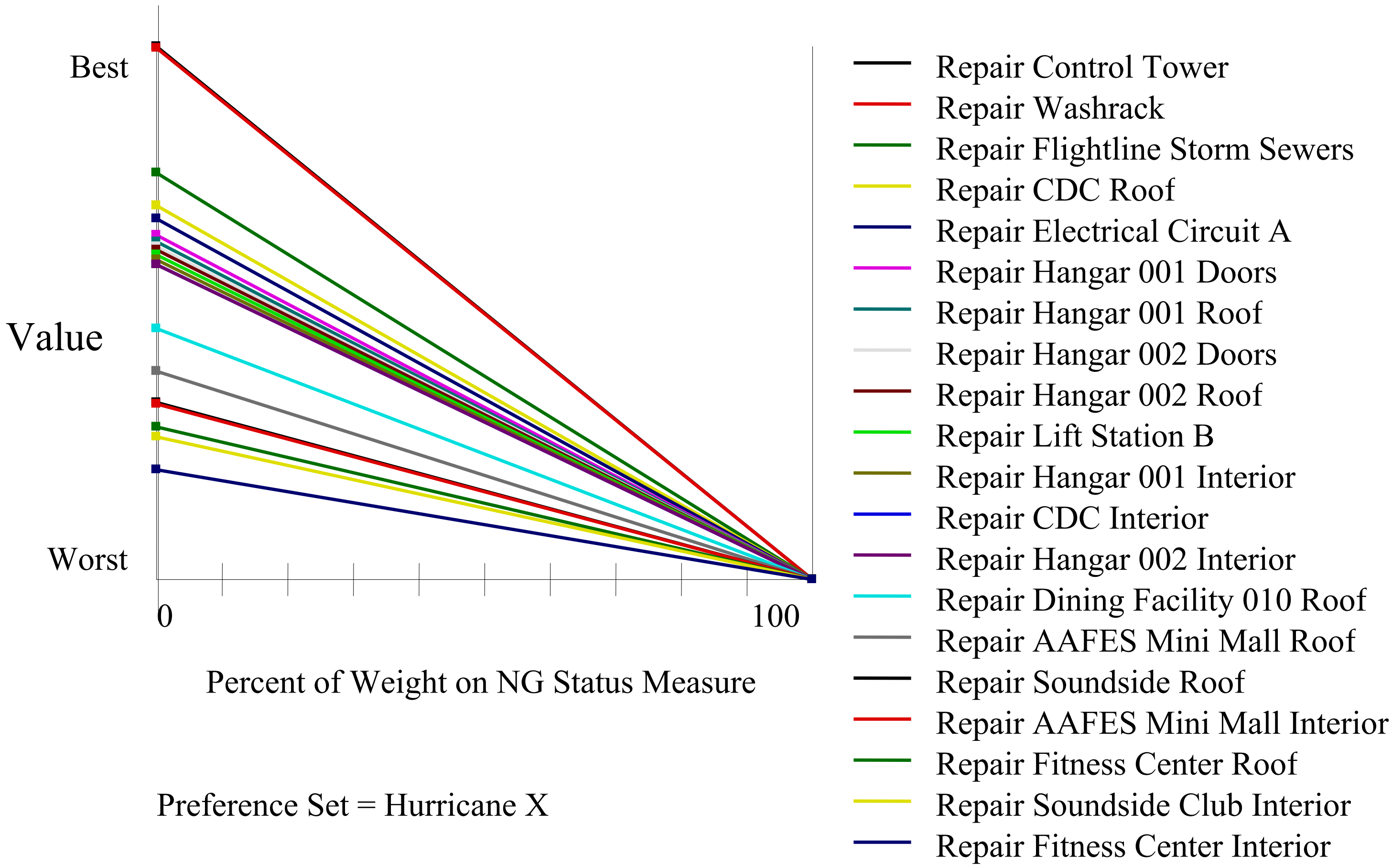

Best
Value
Worst
0
100
Percent of Weight on Estimated Time to Complete Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

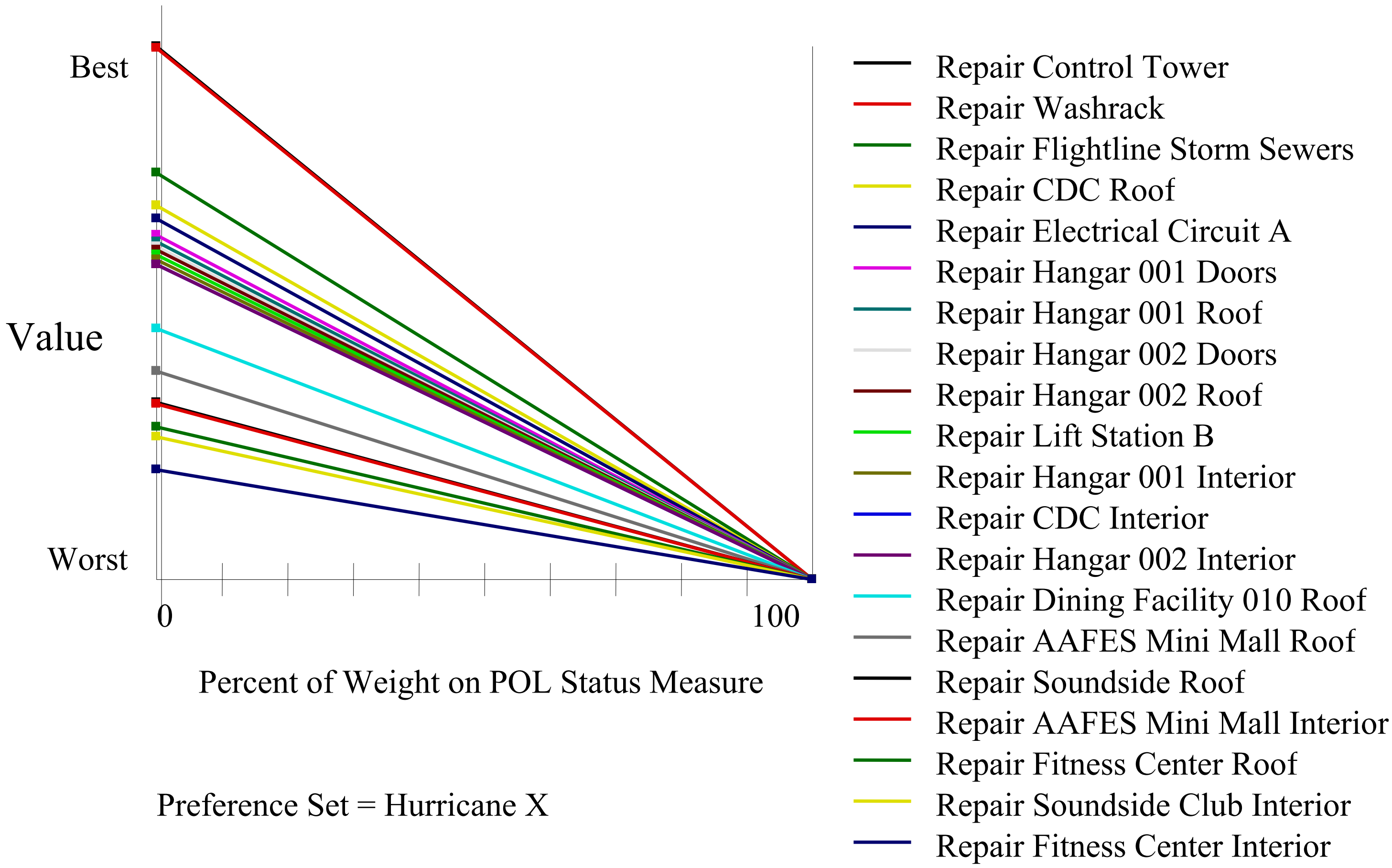

Best
Value
Worst
0
100
Percent of Weight on H2O Status Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

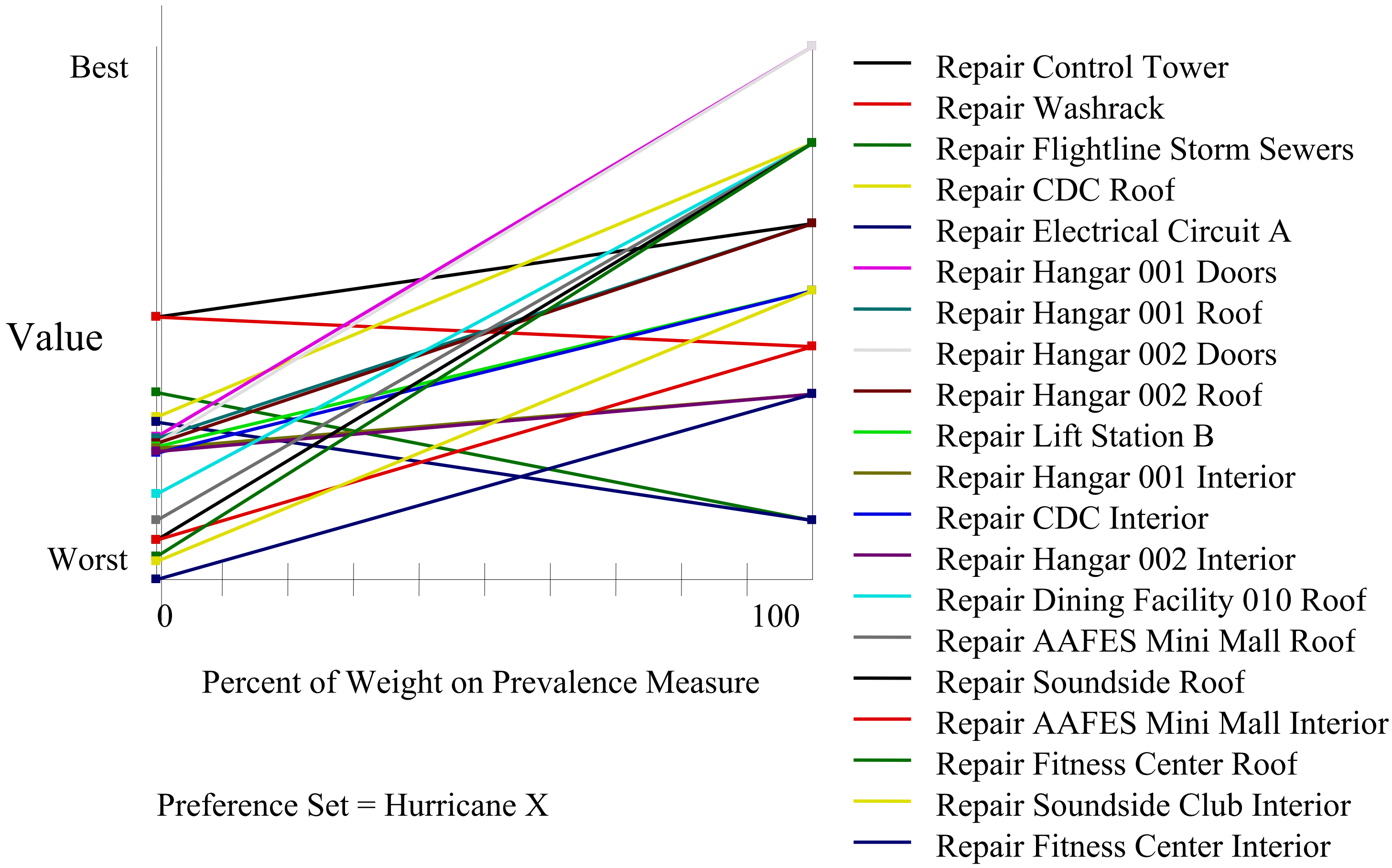


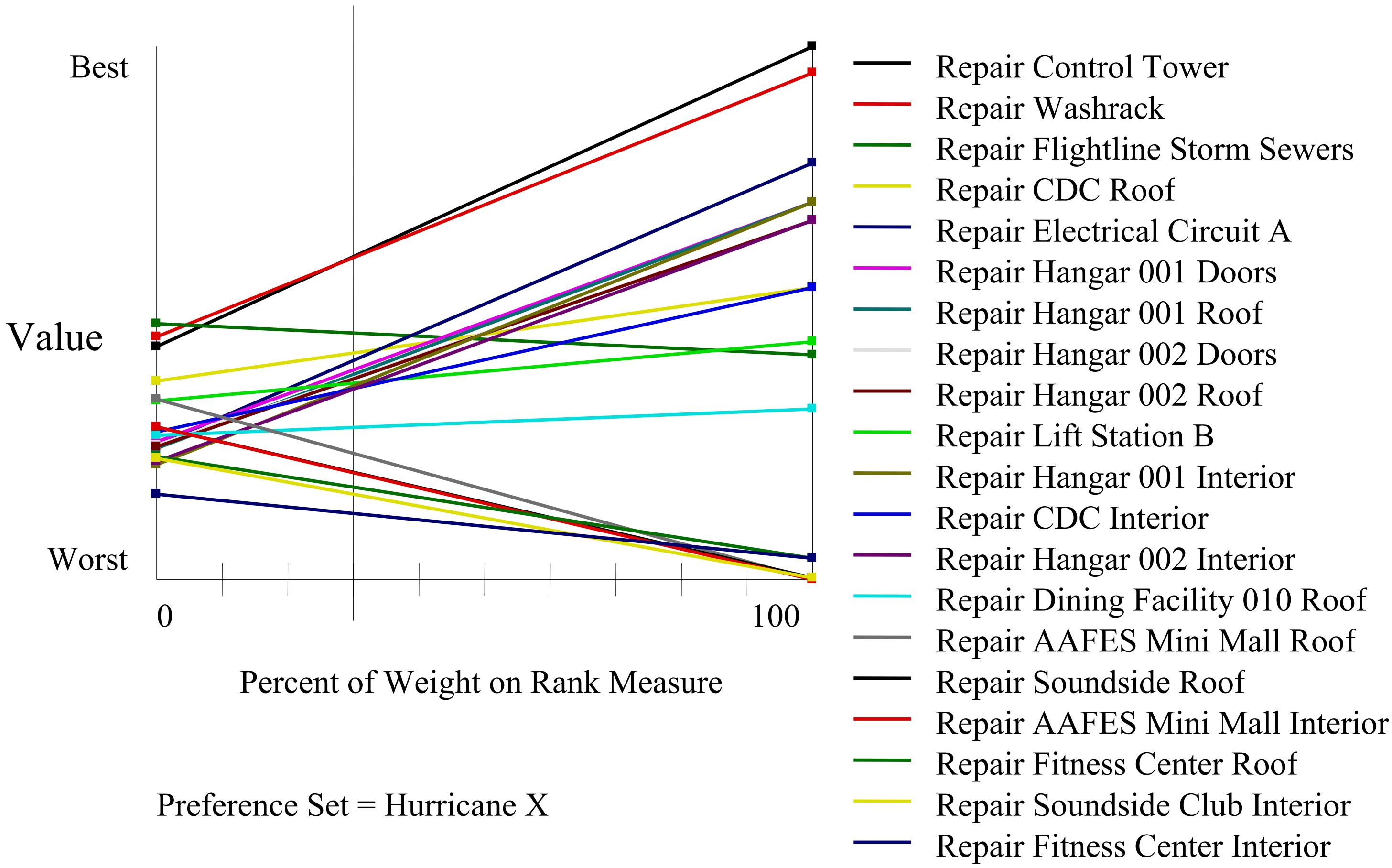
Preference Set = Hurricane X

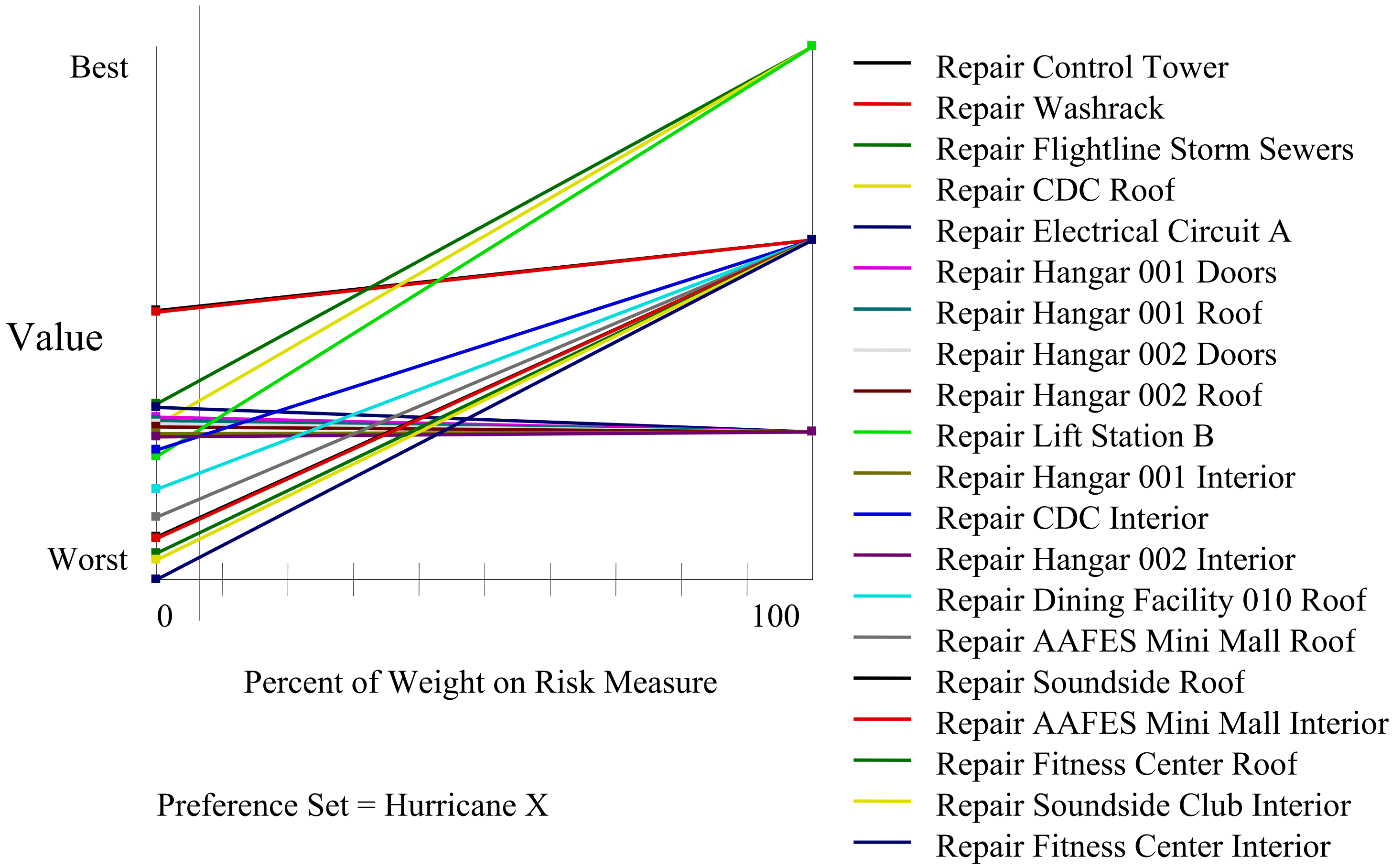

Best
Value
Worst
0
100
Percent of Weight on Level Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

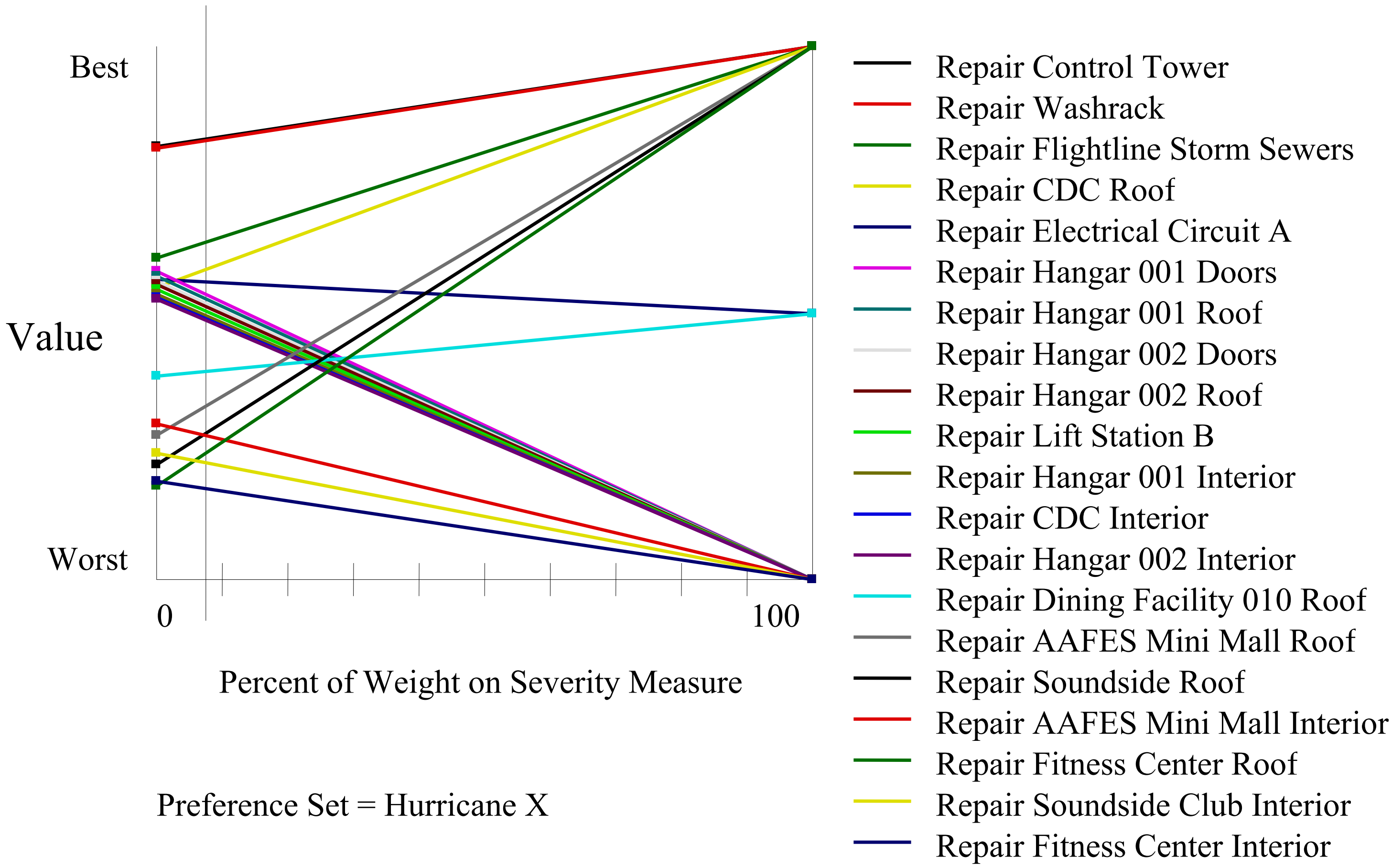

Best
Value
Worst
0
100
Percent of Weight on NG Status Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior


Best
Value
Worst
0
100
Percent of Weight on POL Status Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

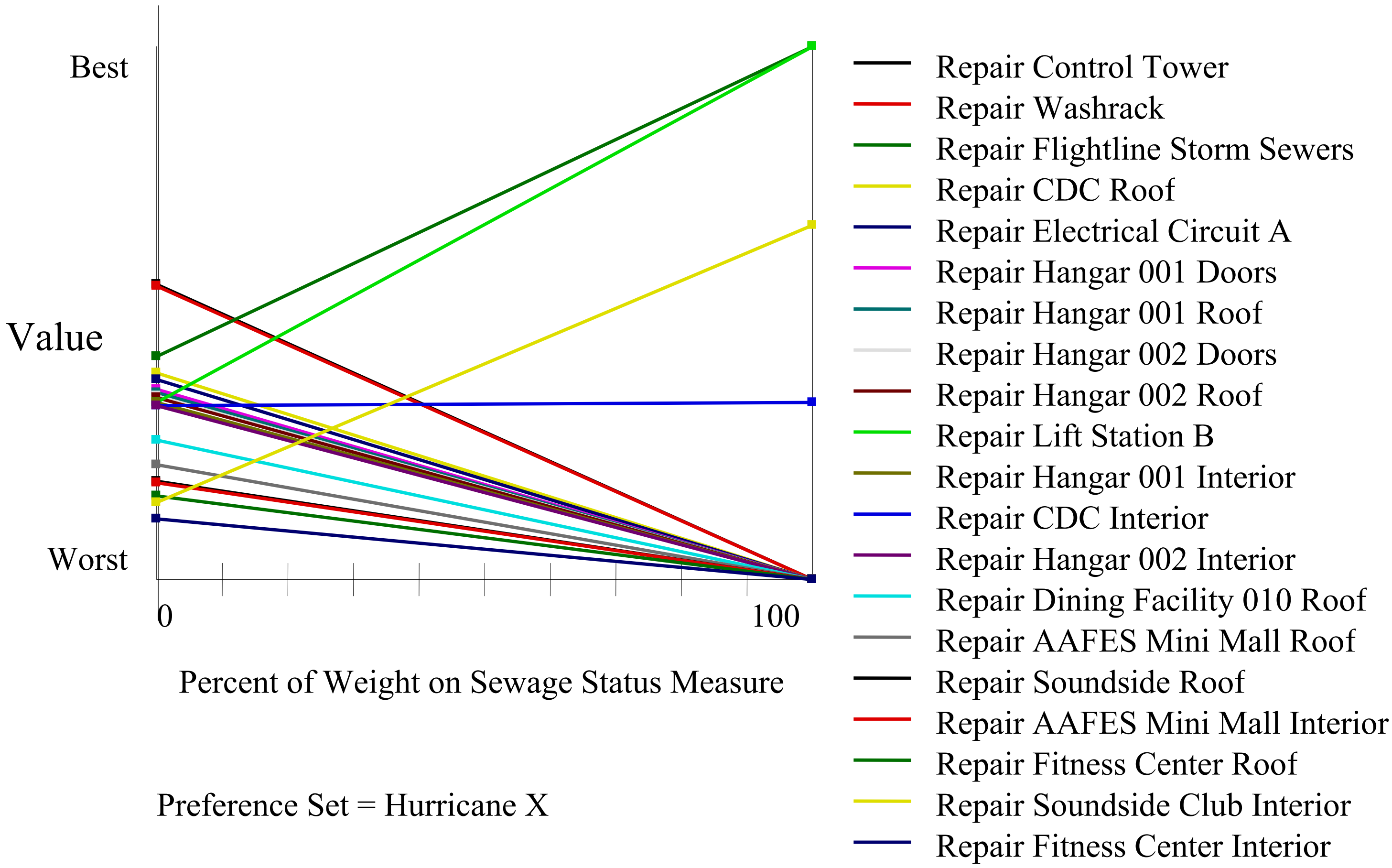

Best
Value
Worst
0
100
Percent of Weight on Prevalence Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

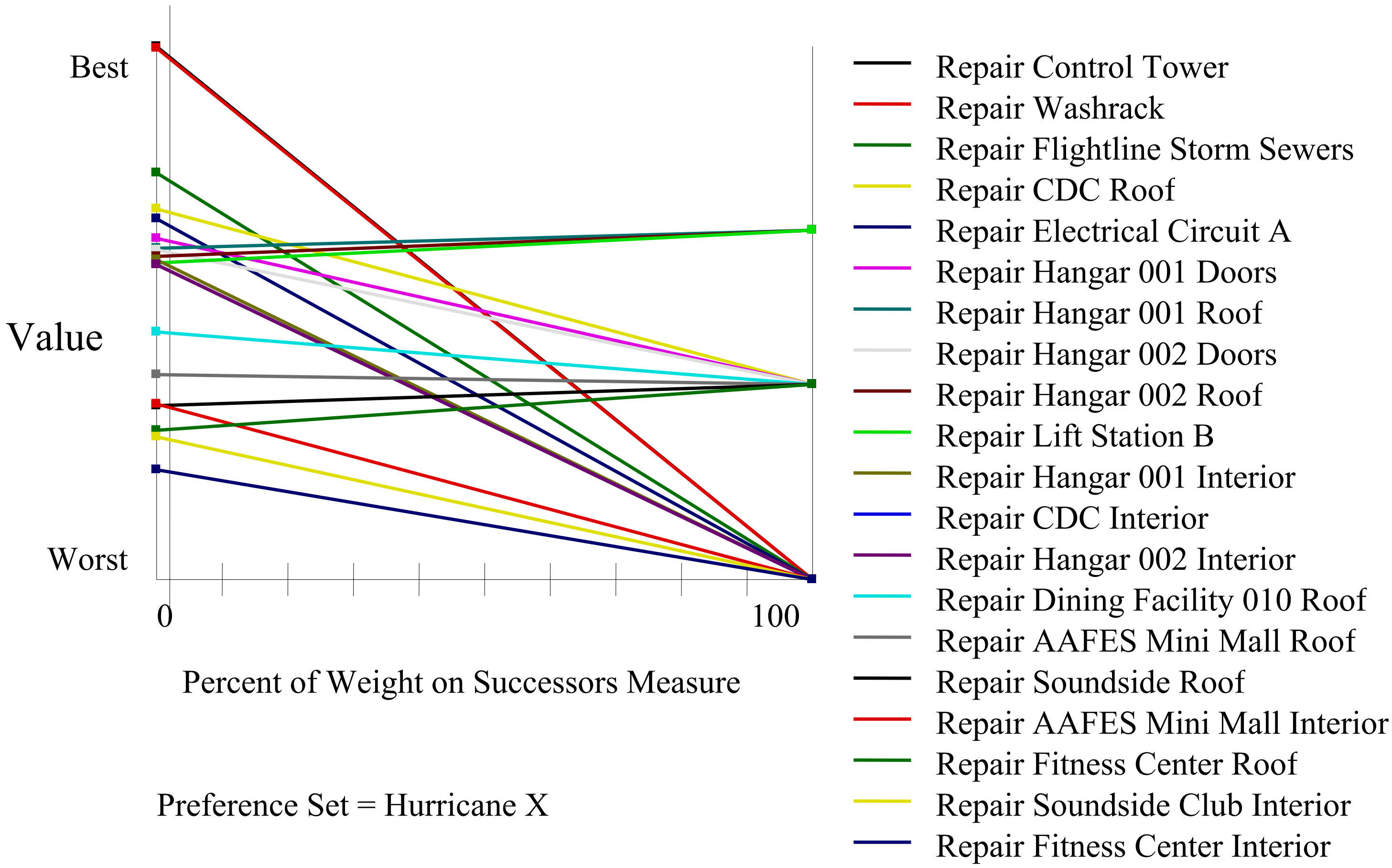

Best
Value
Worst
0
100
Percent of Weight on Rank Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

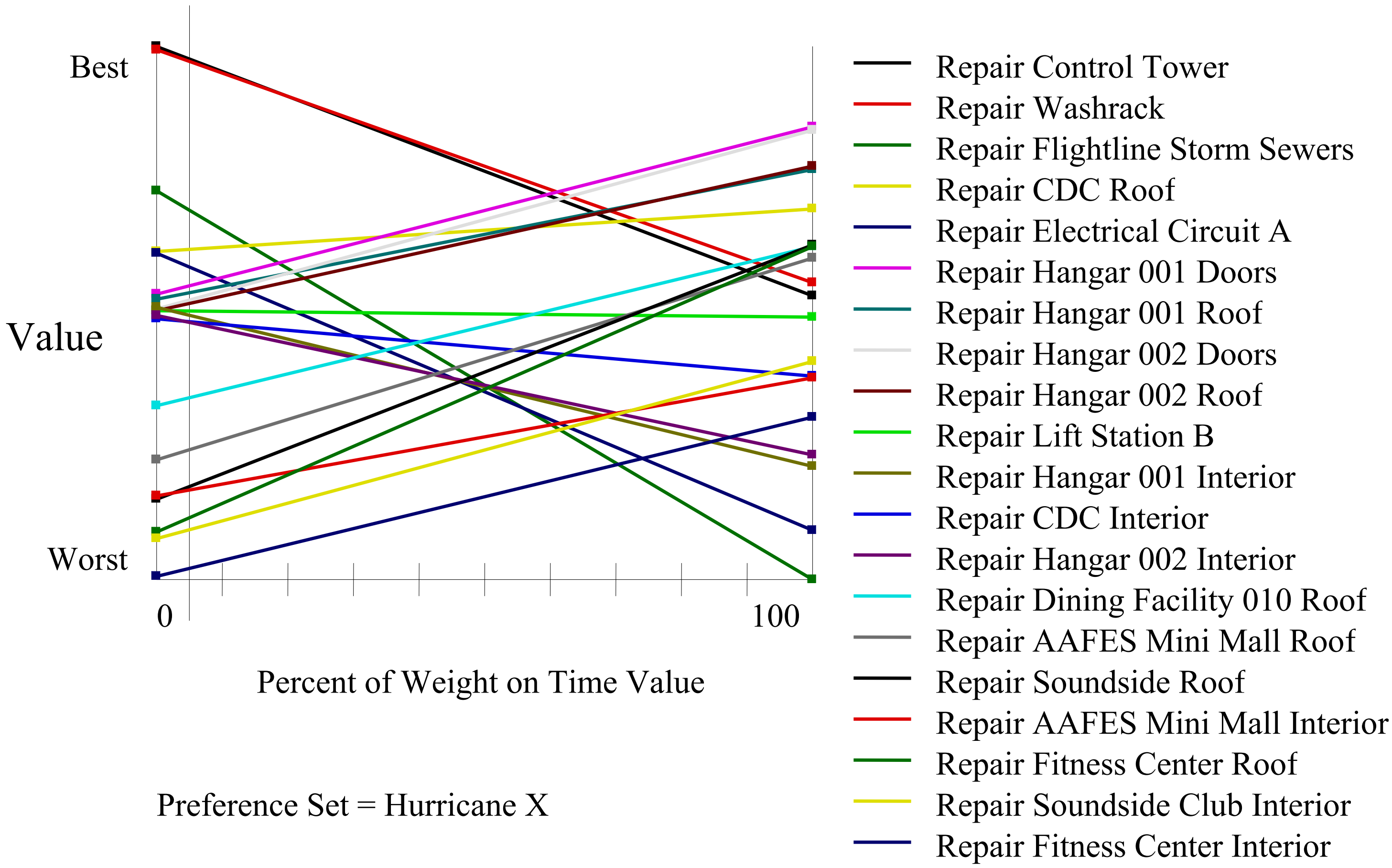

Best
Value
Worst
0
100
Percent of Weight on Risk Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior



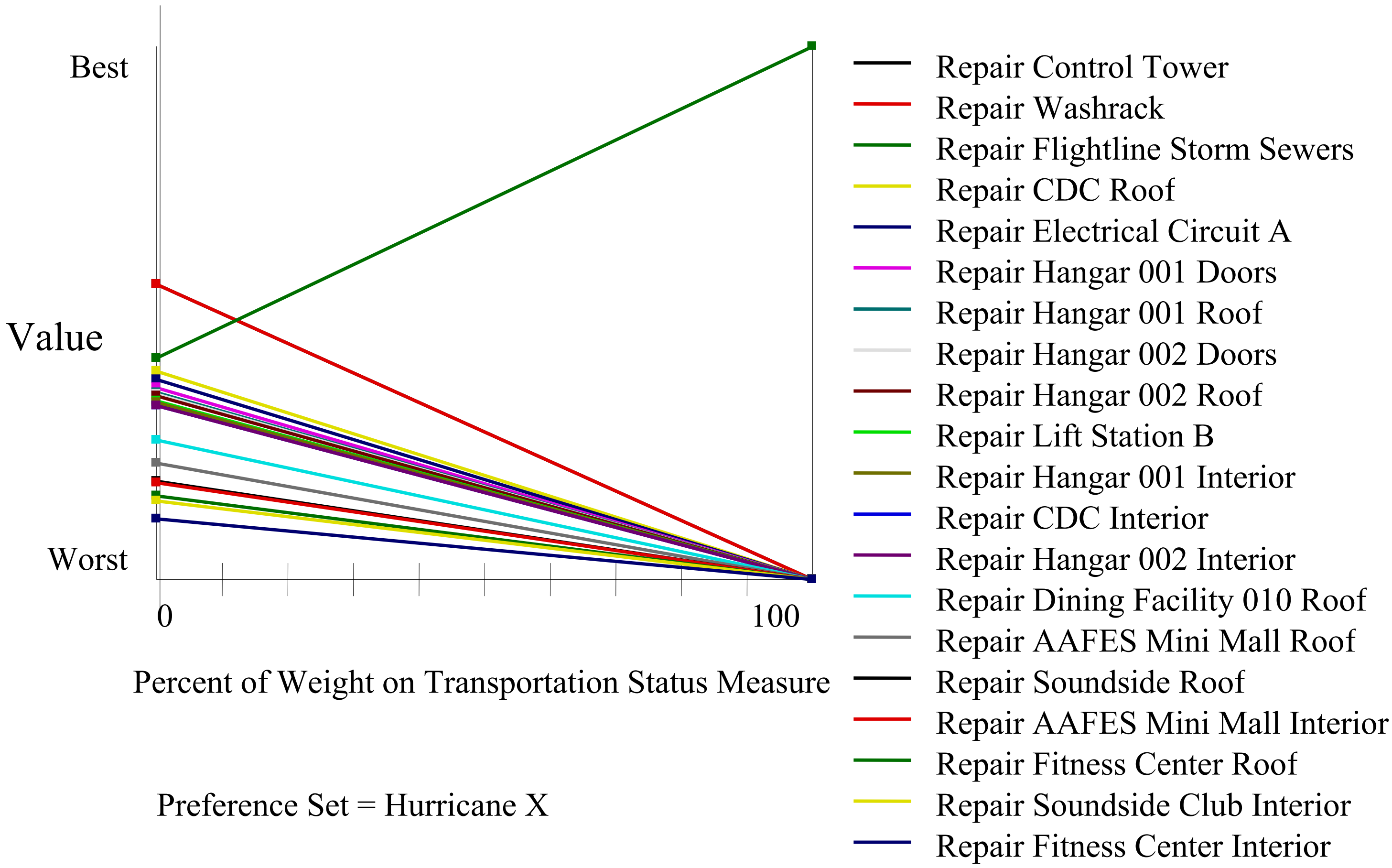
Preference Set = Hurricane X


Best
Value
Worst
0
100
Percent of Weight on Sewage Status Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

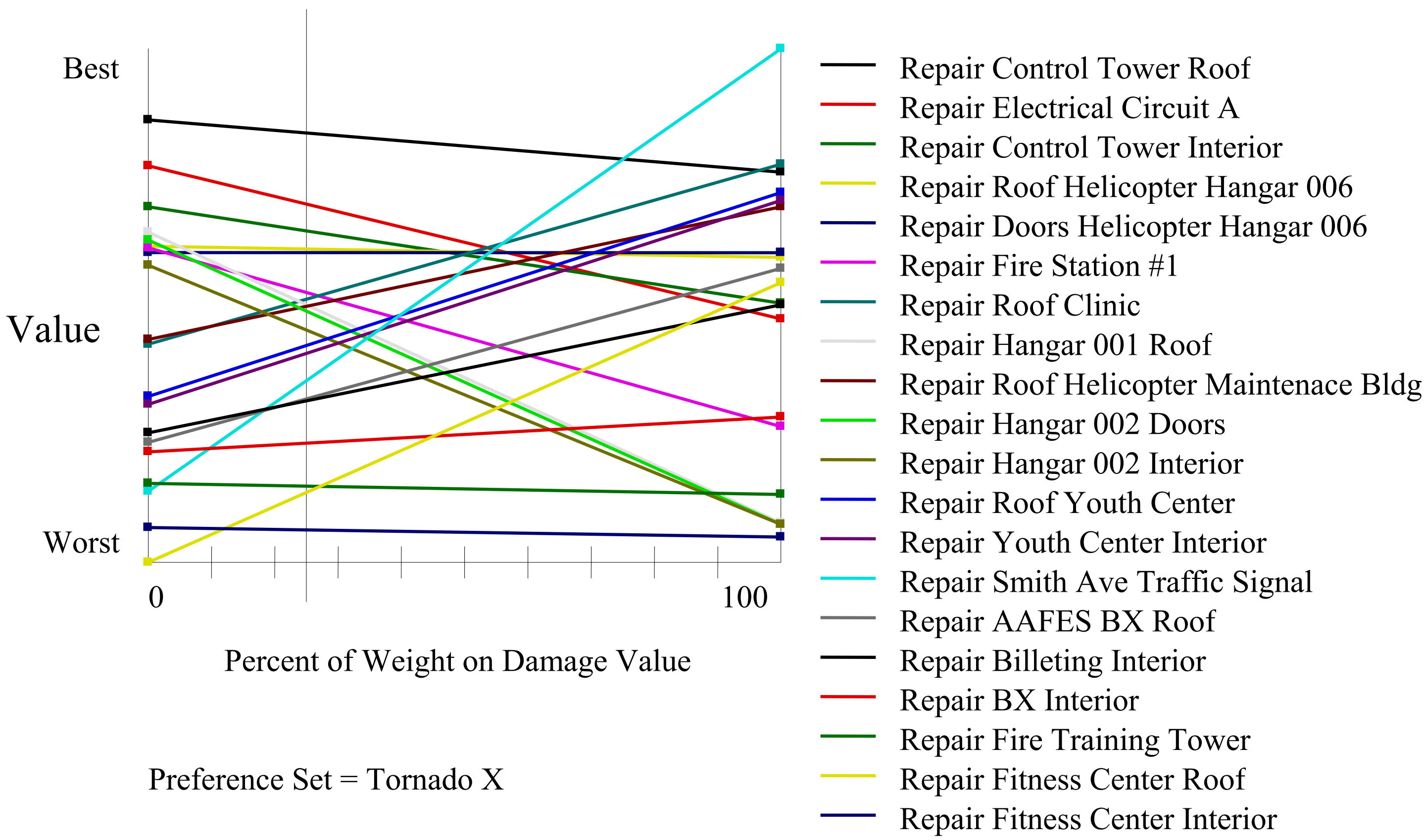

Best
Value
Worst
0
100
Percent of Weight on Successors Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

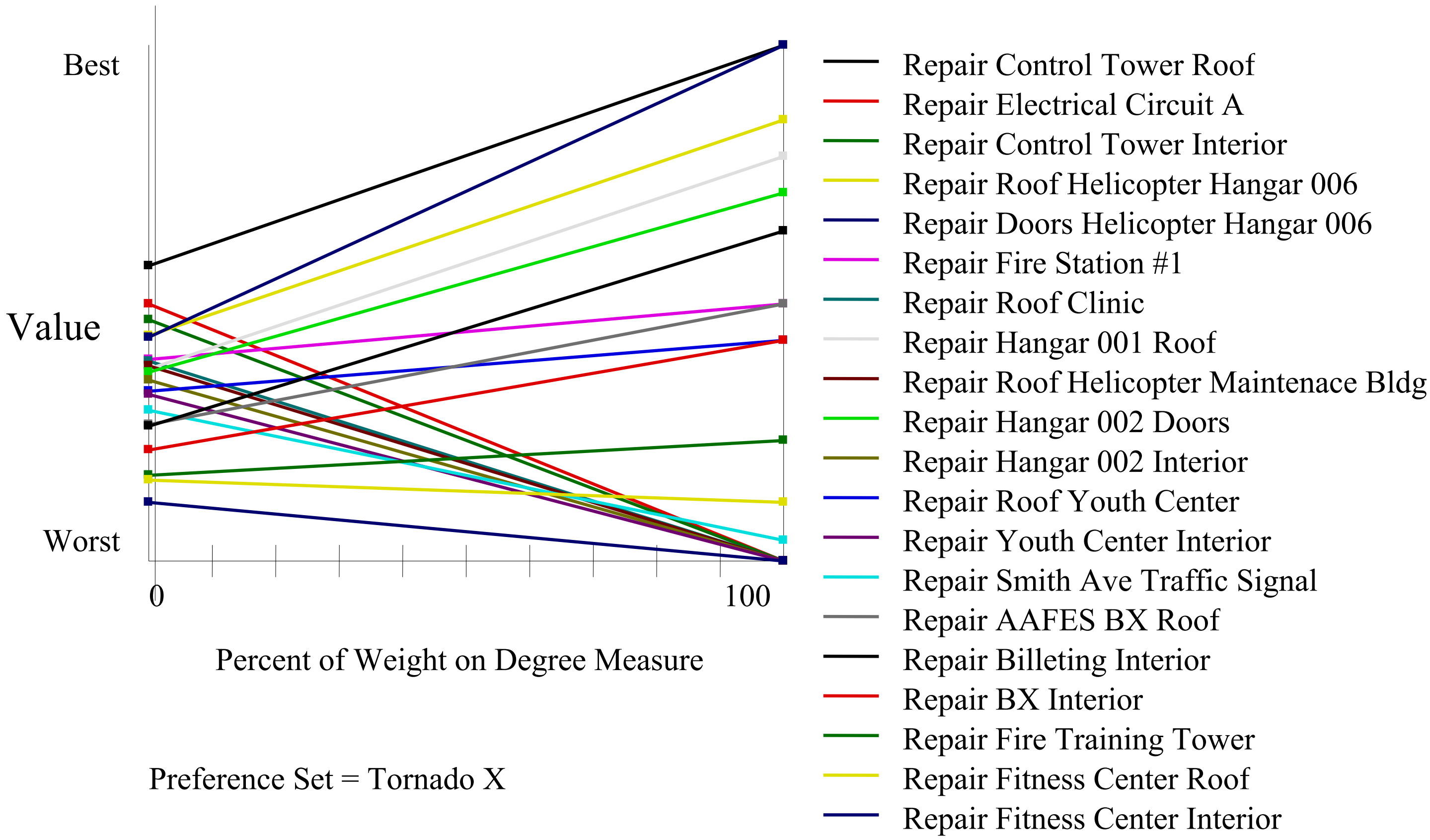


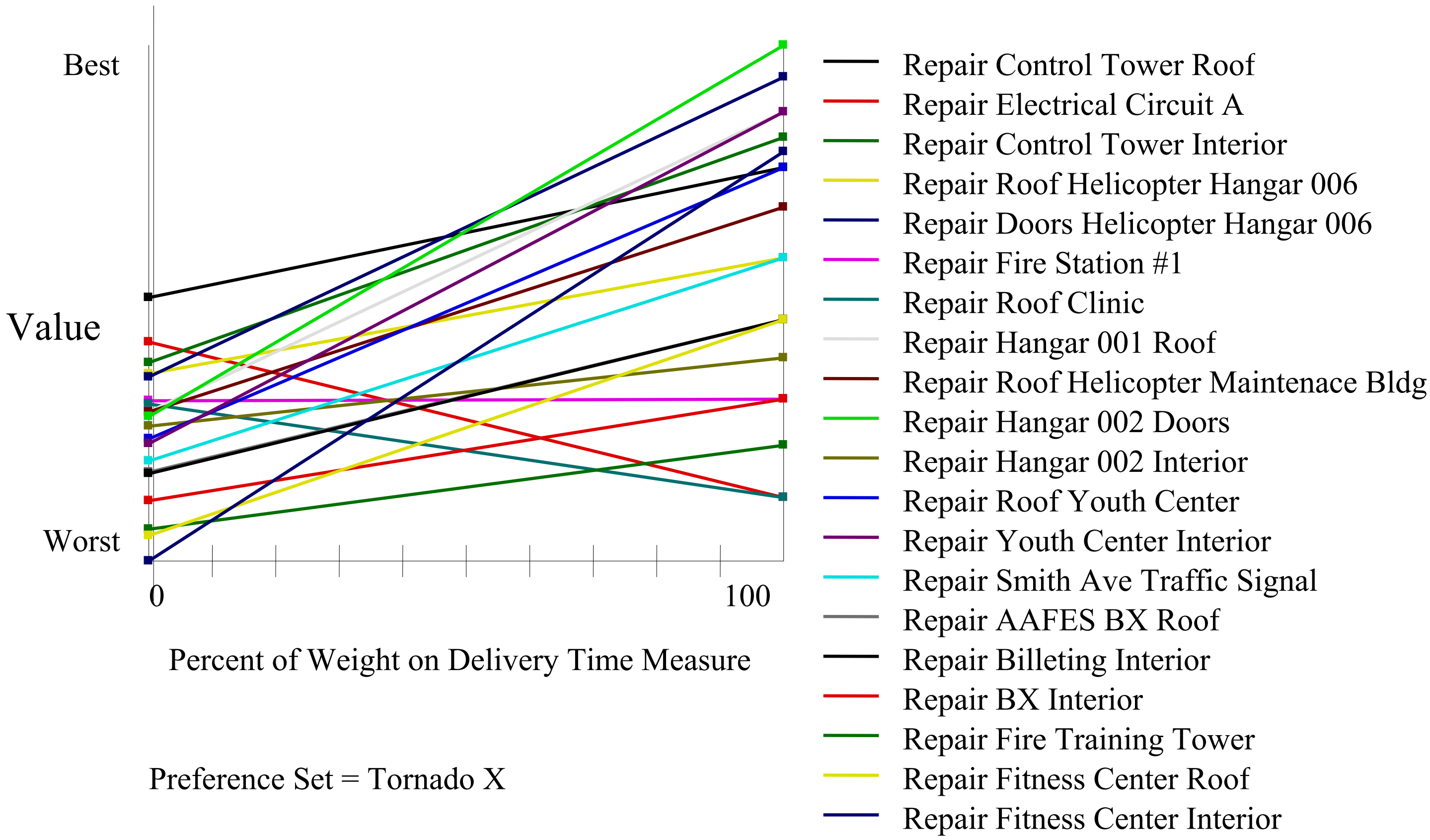
Best
Value
Worst
0
100
Percent of Weight on Time Value
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

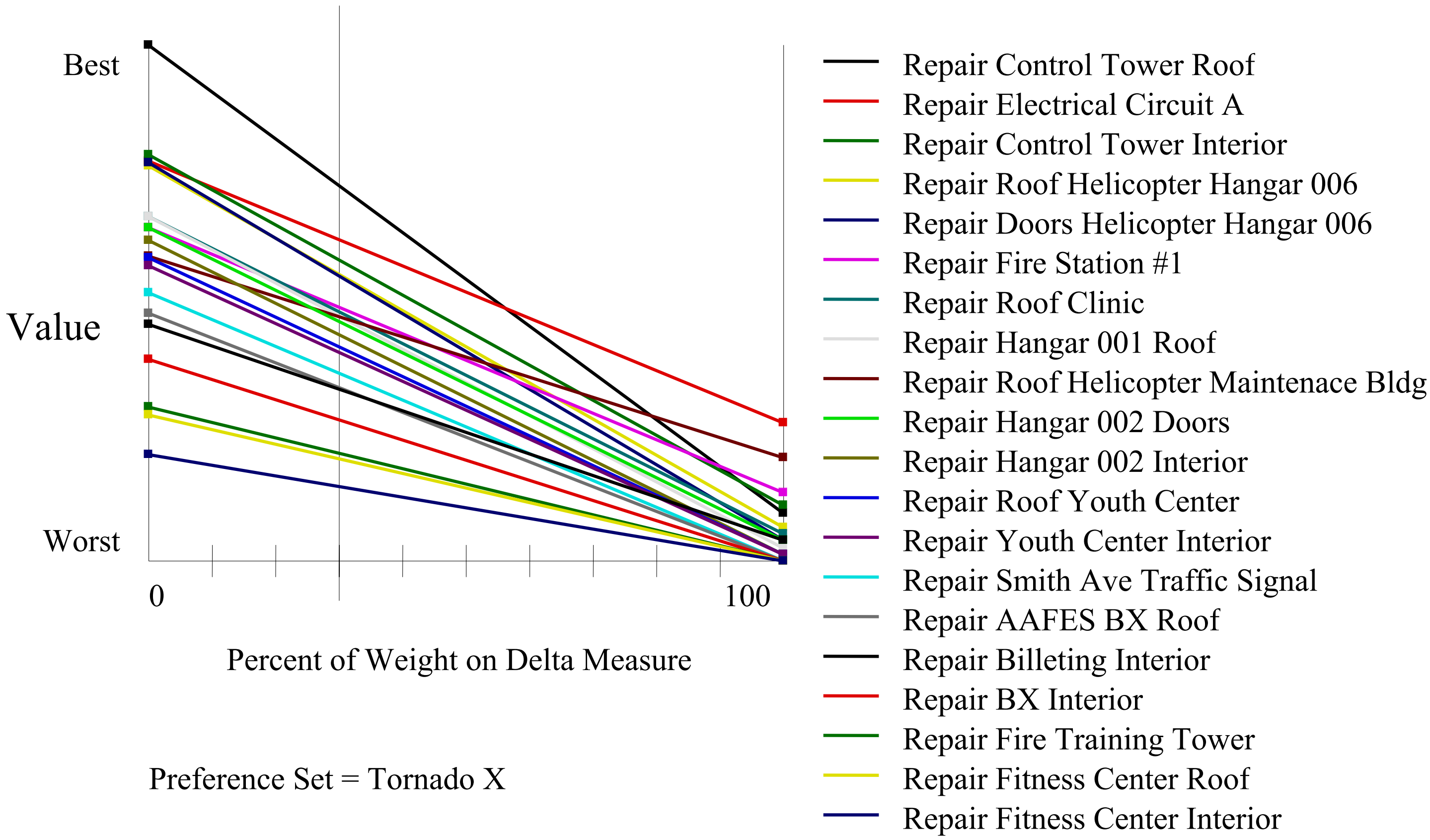

Best
Value
Worst
0
100
Percent of Weight on Transportation Status Measure
Preference Set = Hurricane X
Repair Control Tower
Repair Washrack
Repair Flightline Storm Sewers
Repair CDC Roof
Repair Electrical Circuit A
Repair Hangar 001 Doors
Repair Hangar 001 Roof
Repair Hangar 002 Doors
Repair Hangar 002 Roof
Repair Lift Station B
Repair Hangar 001 Interior
Repair CDC Interior
Repair Hangar 002 Interior
Repair Dining Facility 010 Roof
Repair AAFES Mini Mall Roof
Repair Soundside Roof
Repair AAFES Mini Mall Interior
Repair Fitness Center Roof
Repair Soundside Club Interior
Repair Fitness Center Interior

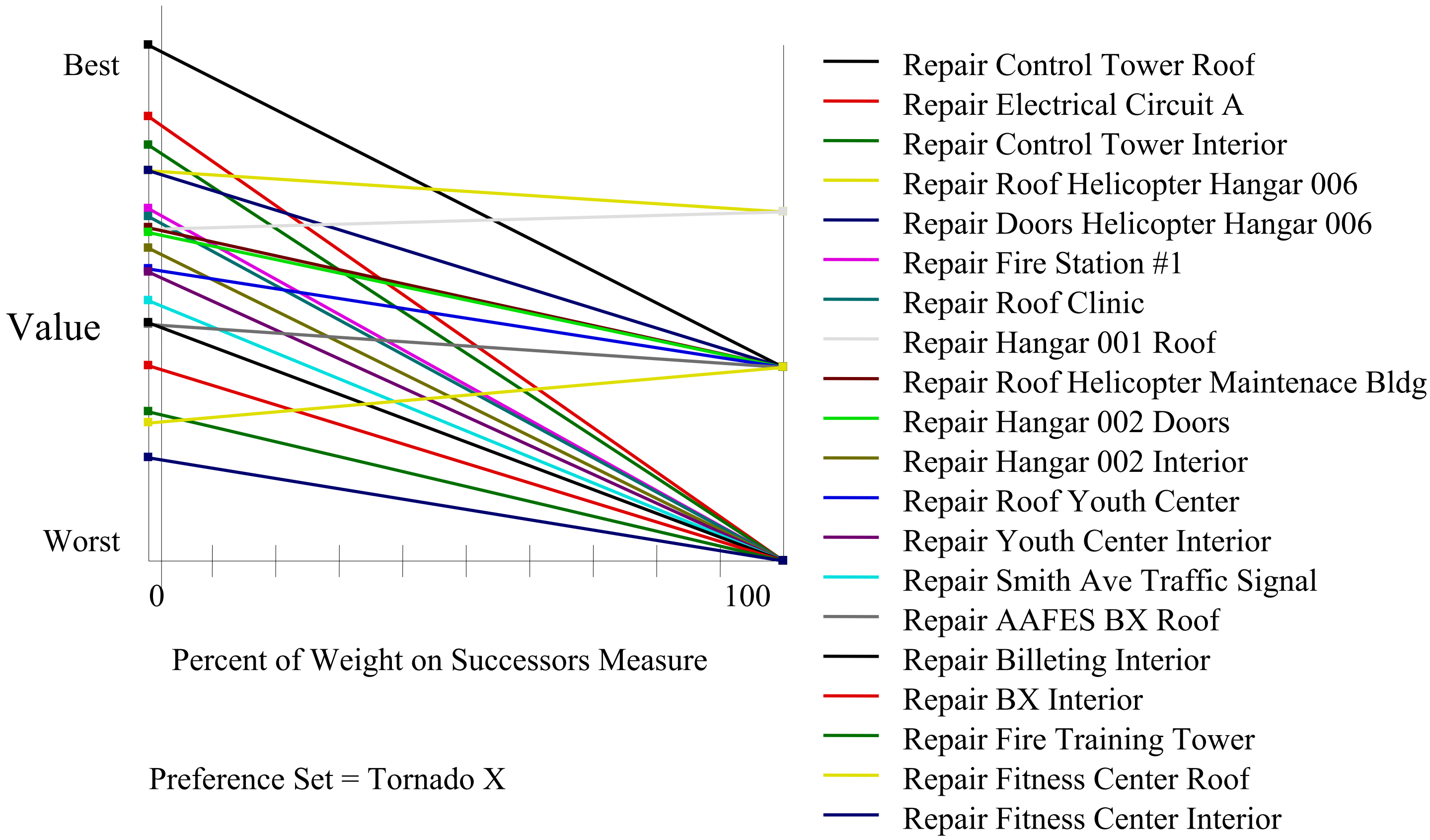
Appendix C: Sensitivity Analysis Graphs (Tornado X)

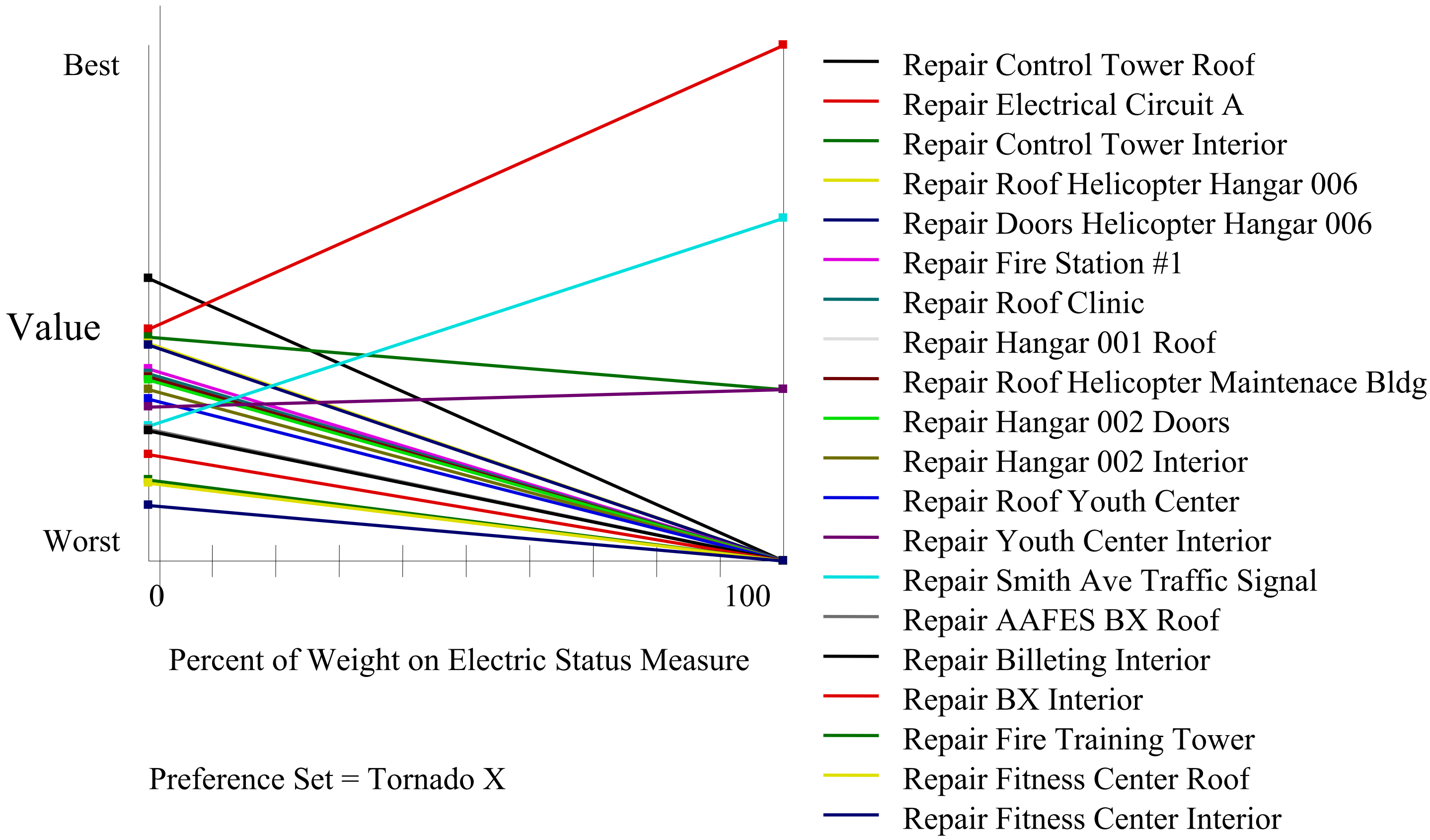


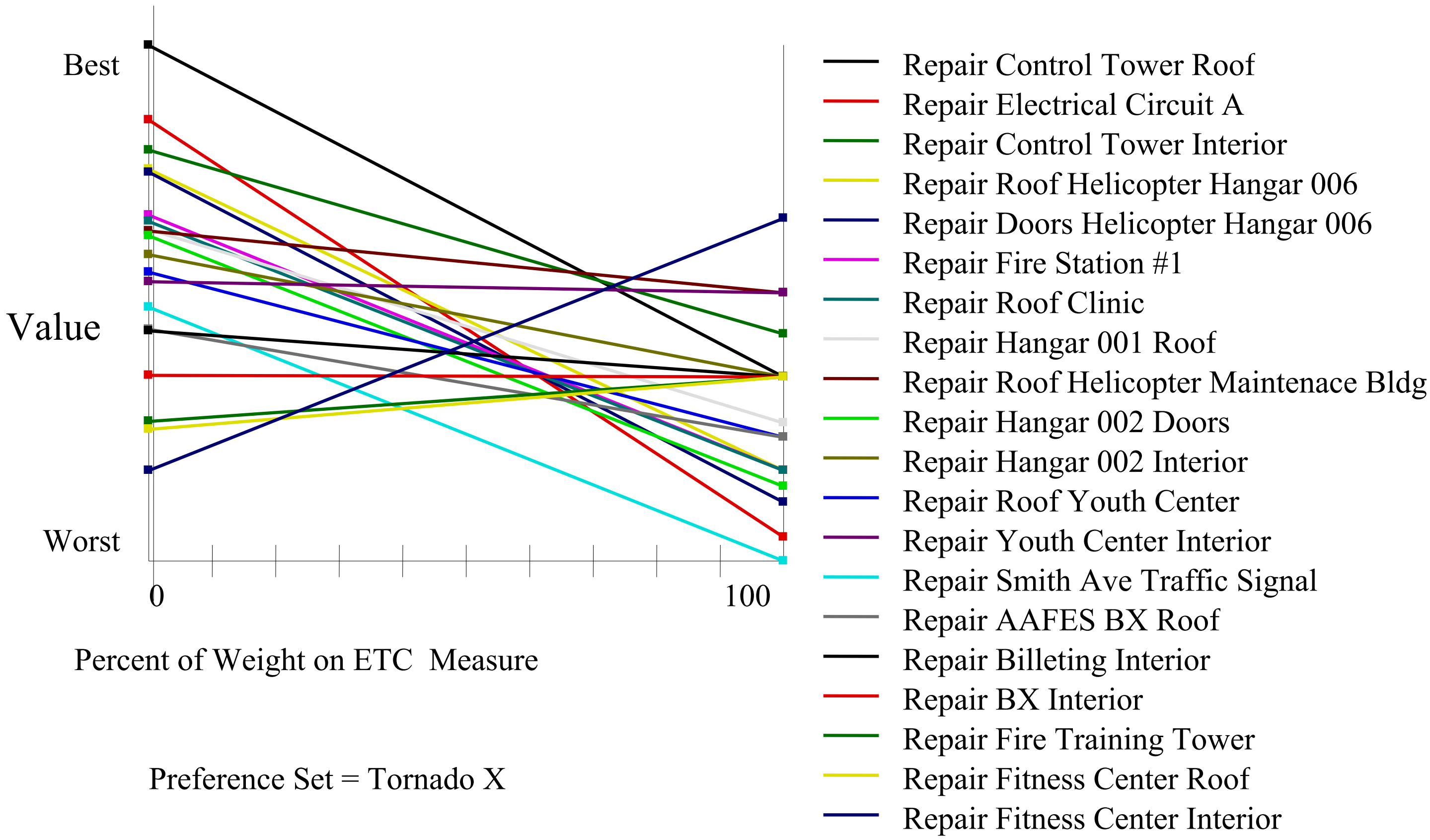

Best
Value
Worst
0
100
Percent of Weight on Degree Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

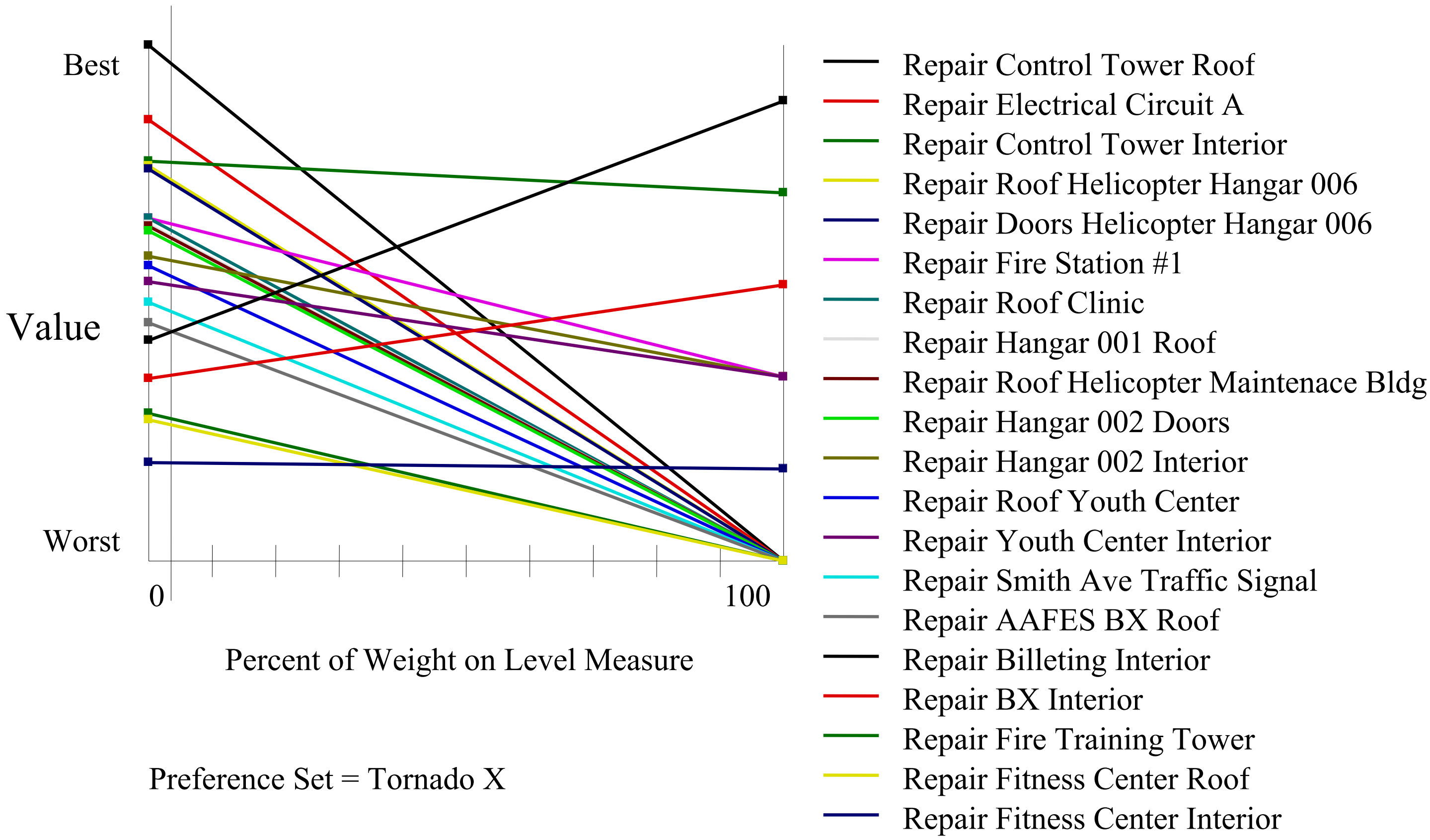

Best
Value
Worst
0
100
Percent of Weight on Delivery Time Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

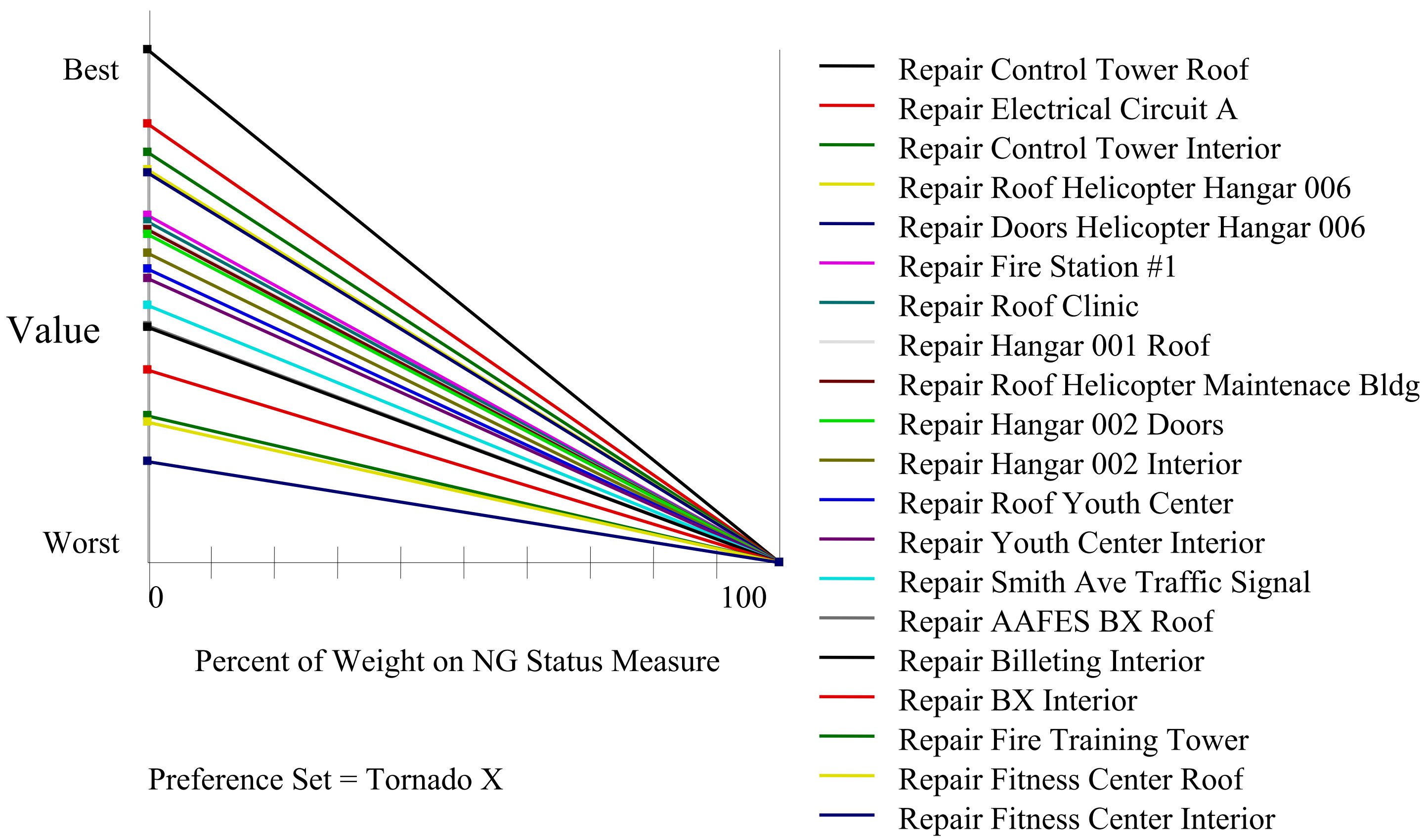

Best
Value
Worst
0
100
Percent of Weight on Delta Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

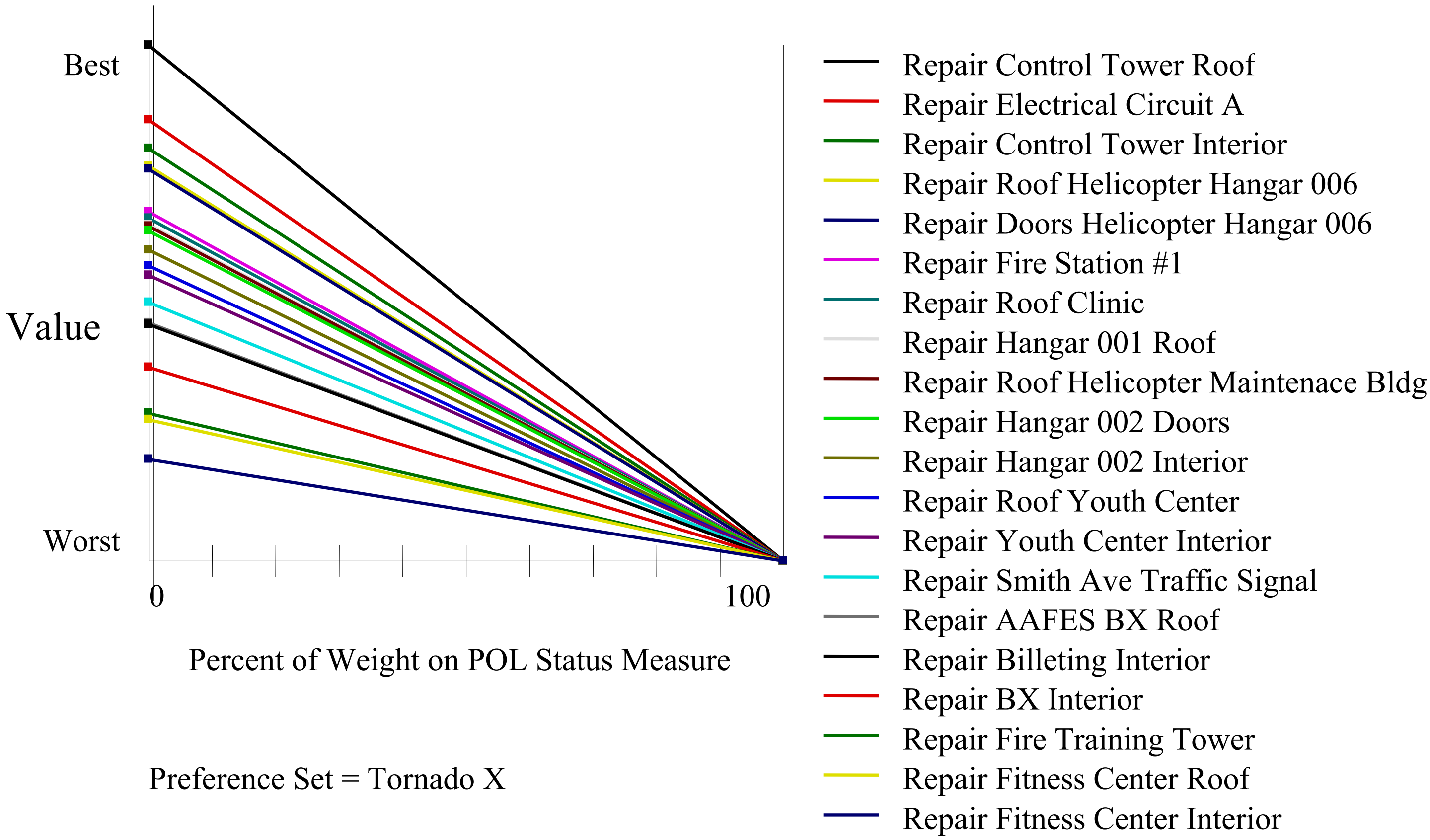

Best
Value
Worst
0
100
Percent of Weight on Successors Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

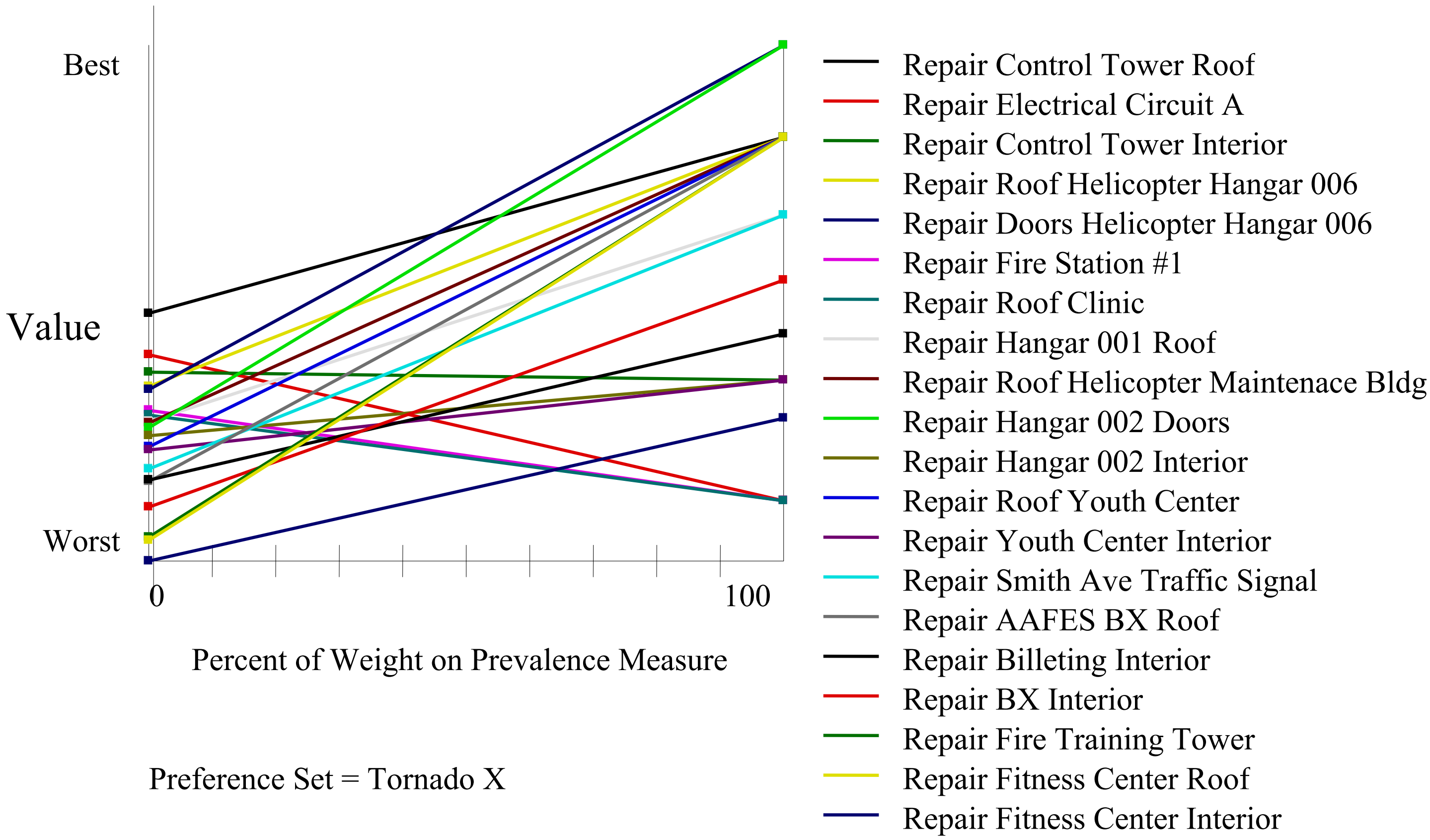

Best
Value
Worst
0
100
Percent of Weight on Electric Status Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior


Best
Value
Worst
0
100
Percent of Weight on ETC Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

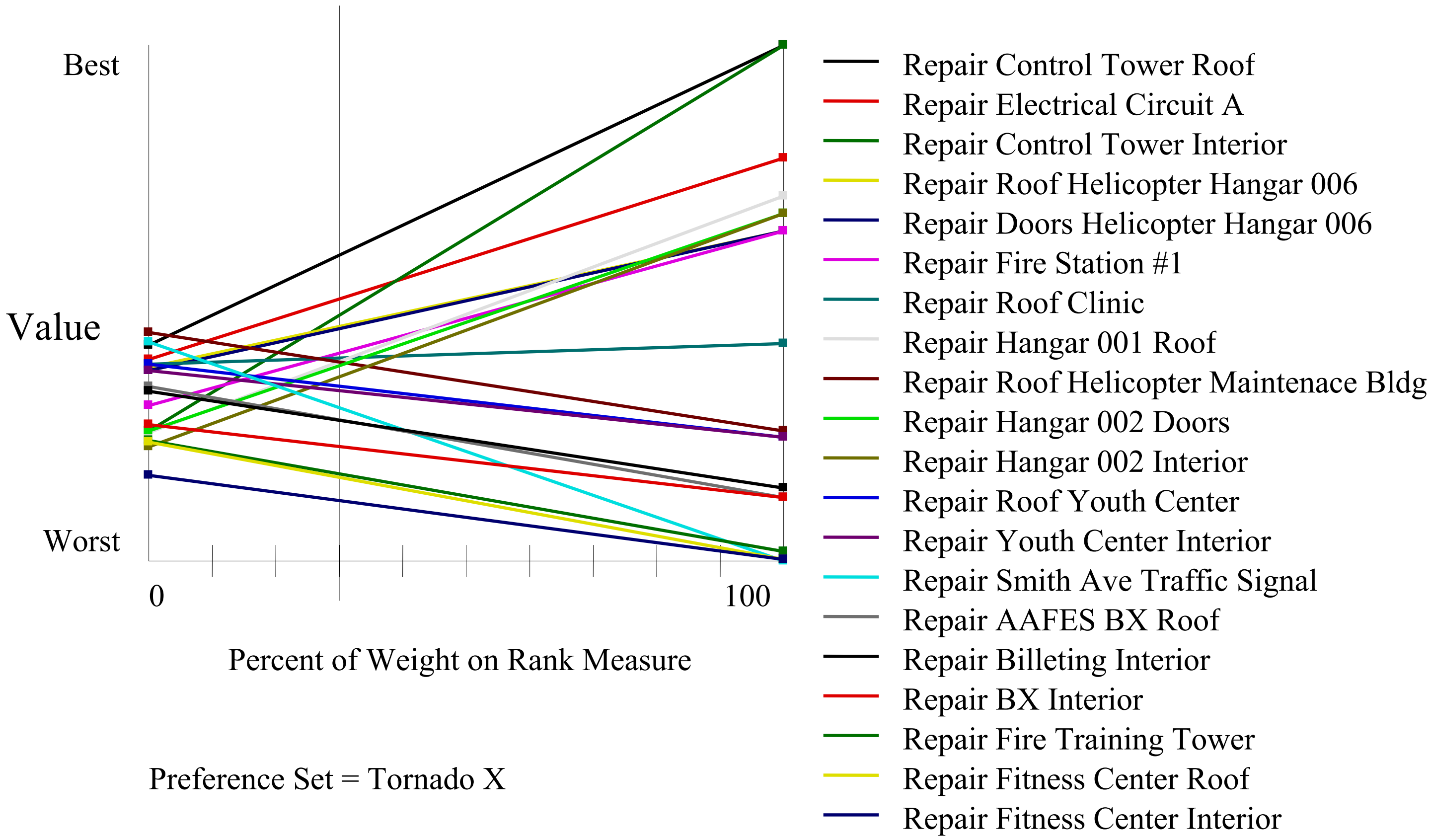

Best
Value
Worst
0
100
Percent of Weight on Level Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

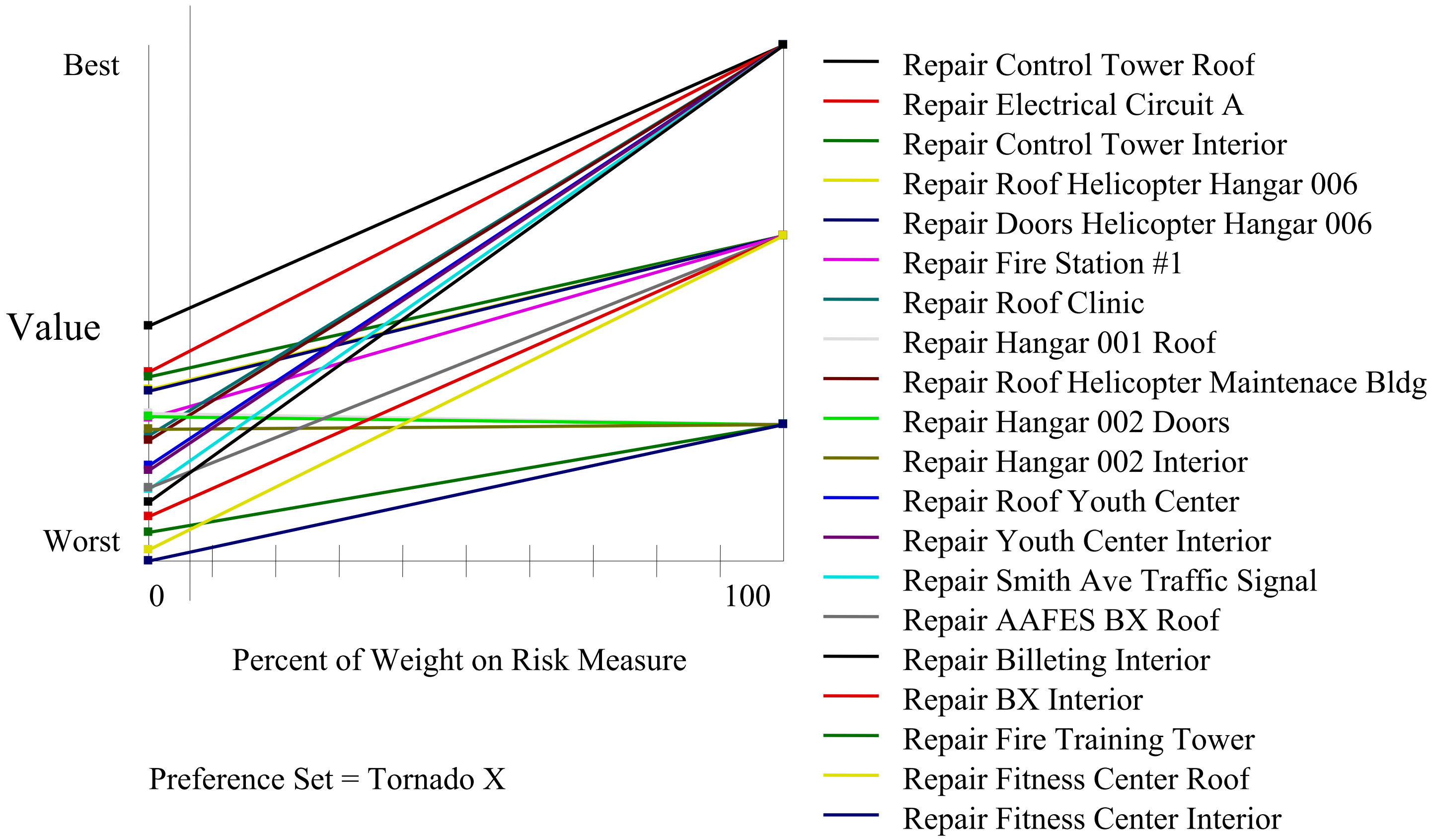

Best
Value
Worst
0
100
Percent of Weight on NG Status Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

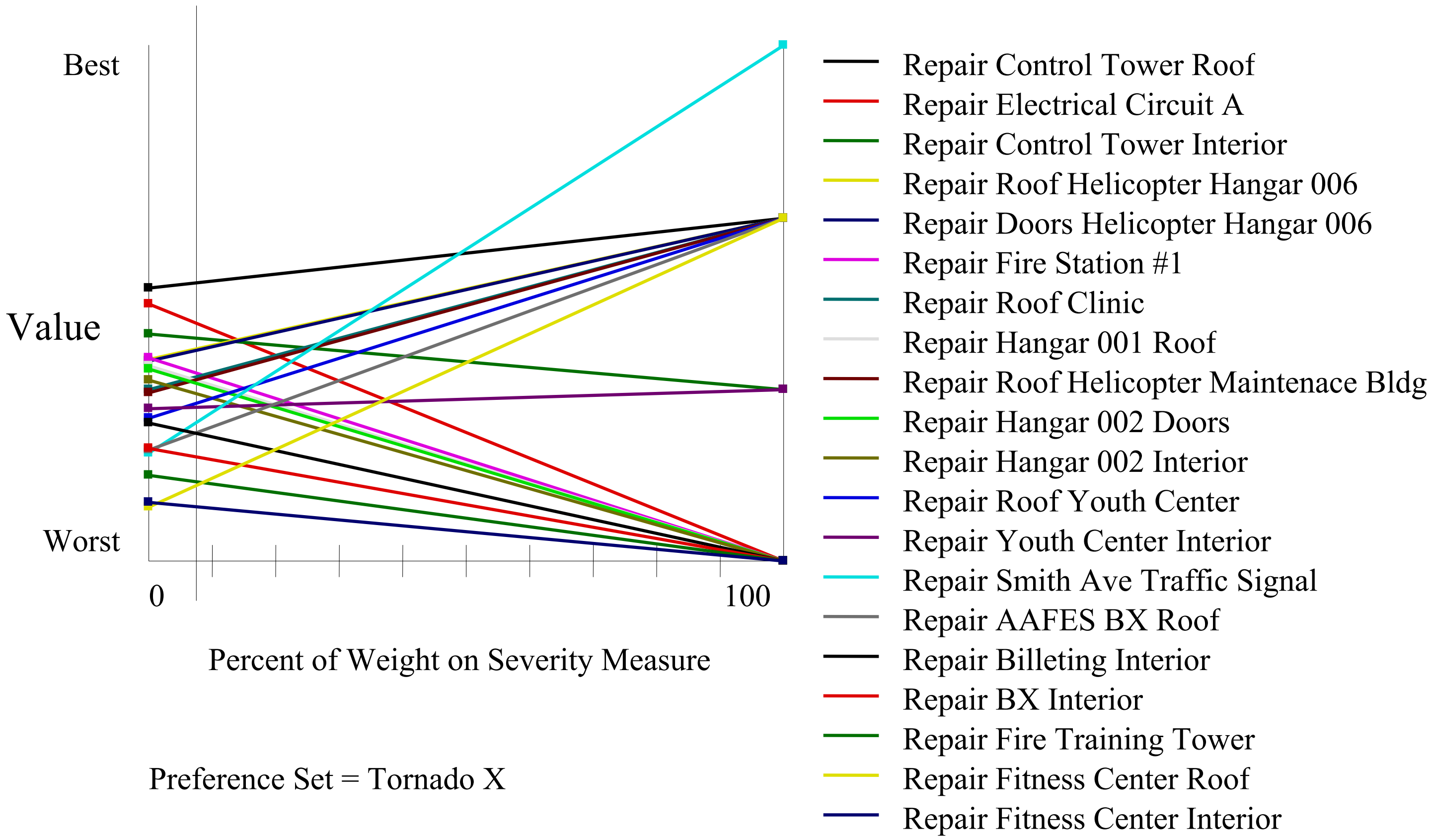

Best
Value
Worst
0
100
Percent of Weight on POL Status Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

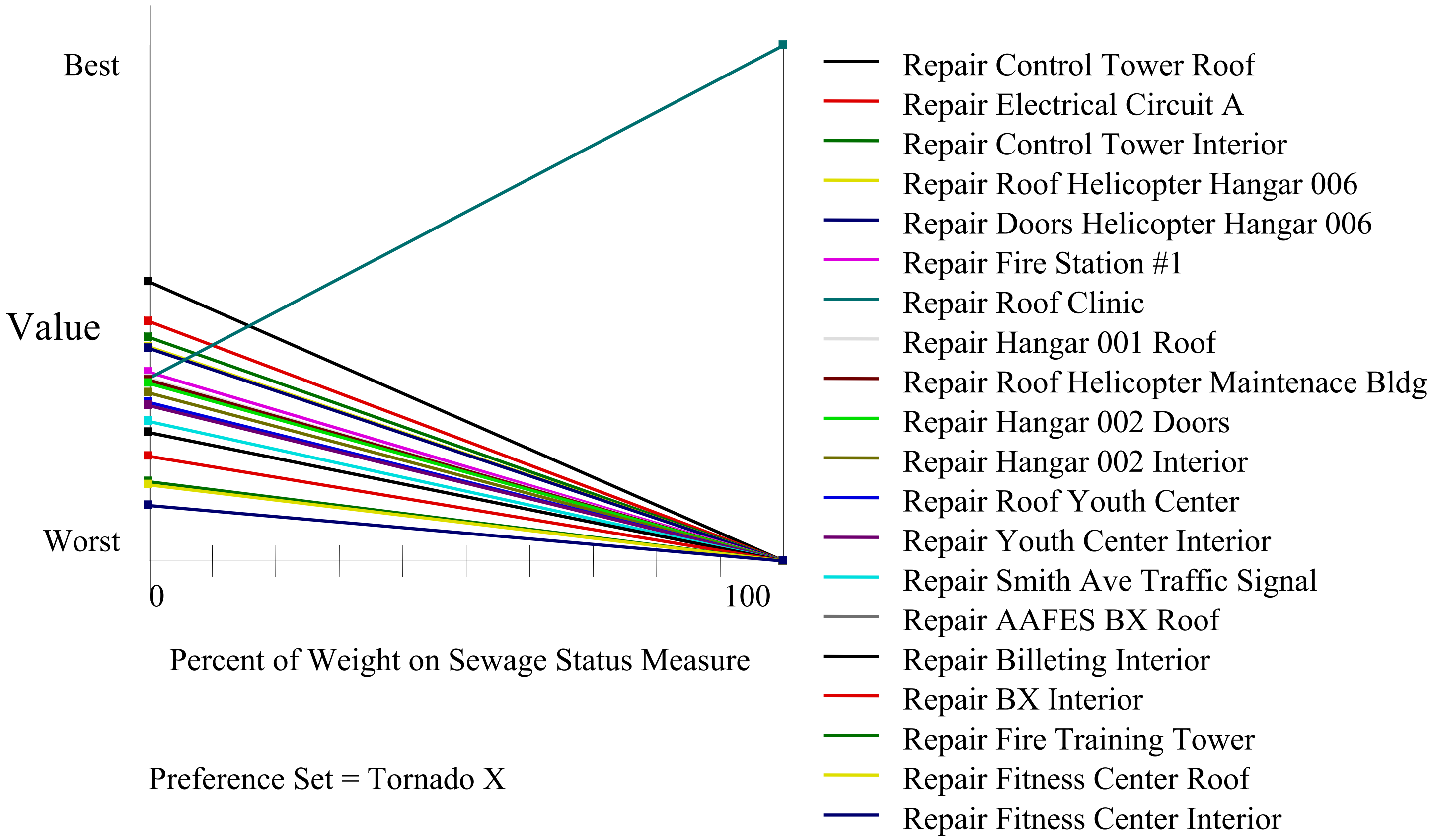


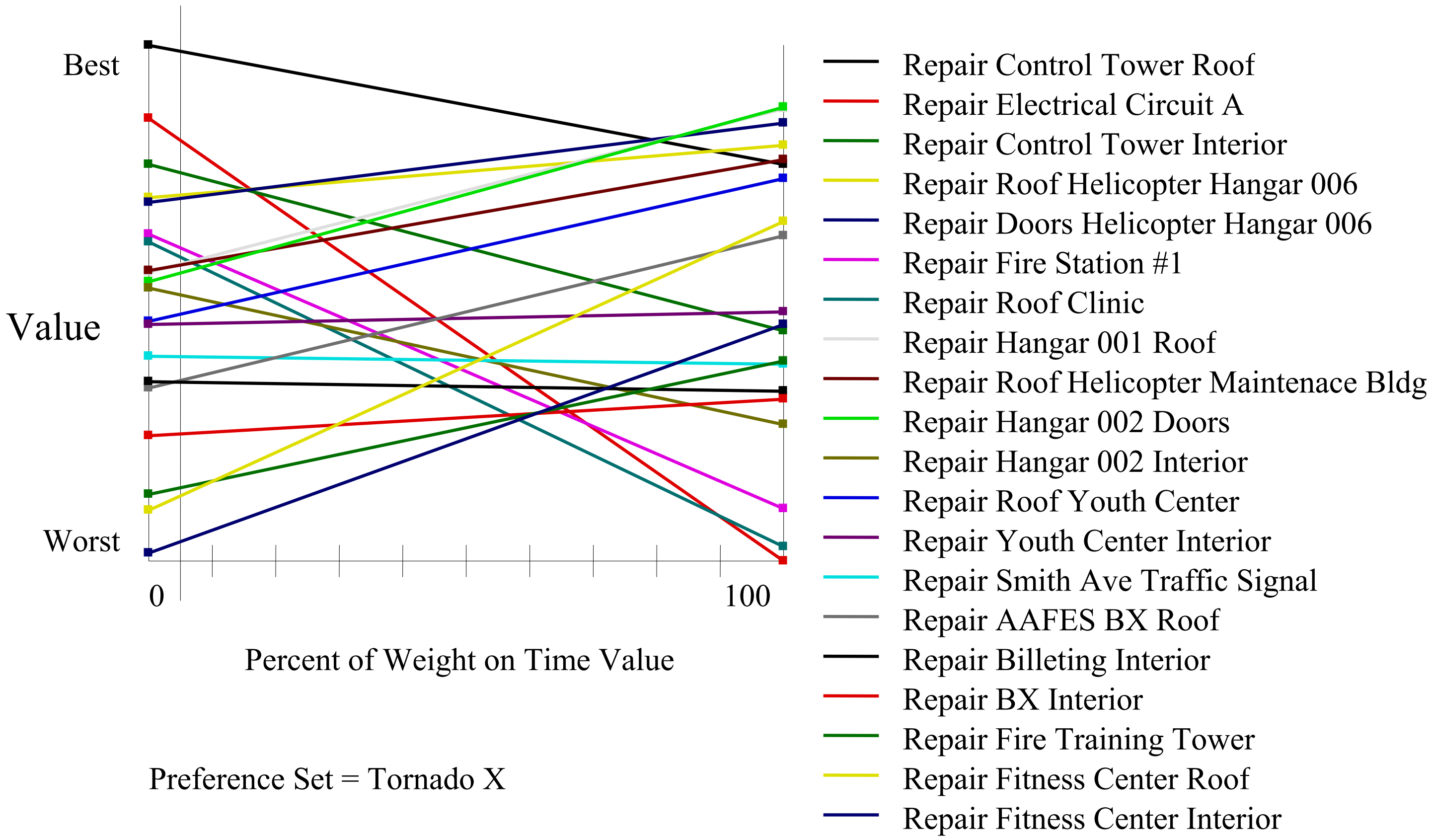
Best
Value
Worst
0
100
Percent of Weight on Prevalence Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

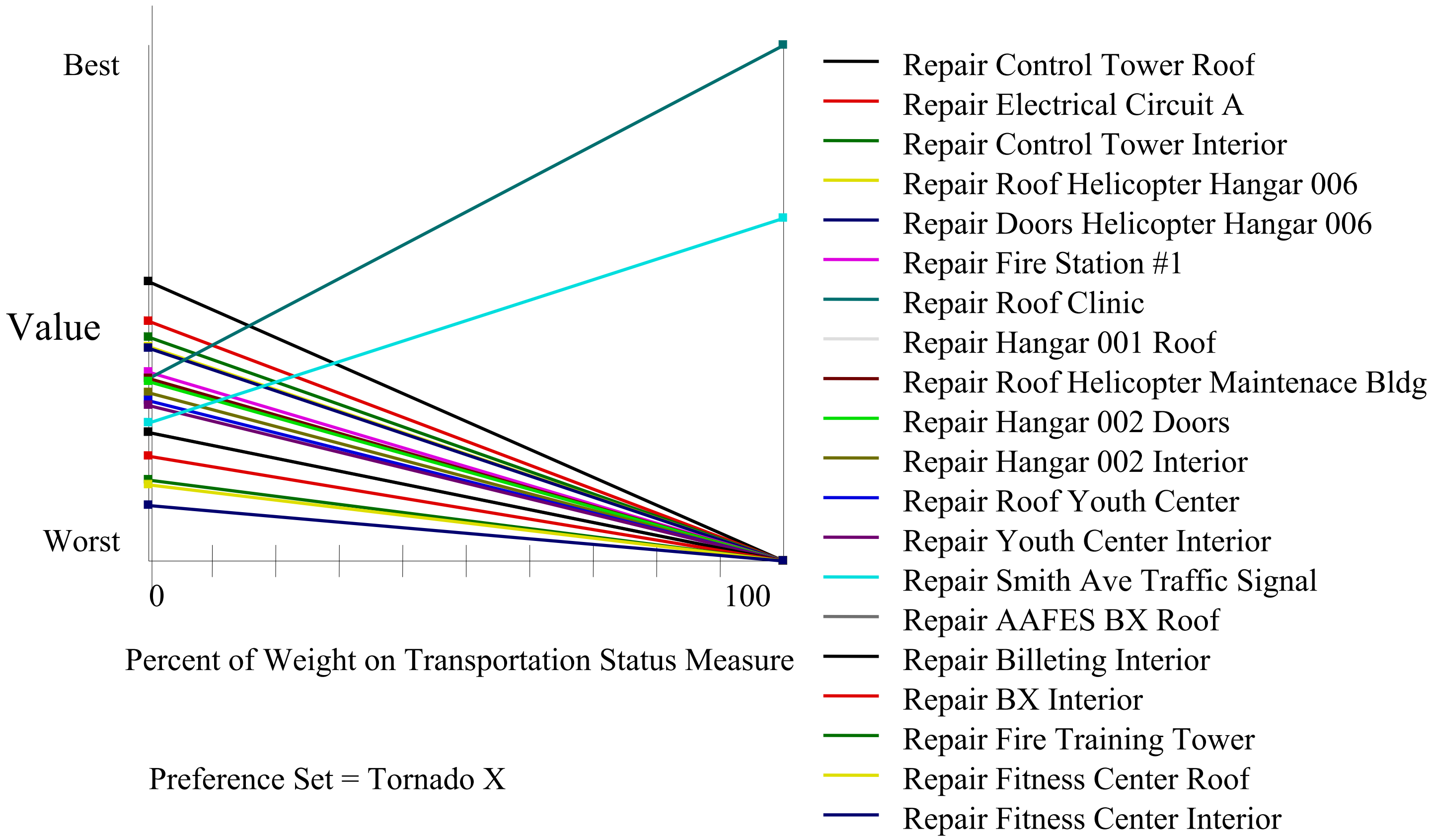

Best
Value
Worst
0
100
Percent of Weight on Rank Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

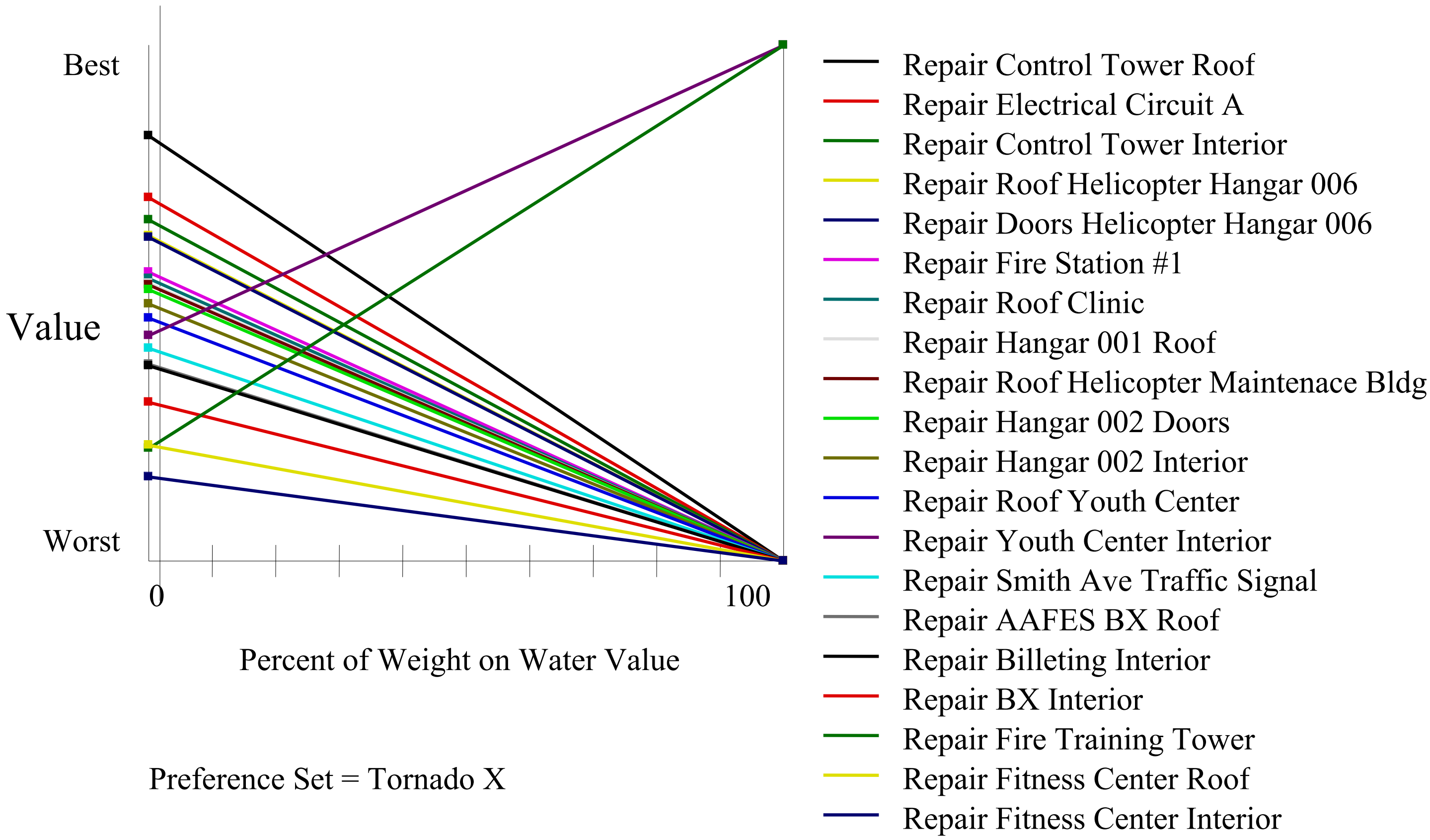

Best
Value
Worst
0
100
Percent of Weight on Risk Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior


Best
Value
Worst
0
100
Percent of Weight on Severity Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

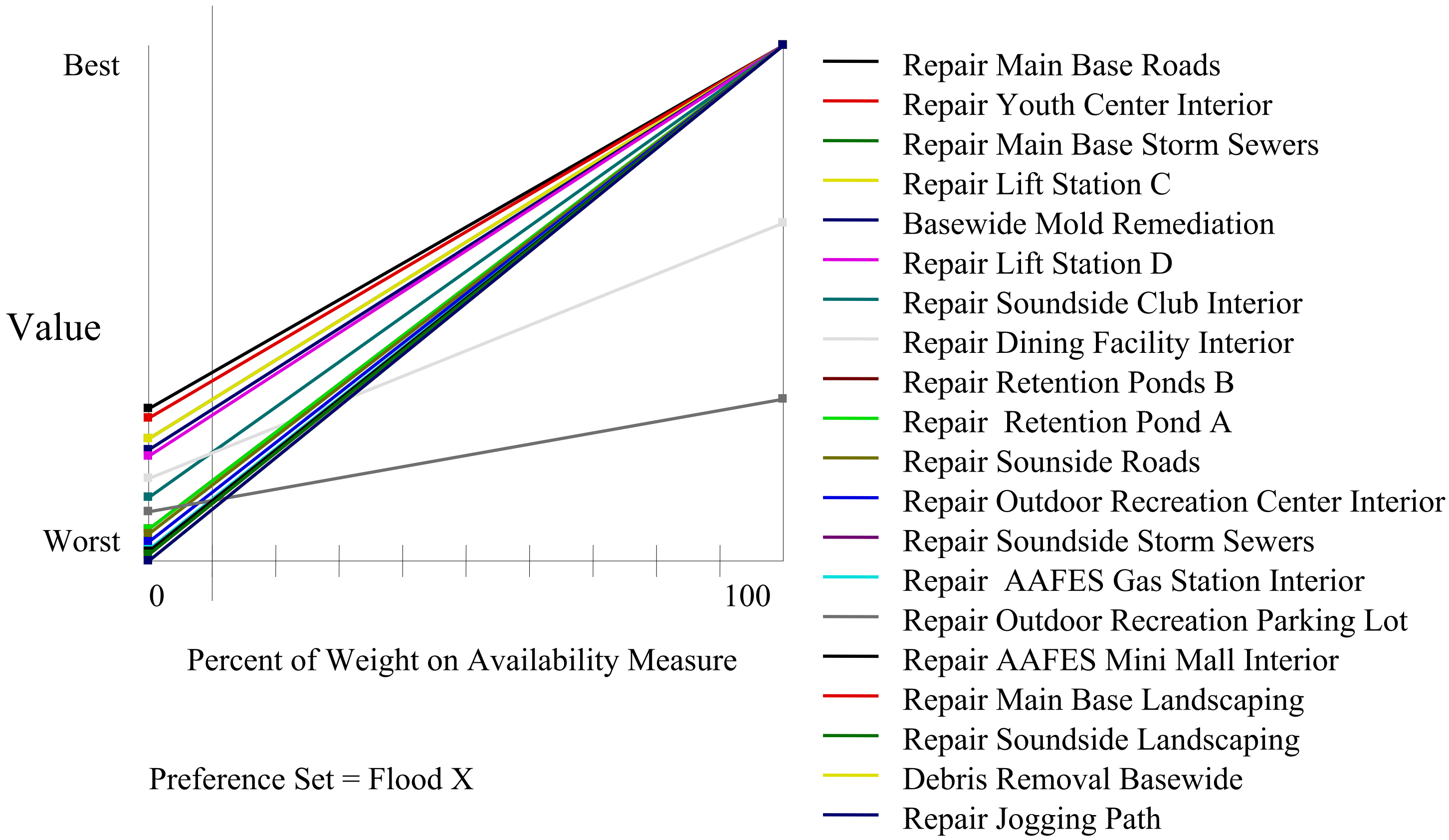

Best
Value
Worst
0
100
Percent of Weight on Sewage Status Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

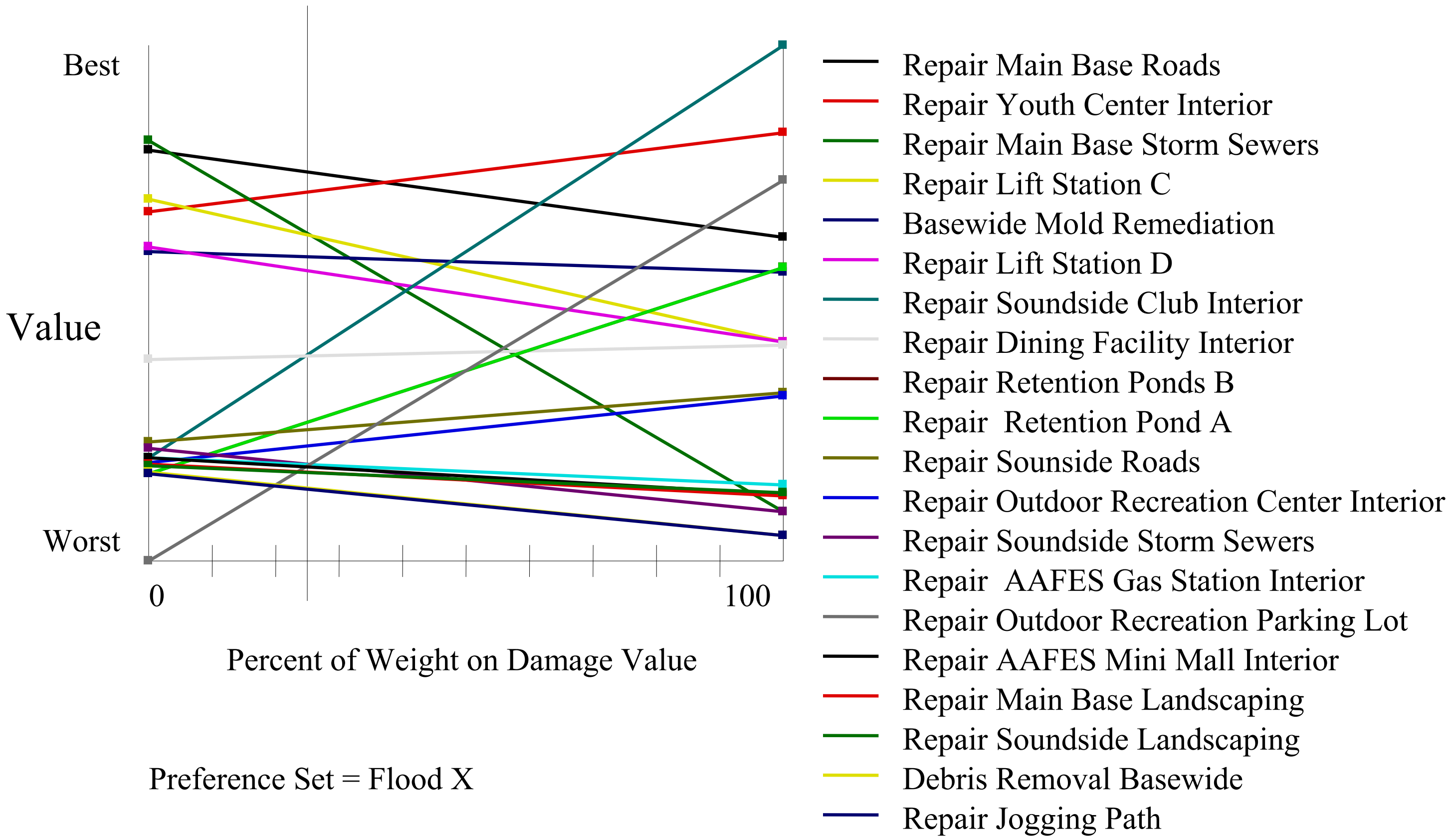

Best
Value
Worst
0
100
Percent of Weight on Time Value
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

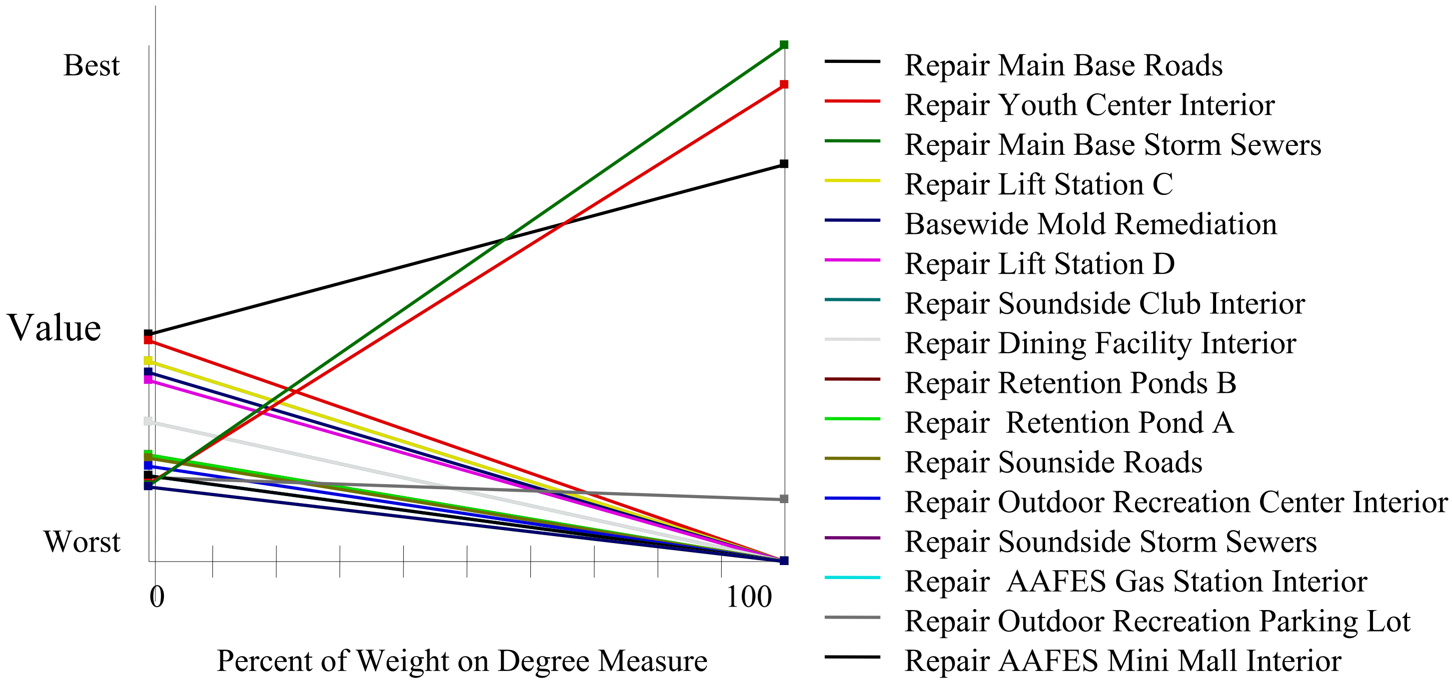

Best
Value
Worst
0
100
Percent of Weight on Transportation Status Measure
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior


Best
Value
Worst
0
100
Percent of Weight on Water Value
Preference Set = Tornado X
Repair Control Tower Roof
Repair Electrical Circuit A
Repair Control Tower Interior
Repair Roof Helicopter Hangar 006
Repair Doors Helicopter Hangar 006
Repair Fire Station #1
Repair Roof Clinic
Repair Hangar 001 Roof
Repair Roof Helicopter Maintenace Bldg
Repair Hangar 002 Doors
Repair Hangar 002 Interior
Repair Roof Youth Center
Repair Youth Center Interior
Repair Smith Ave Traffic Signal
Repair AAFES BX Roof
Repair Billeting Interior
Repair BX Interior
Repair Fire Training Tower
Repair Fitness Center Roof
Repair Fitness Center Interior

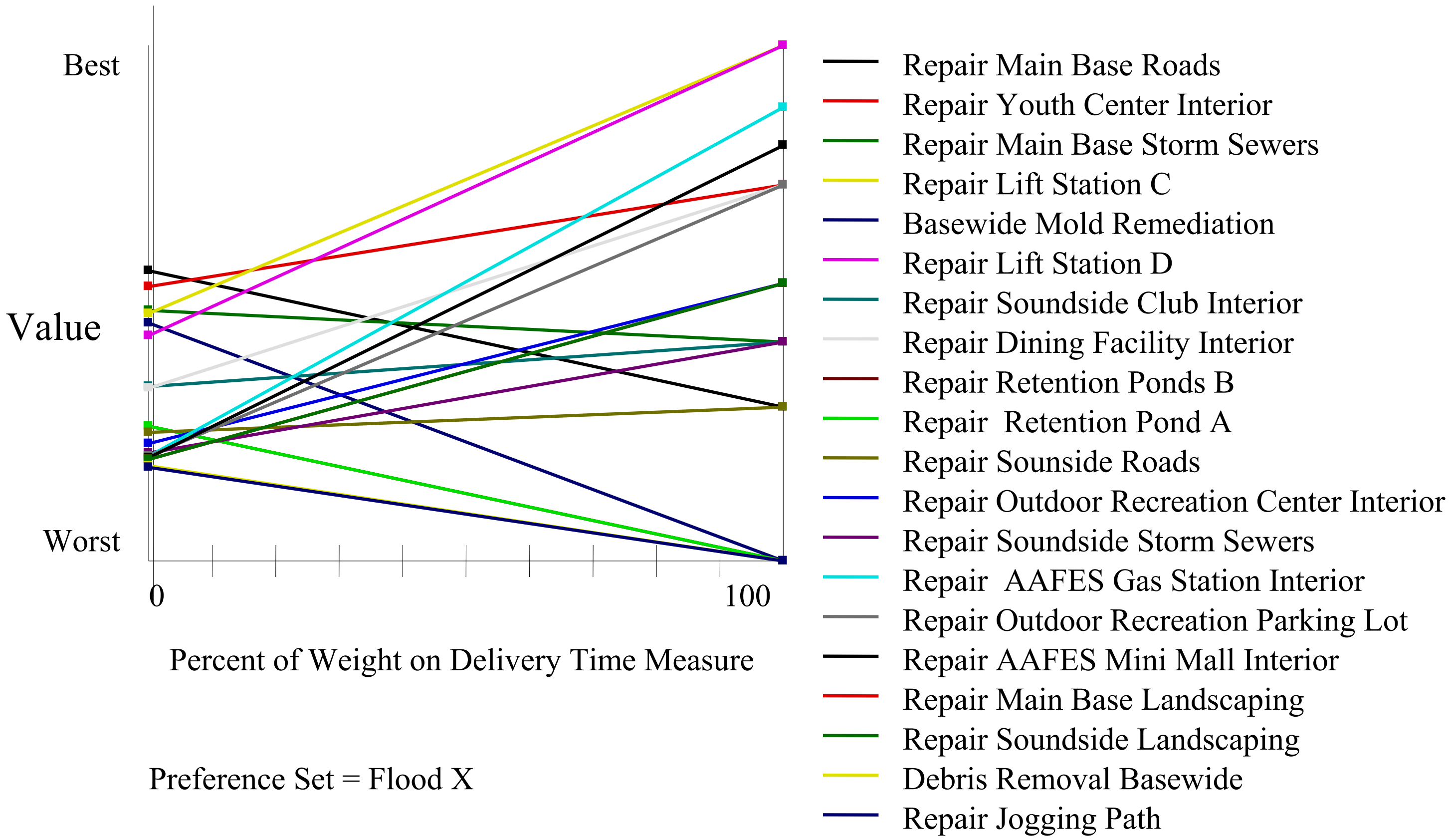
Appendix C: Sensitivity Analysis Graphs (Flood X)

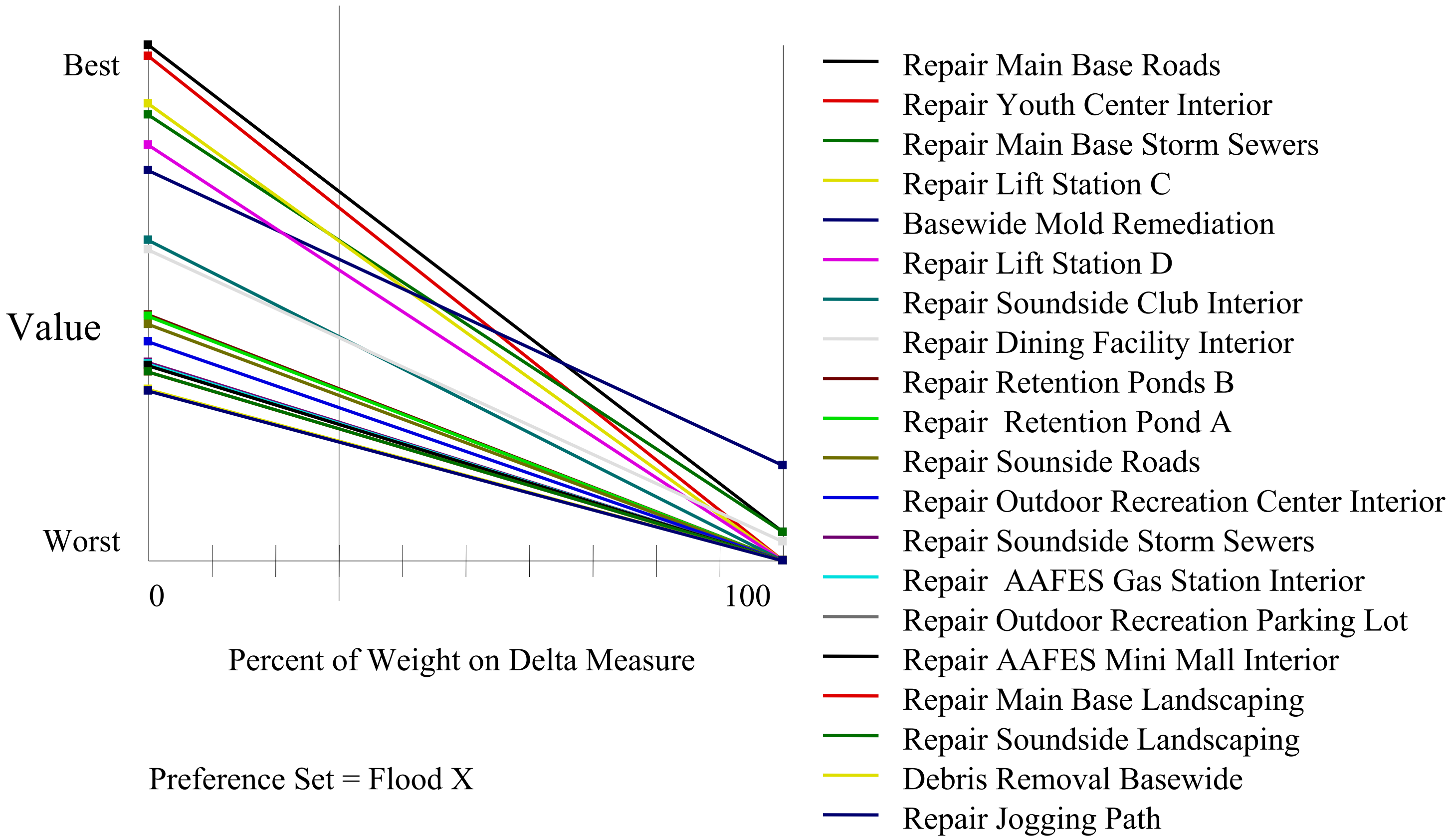

Best
Value
Worst
0
100
Percent of Weight on Availability Measure
Preference Set = Flood X
Repair Main Base Roads
Repair Youth Center Interior
Repair Main Base Storm Sewers
Repair Lift Station C
Basewide Mold Remediation
Repair Lift Station D
Repair Soundside Club Interior
Repair Dining Facility Interior
Repair Retention Ponds B
Repair Retention Pond A
Repair Sounside Roads
Repair Outdoor Recreation Center Interior
Repair Soundside Storm Sewers
Repair AAFES Gas Station Interior
Repair Outdoor Recreation Parking Lot
Repair AAFES Mini Mall Interior
Repair Main Base Landscaping
Repair Soundside Landscaping
Debris Removal Basewide
Repair Jogging Path

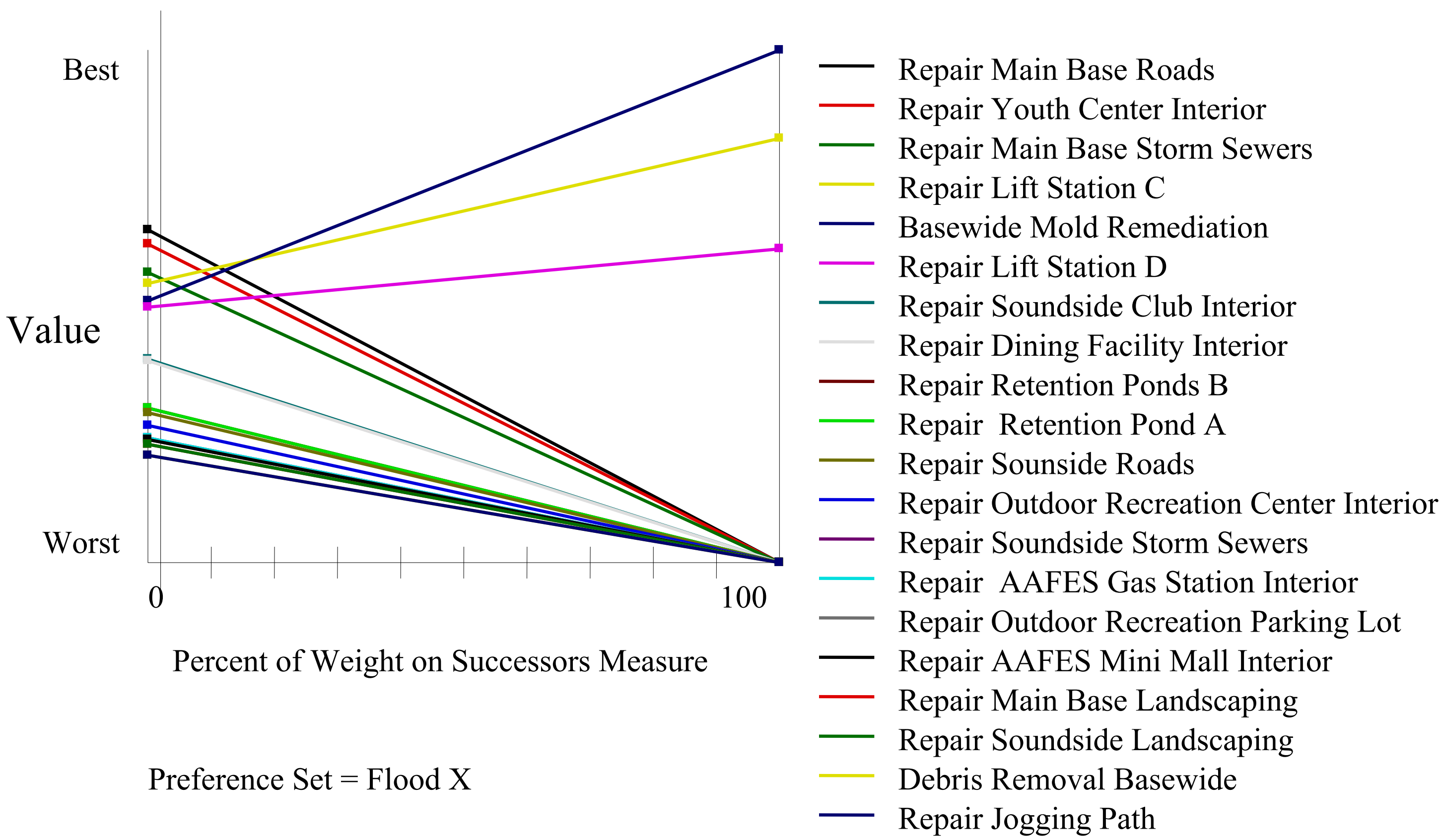

Best
Value
Worst
0
100
Percent of Weight on Damage Value
Preference Set = Flood X
Repair Main Base Roads
Repair Youth Center Interior
Repair Main Base Storm Sewers
Repair Lift Station C
Basewide Mold Remediation
Repair Lift Station D
Repair Soundside Club Interior
Repair Dining Facility Interior
Repair Retention Ponds B
Repair Retention Pond A
Repair Sounside Roads
Repair Outdoor Recreation Center Interior
Repair Soundside Storm Sewers
Repair AAFES Gas Station Interior
Repair Outdoor Recreation Parking Lot
Repair AAFES Mini Mall Interior
Repair Main Base Landscaping
Repair Soundside Landscaping
Debris Removal Basewide
Repair Jogging Path

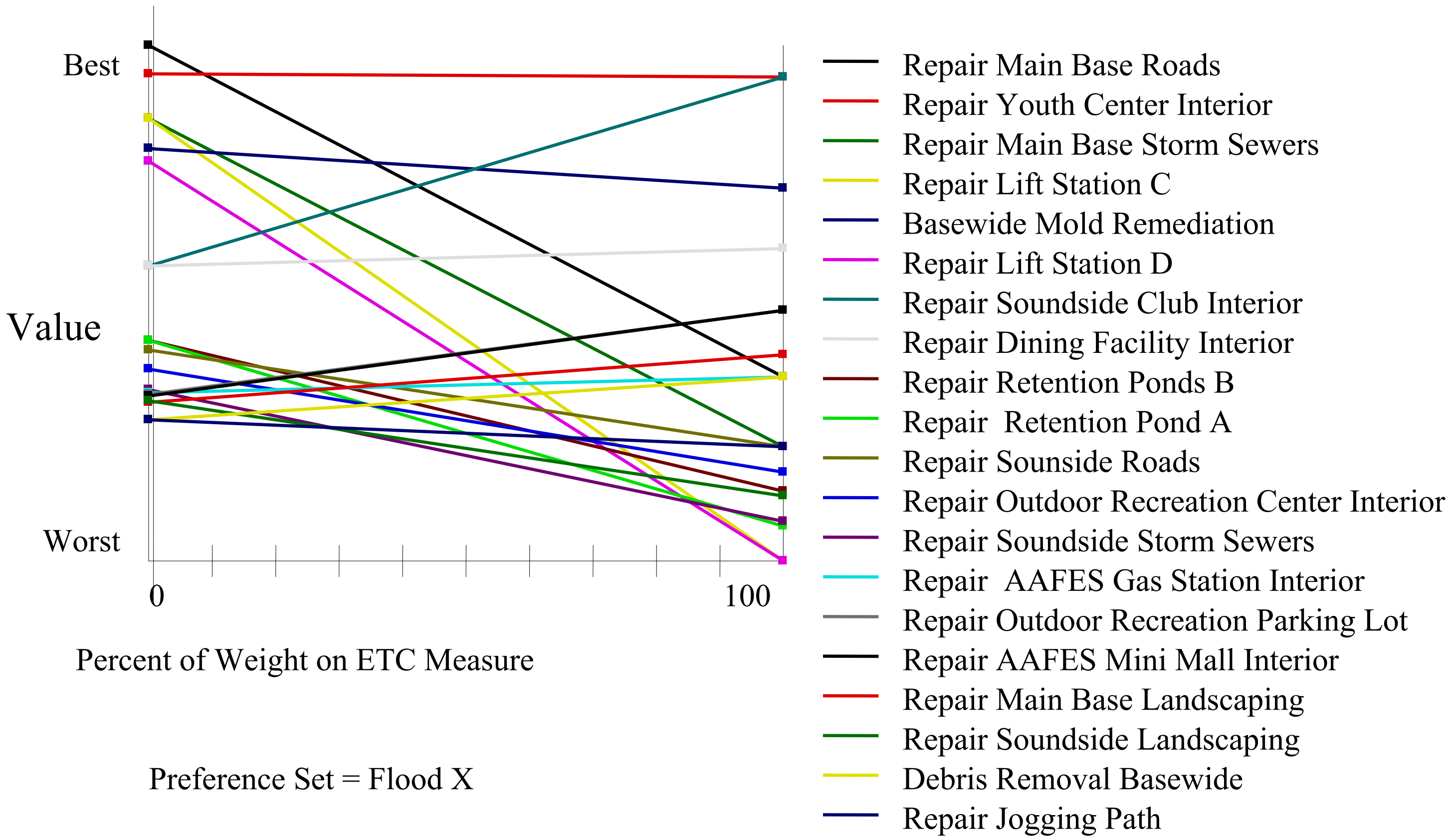


Preference Set = Flood X


Best
Value
Worst
0
100
Percent of Weight on Delivery Time Measure
Preference Set = Flood X
Repair Main Base Roads
Repair Youth Center Interior
Repair Main Base Storm Sewers
Repair Lift Station C
Basewide Mold Remediation
Repair Lift Station D
Repair Soundside Club Interior
Repair Dining Facility Interior
Repair Retention Ponds B
Repair Retention Pond A
Repair Sounside Roads
Repair Outdoor Recreation Center Interior
Repair Soundside Storm Sewers
Repair AAFES Gas Station Interior
Repair Outdoor Recreation Parking Lot
Repair AAFES Mini Mall Interior
Repair Main Base Landscaping
Repair Soundside Landscaping
Debris Removal Basewide
Repair Jogging Path


Best
Value
Worst
0
100
Percent of Weight on Delta Measure
Preference Set = Flood X
Repair Main Base Roads
Repair Youth Center Interior
Repair Main Base Storm Sewers
Repair Lift Station C
Basewide Mold Remediation
Repair Lift Station D
Repair Soundside Club Interior
Repair Dining Facility Interior
Repair Retention Ponds B
Repair Retention Pond A
Repair Sounside Roads
Repair Outdoor Recreation Center Interior
Repair Soundside Storm Sewers
Repair AAFES Gas Station Interior
Repair Outdoor Recreation Parking Lot
Repair AAFES Mini Mall Interior
Repair Main Base Landscaping
Repair Soundside Landscaping
Debris Removal Basewide
Repair Jogging Path


Best
Value
Worst
0
100
Percent of Weight on Successors Measure
Preference Set = Flood X
Repair Main Base Roads
Repair Youth Center Interior
Repair Main Base Storm Sewers
Repair Lift Station C
Basewide Mold Remediation
Repair Lift Station D
Repair Soundside Club Interior
Repair Dining Facility Interior
Repair Retention Ponds B
Repair Retention Pond A
Repair Sounside Roads
Repair Outdoor Recreation Center Interior
Repair Soundside Storm Sewers
Repair AAFES Gas Station Interior
Repair Outdoor Recreation Parking Lot
Repair AAFES Mini Mall Interior
Repair Main Base Landscaping
Repair Soundside Landscaping
Debris Removal Basewide
Repair Jogging Path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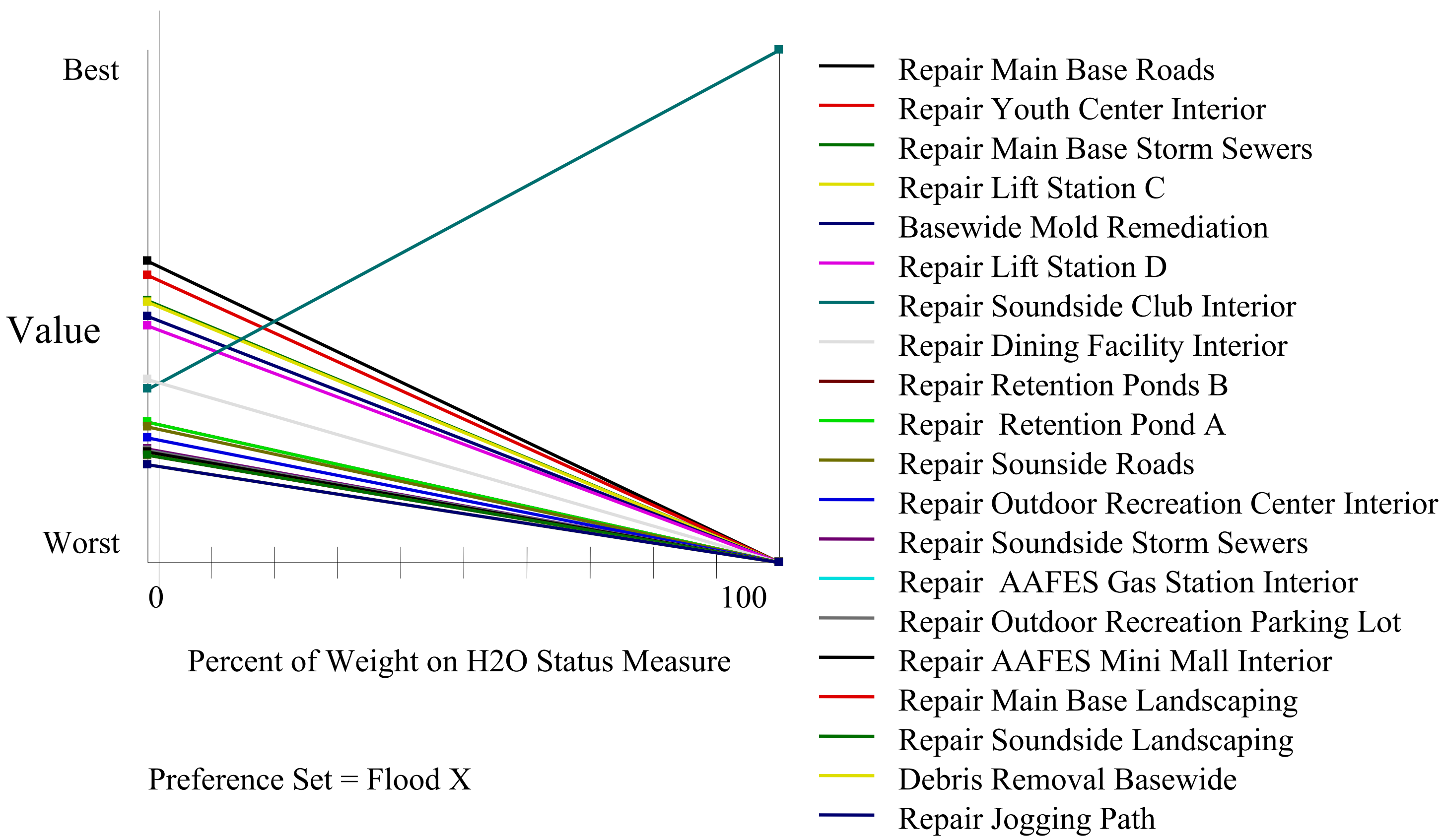
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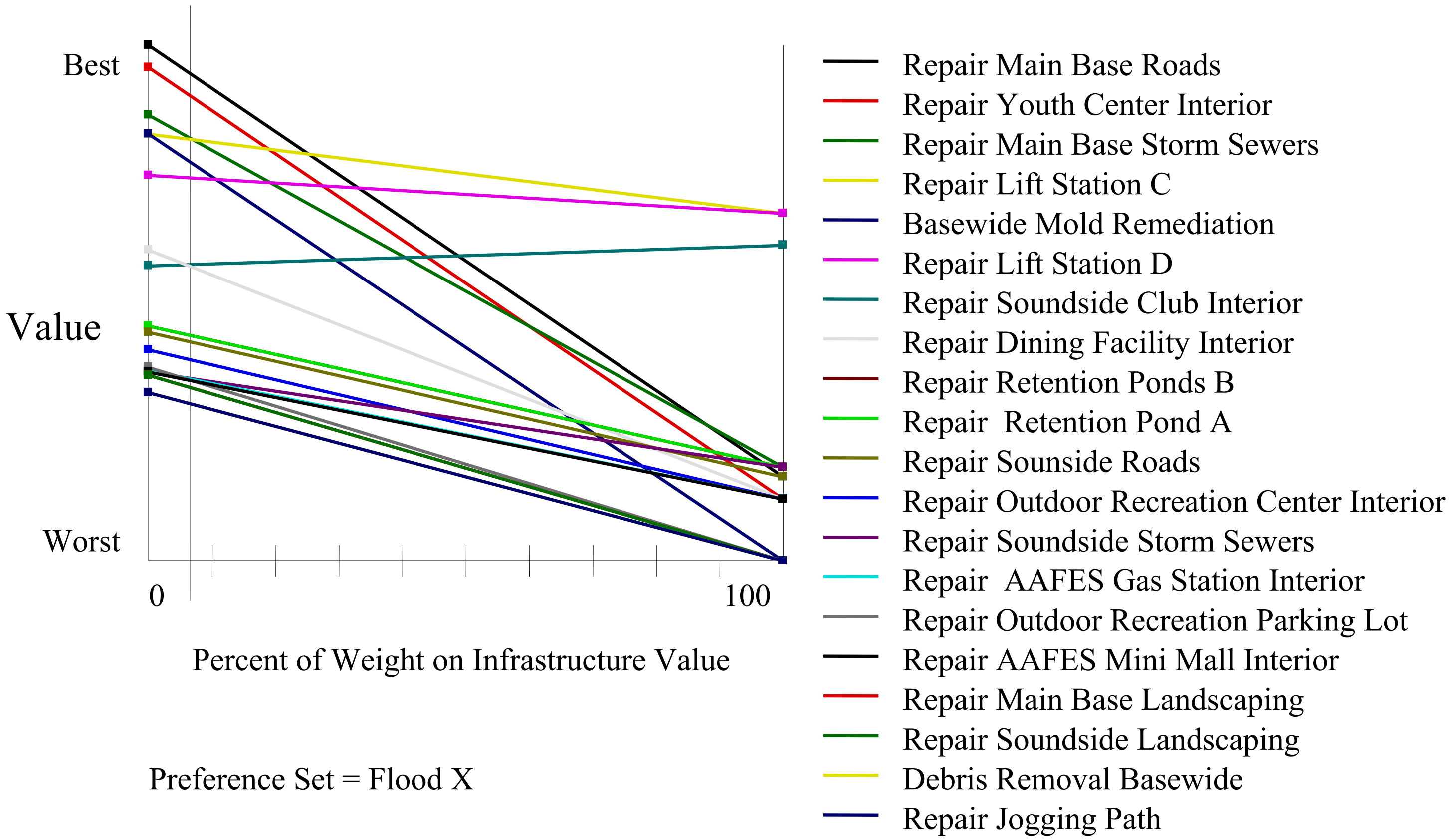
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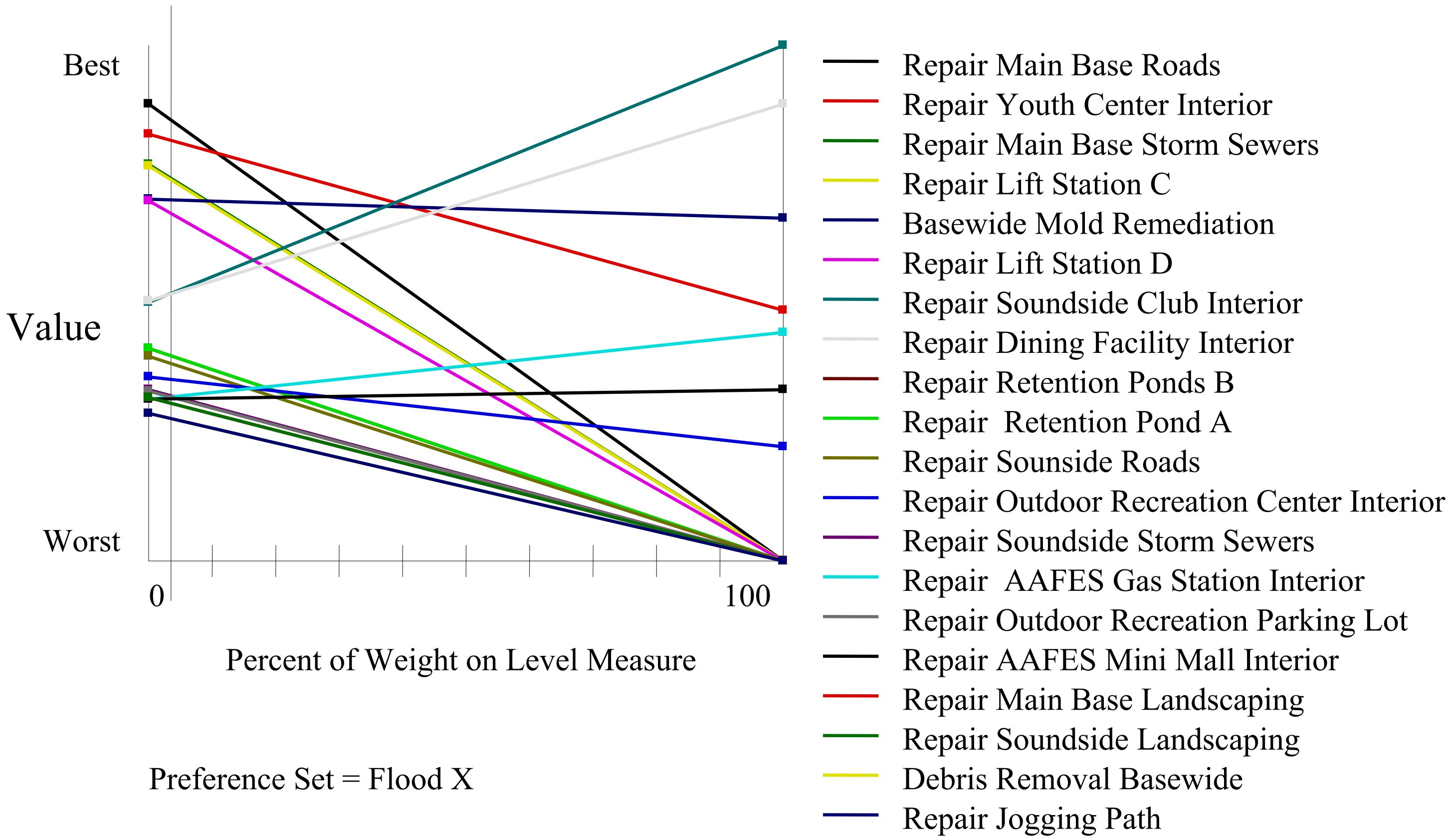
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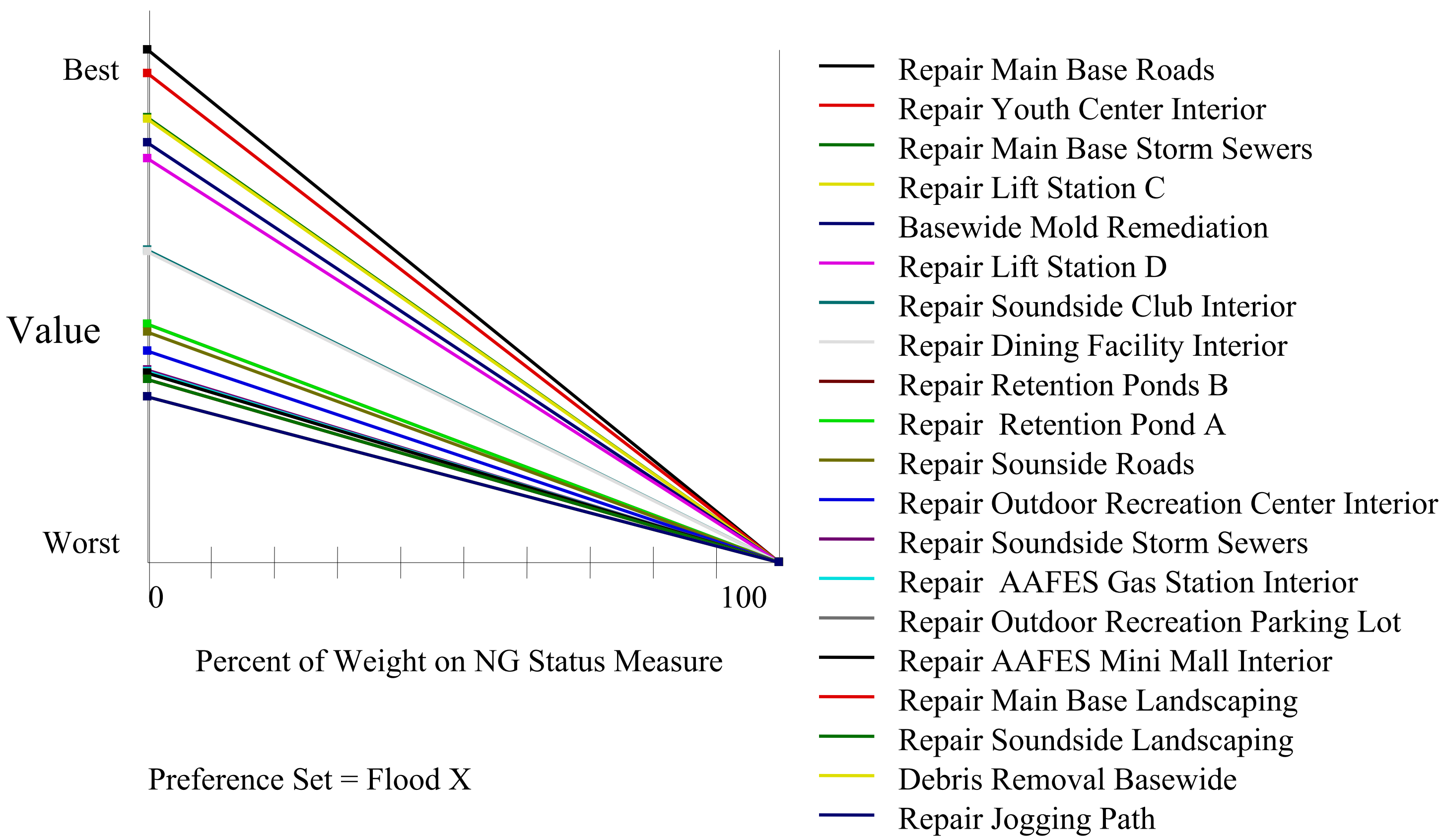
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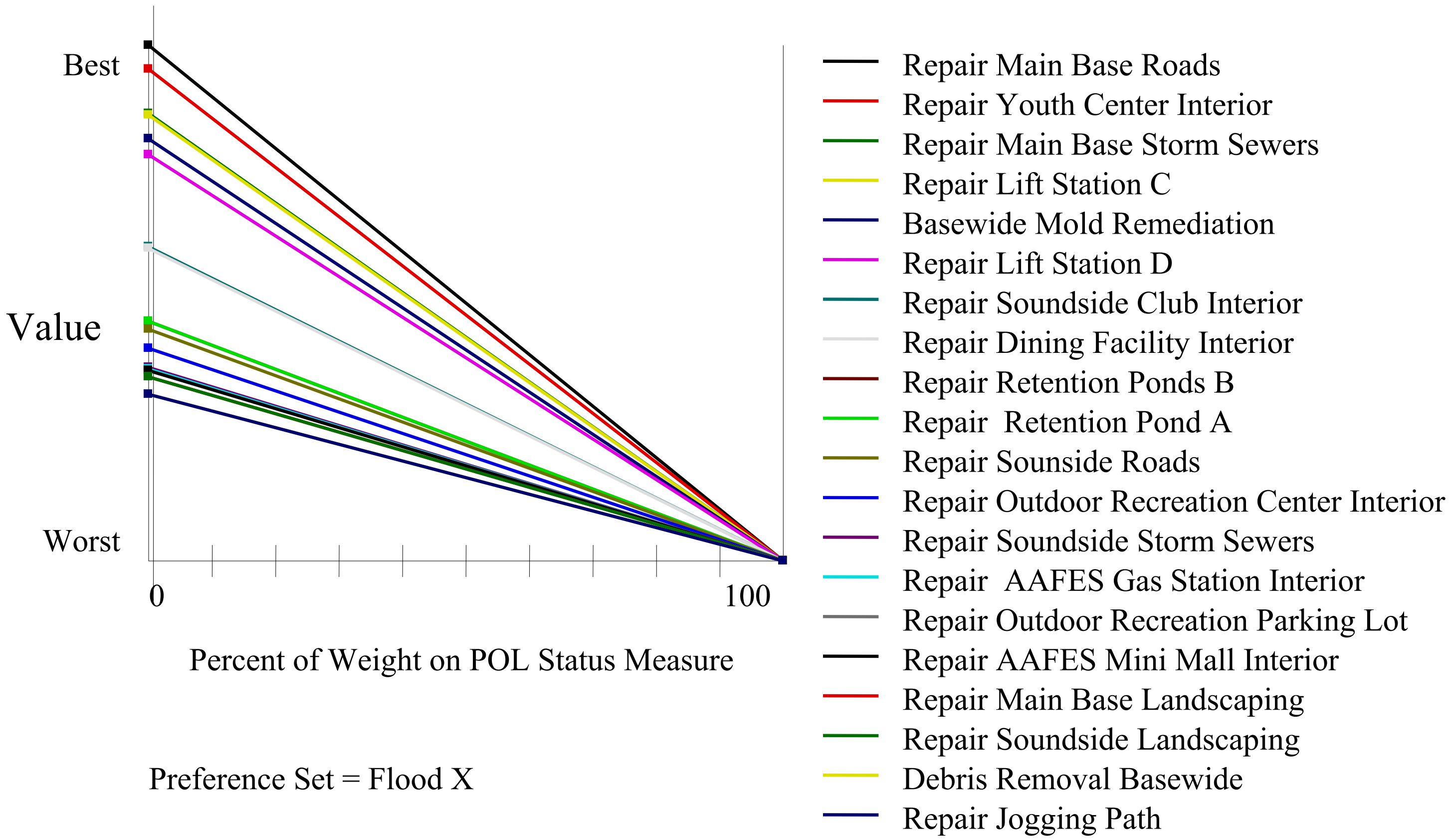
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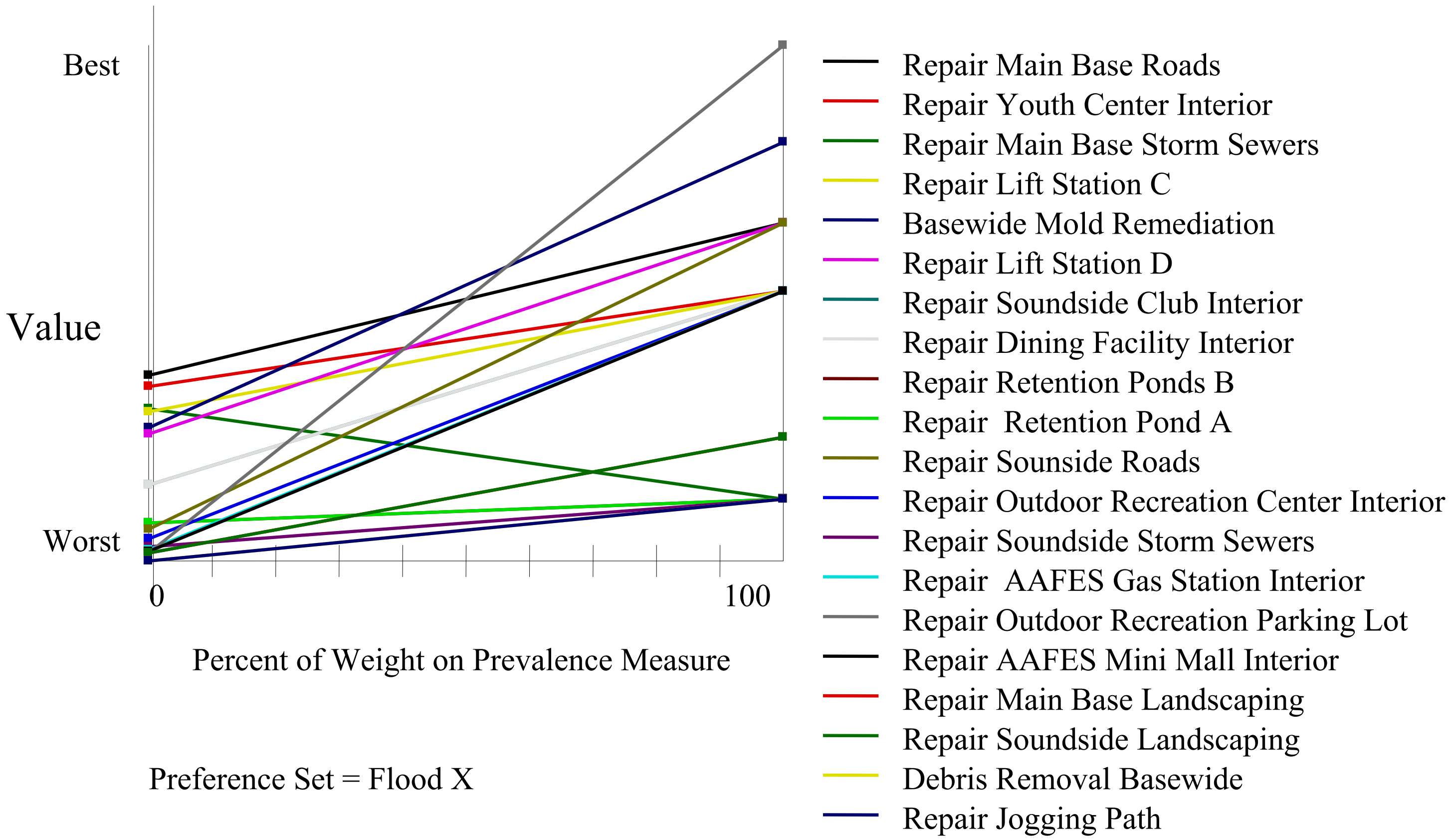
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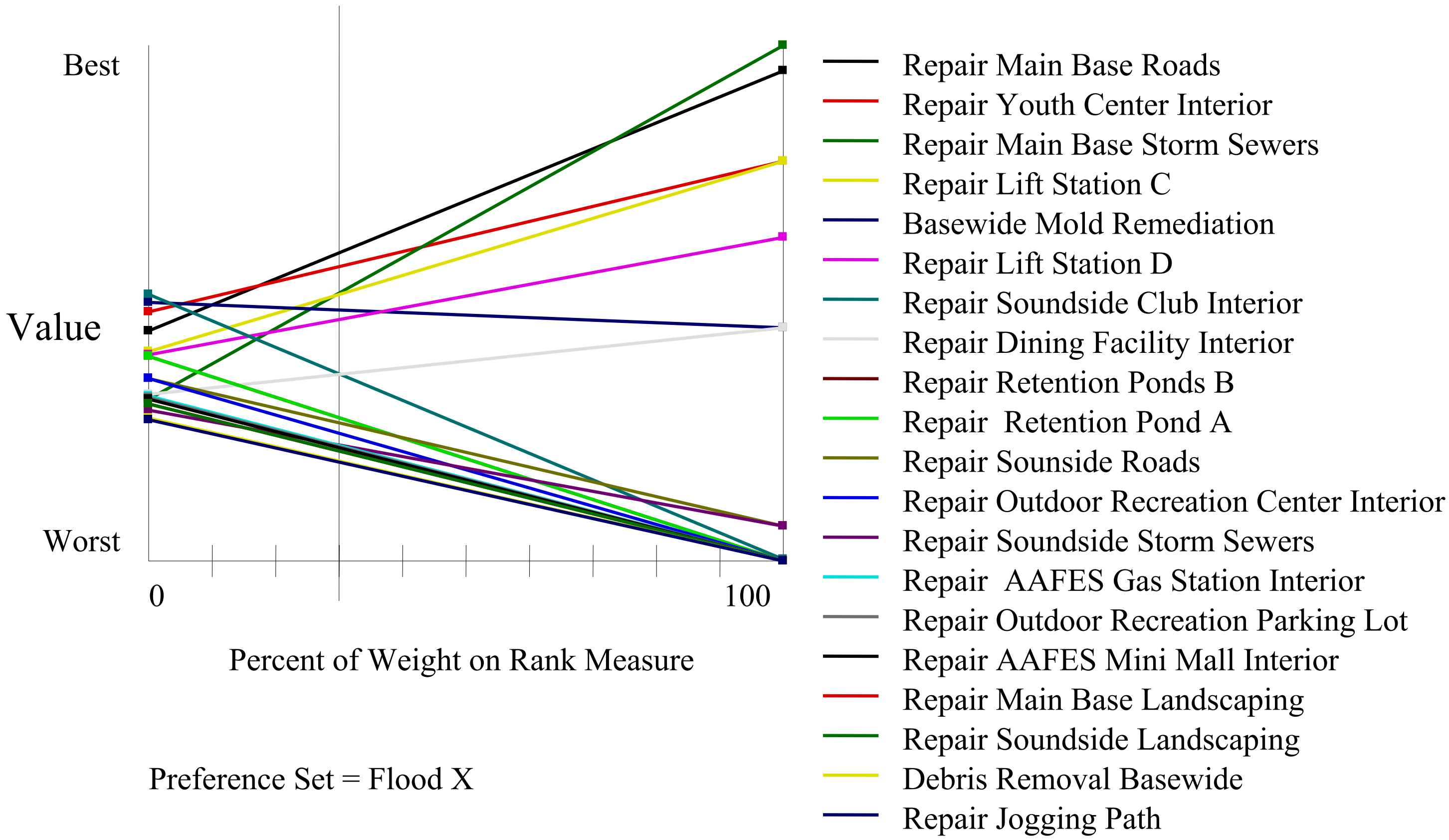

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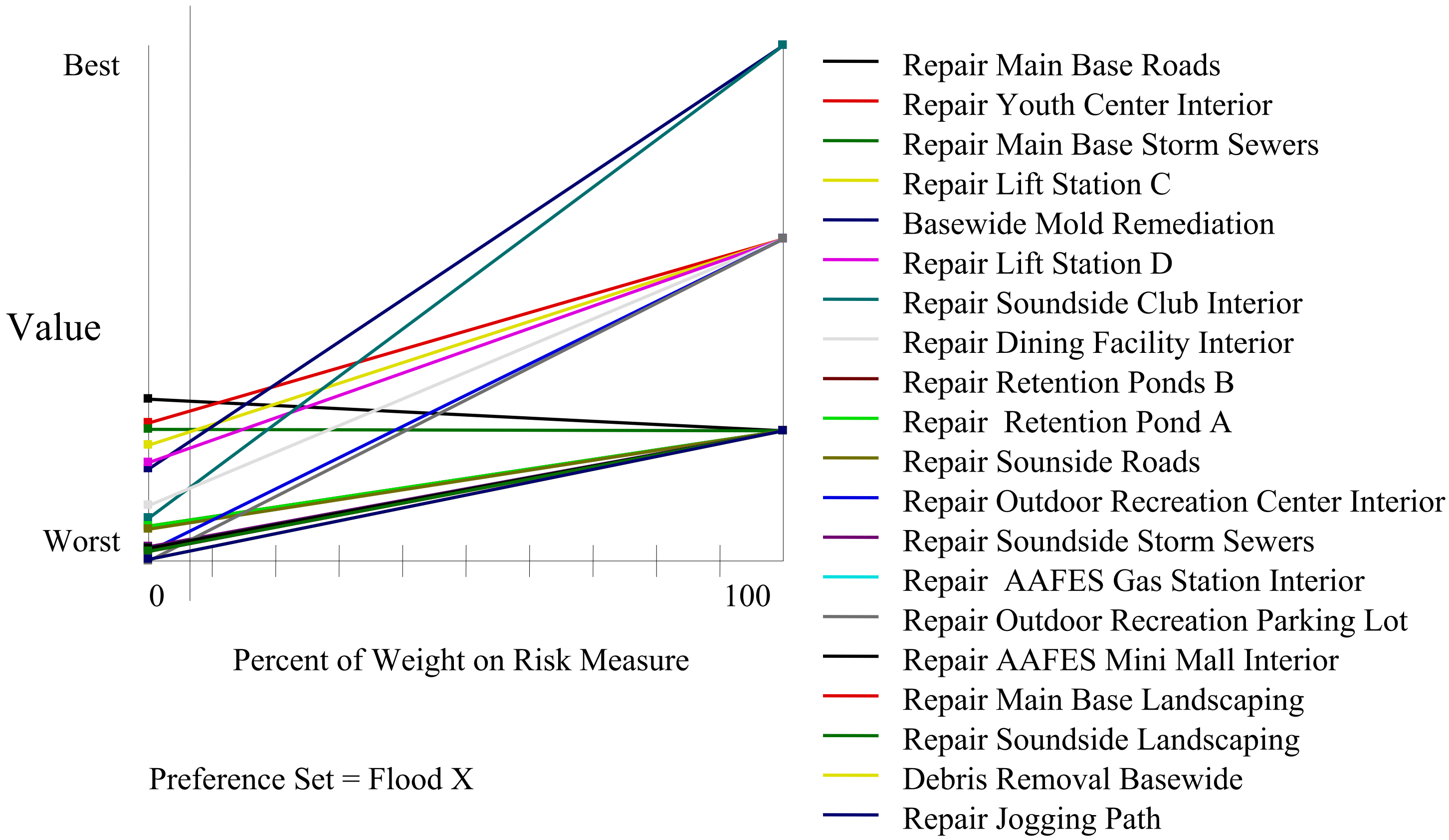
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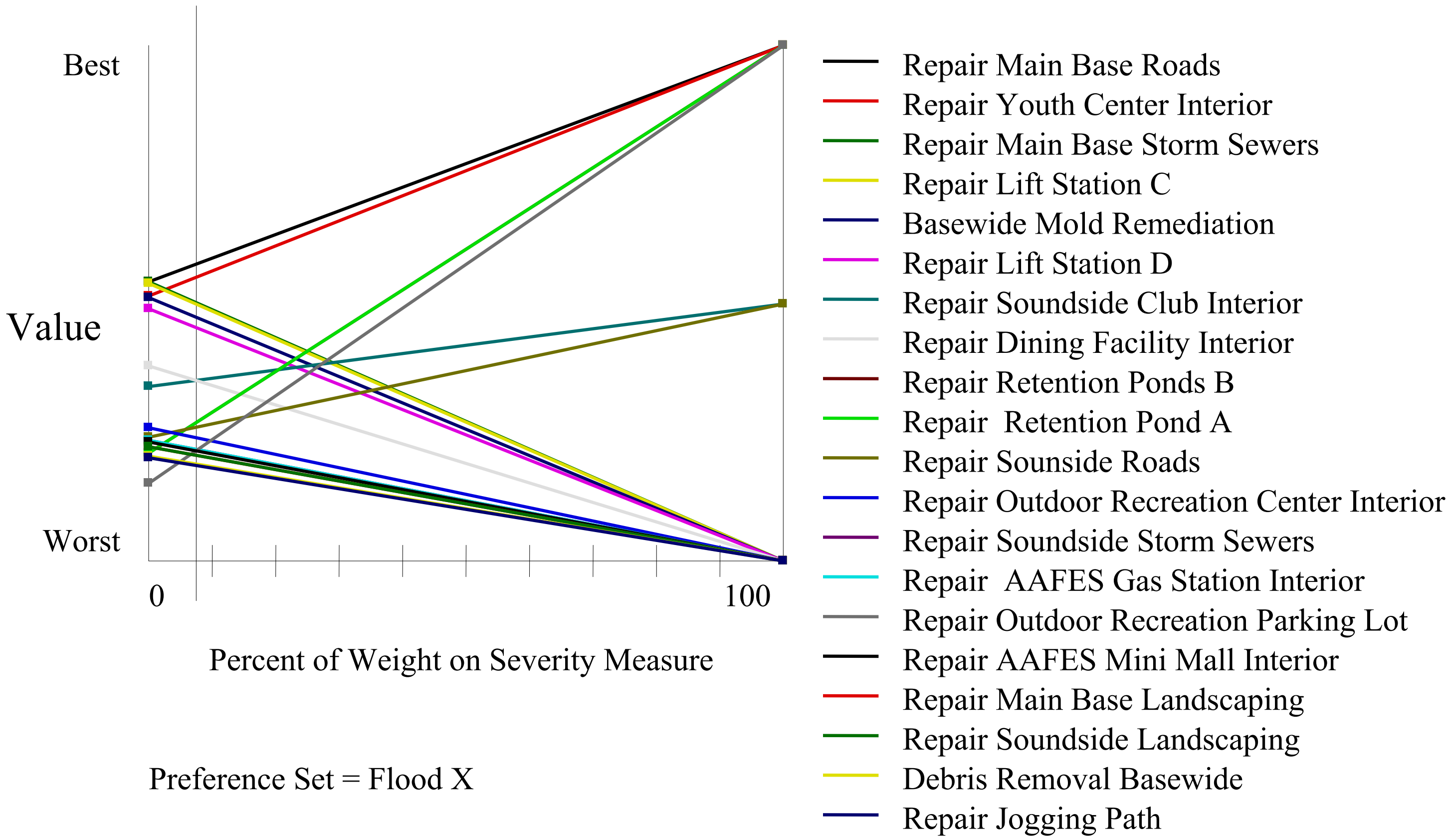
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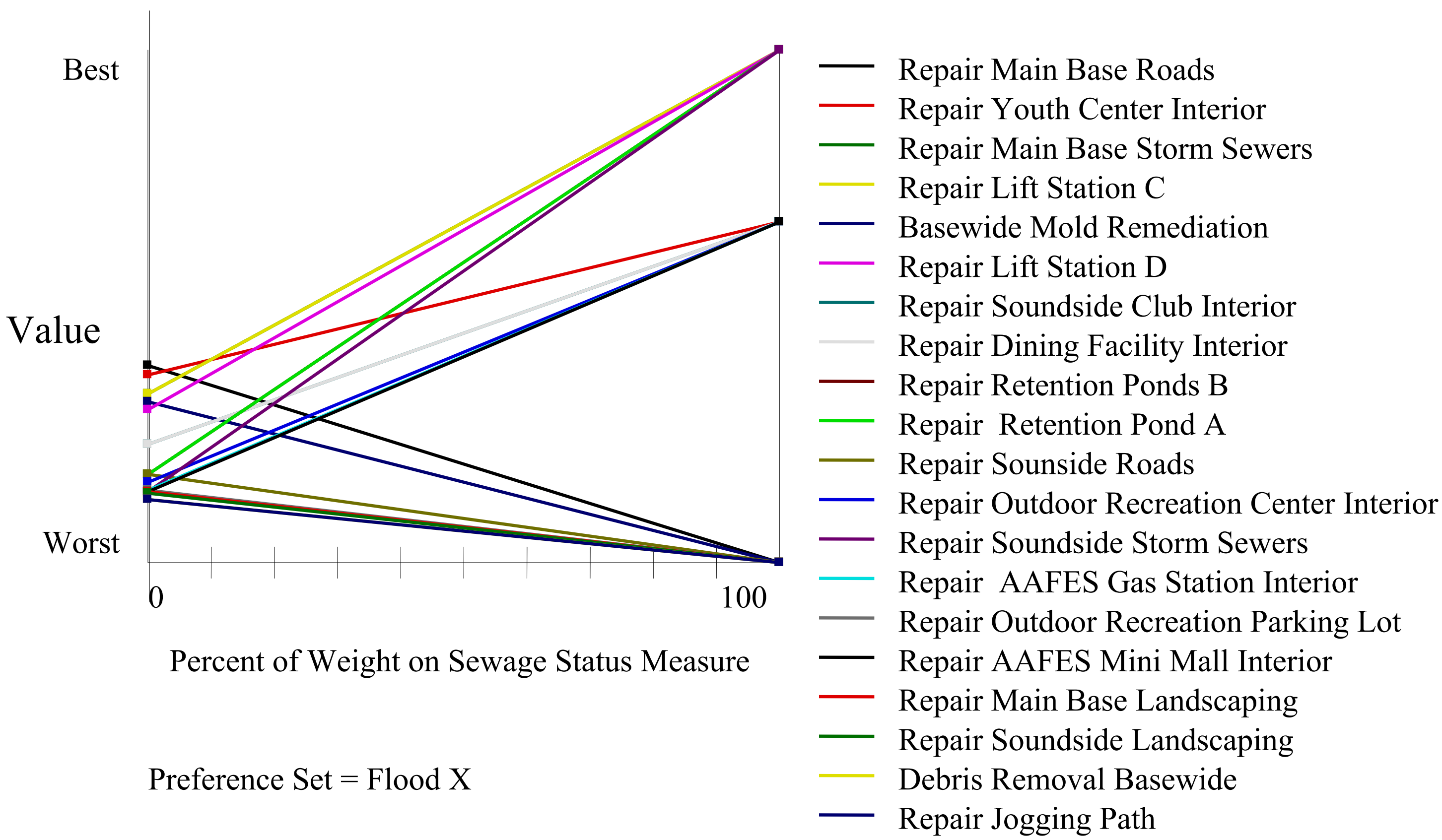
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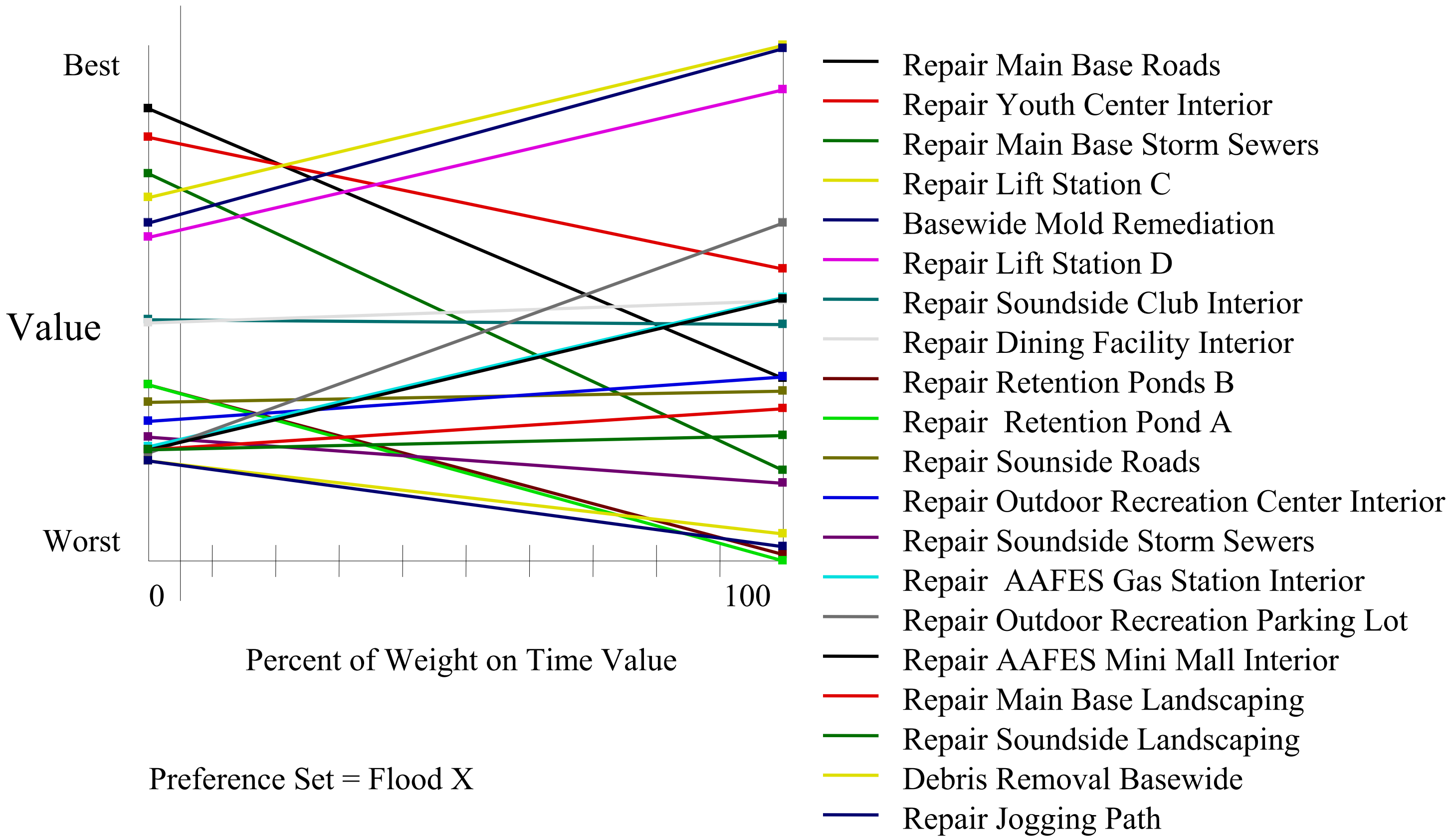
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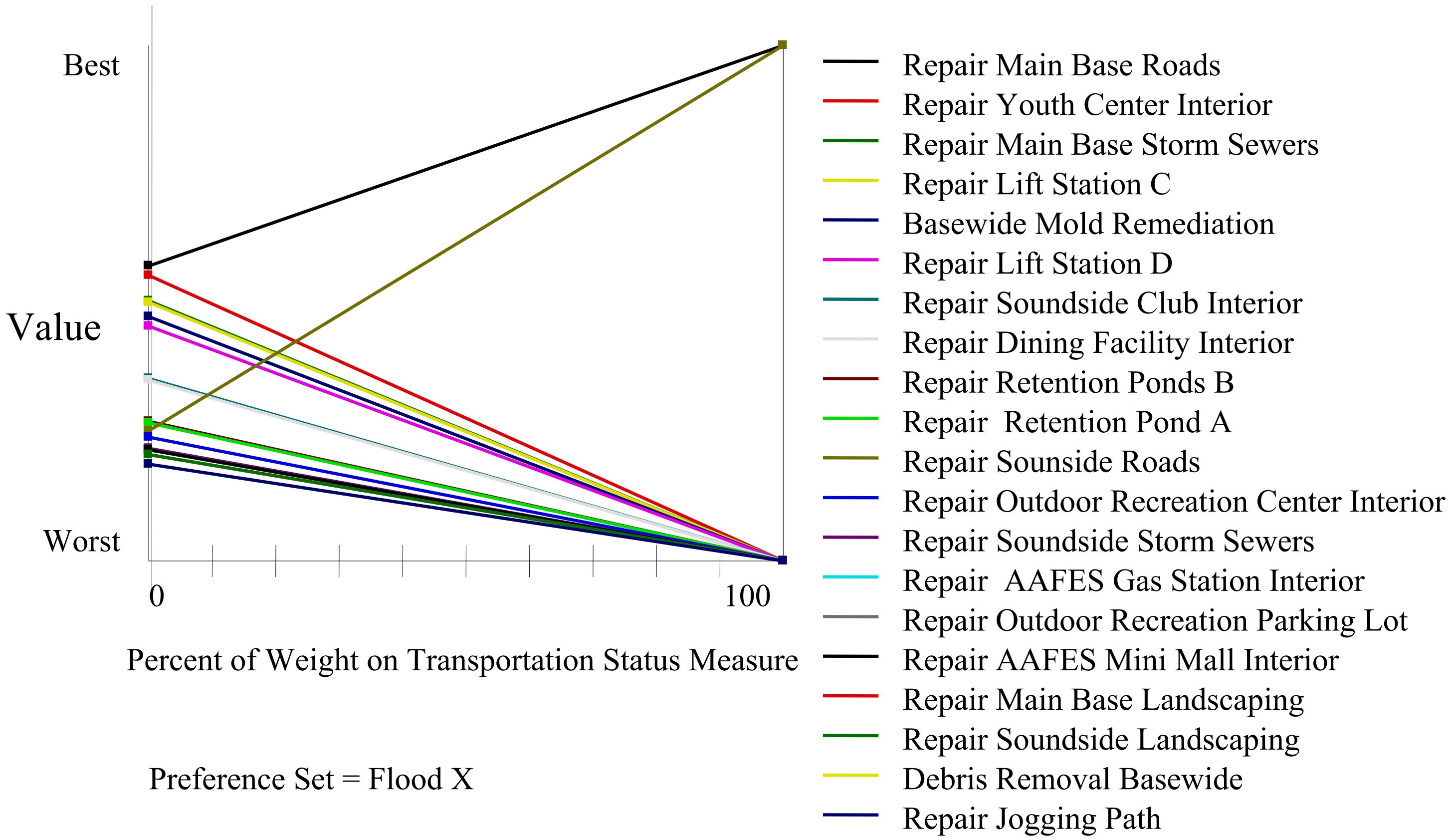
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Debris Removal Basewide
Repair Jogging Path

Appendix D: Correspondence (Value Solicitation Workshop)

Optimizing the Prioritization of Natural Disaster Recovery Projects Through Value Focused Thinking

1st Lt Jason M. Aftanas
Air Force Institute of Technology

Overview

- Thesis research topic
- Overview of methodology
- Brainstorm for Values
- Construct Hierarchy
- Consider Measures

Thesis Research

- Currently, no formalized, systematic, and repeatable process for optimizing the prioritization of natural disaster recovery projects exists
- Critical initial funding deadlines must be met within days after the disaster occurs with final funding requirements being demanded just weeks later
- Purpose: This thesis will examine the complex problem of identifying, quantifying, and prioritizing base recovery projects following natural disasters with the purpose of expediting the funding and obligation process.

Methodology

- Decision Analysis (DA) and Integer programming will provide an objective approach for analyzing the project prioritization process.
- This process will be developed in conjunction with senior leaders in the Installation and Mission Support Directorate of AFSOC and the 16 CES in order to utilize their experience and subject matter expertise.

Decision Analysis

- **Decision**: An irrevocable allocation of "limited" resources
- **Decision Analysis**: The discipline for systematically making complex decisions considering
  - alternatives (necessary?, implemented?)
  - uncertain variables
  - preferences (value, risk, & time)
- **Purpose**: Give insight to decision-makers

Decision Analysis Tenets

- Quality decision-making requires a systematic process to incorporate
  - Information, expert opinion, and preferences
- Complex decisions in large organizations involve
  - Functional experts (inside)
    - R&D, engineers, operations, contracting, finance, etc.
  - Interested stakeholders (outside)
    - stockholders, government, community, etc.

Decision Analysis Tenets (cont'd)

- Quantification offers significant benefits
  - Clarifies thinking
    - Values
    - Uncertainties (Probability)
    - Preferences
  - Improves communications
  - Enables logical reasoning
- Support decision-maker judgments
  - Provide insights

Scope of Decision Analysis

Methodology	Descriptive ____X______	Prescriptive
Decision Difficulty	Easy ____ X______	Hard
Problem Structure	Known/Simple ____X______	Unknown/Complex
Problem Variables	Deterministic ____X_______	Uncertain
Objectives	Single ______X________________________________X_______	Multiple
Risk	Low _______________________X_____________X________	High

Decision Analysis Summary

- Systematic process with well developed set of analysis techniques and computer software
- Incorporates information from functional experts and interested stakeholders
- Appropriate technique for quantifying values and uncertainties
- Provides analysis support to decision-makers

What is Value Focused Thinking?

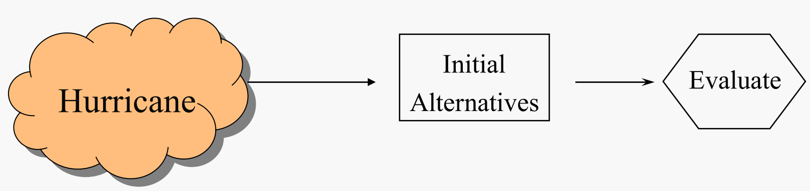
- VFT is a "Top-Down" DA approach
- VFT provides a "conceptual framework" for developing and selecting alternatives
- The basis of VFT is that it is more important to know the values of the decision makers, rather than the available alternatives, in order to accurately access what is important when one is faced with a decision opportunity [Keeney, 1992:3]

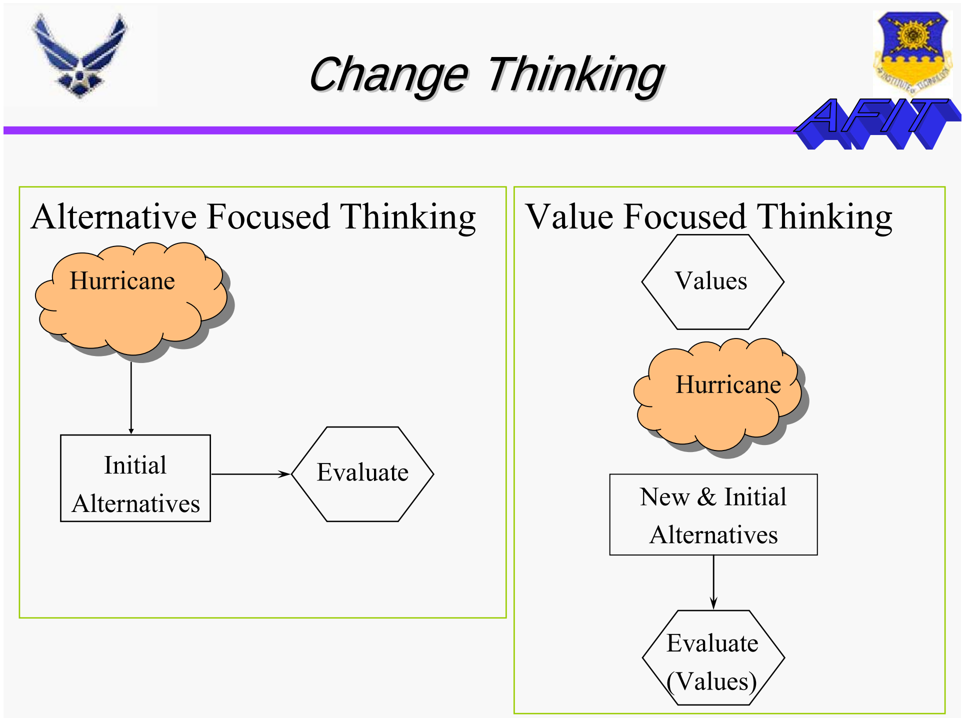
Value Focused (Cont'd)

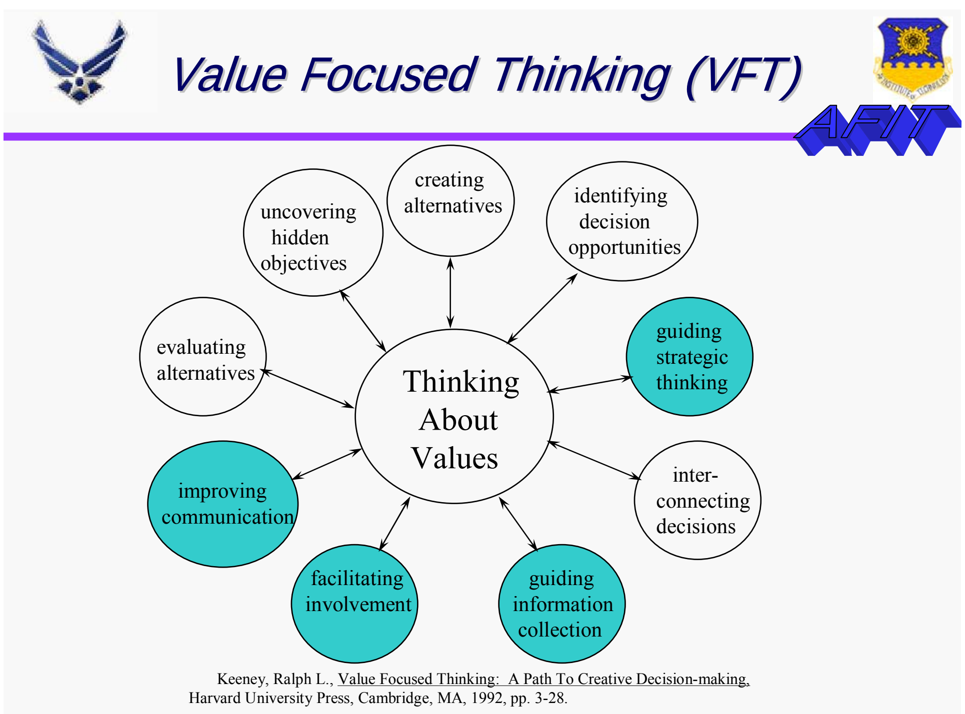
- A value structure "encompasses the entire set of evaluations considerations, objectives, and evaluation measures" for any decision opportunity [Kirkwood, 1997:12]
- Keeney describes values as "what we fundamentally care about;" "the driving force of our decision making;" and "principles used for evaluation" when faced with a decision [Keeney, 1994(b):793;1992:6]
- In short, rather than making a decision based solely on alternatives, VFT utilizes the knowledge of a decision-maker's values to start at the ideal solution and work towards making it a reality [Keeney, 1992:6]

"Old" Way

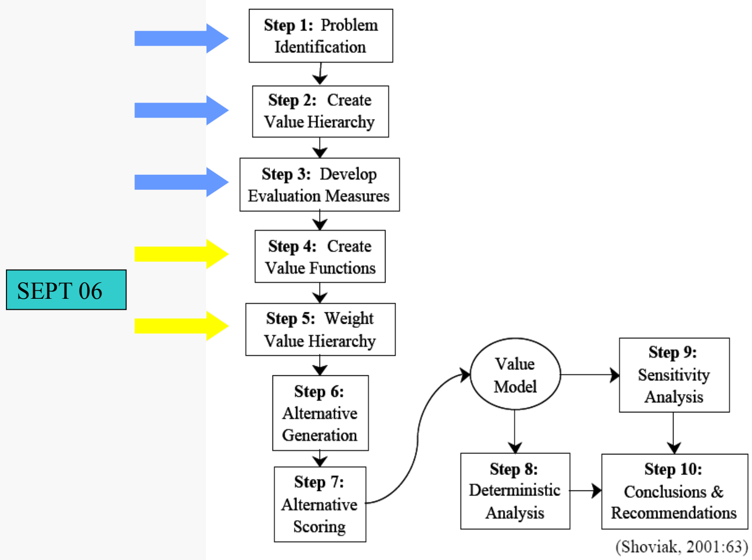
Alternative Focused Thinking




Change Thinking
AFIT
Alternative Focused Thinking
Hurricane
Initial Alternatives
Evaluate
Value Focused Thinking
Values
Hurricane
New & Initial Alternatives
Evaluate (Values)


Value Focused Thinking (VFT)
AFIT
Thinking About Values
creating alternatives
identifying decision opportunities
guiding strategic thinking
inter-connecting decisions
guiding information collection
facilitating involvement
improving communication
evaluating alternatives
uncovering hidden objectives
Keeney, Ralph L., Value Focused Thinking: A Path To Creative Decision-making, Harvard University Press, Cambridge, MA, 1992, pp. 3-28.

VFT Process



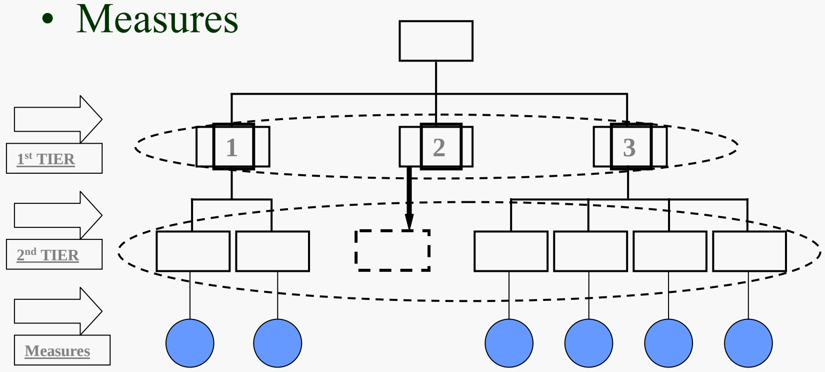
(Shoviak, 2001:63)

VFT Terms

Fundamental Objective	"…an essential reason for interest in the decision situation" (Keeney, 1992:34). Also known as the "ends objective," it is the top block in the value hierarchy.
Value	What is important to the decision maker (Clemen, 1996:19). The values are the decomposition of the fundamental objective. They are the building blocks of the value hierarchy.
Value Hierarchy	A pictorial representation of a value structure (consisting of the fundamental objective, the values, and the measures) (Kirkwood, 1997:12).
Local Weight	The amount of weight a set of lower-tier values or measures contributes to the value directly above it in the hierarchy (Shoviak, 2001:57).
Global Weight	The amount of weight each lower-tier value or measure contributes to the weight of the hierarchy's fundamental objective (Shoviak, 2001:57).
Measure	Analogous to the term "metric," it notes the "degree of attainment" of a value (Kirkwood, 1997:12).
Score	A "specific numerical rating for a particular alternative with respect to a specified measure" (Kirkwood, 1997:12).
Single dimensional value function (SDVF)	A specific, monotonically increasing or decreasing function for each measure used to convert an alternative's "score" on the x-axis to a "value" on the y-axis.
Alternative	"…the means to achieve the… values" (Keeney, 1992:3).

Value Hierarchy Structure

- Hierarchy
- Tiers
- Measures



Evaluation Measure Types

	Natural	Constructed
Direct	Net Present Value Time to Remediate Cost to Remediate System Reliability Bandwidth per sec Revisit time	Olympic Diving Scoring Weather Prediction Categories Project Funding Categories R&D Project Categories
Proxy	Gross National Product (Economic growth) Site Cleanup (Time to Remediate) Number of Subsystems (System Reliability)	Performance Evaluation Categories (Promotion Potential) Instructor Evaluation Scales (Instructor Quality) Student Grades (Student Learning)

Value Hierarchy Example

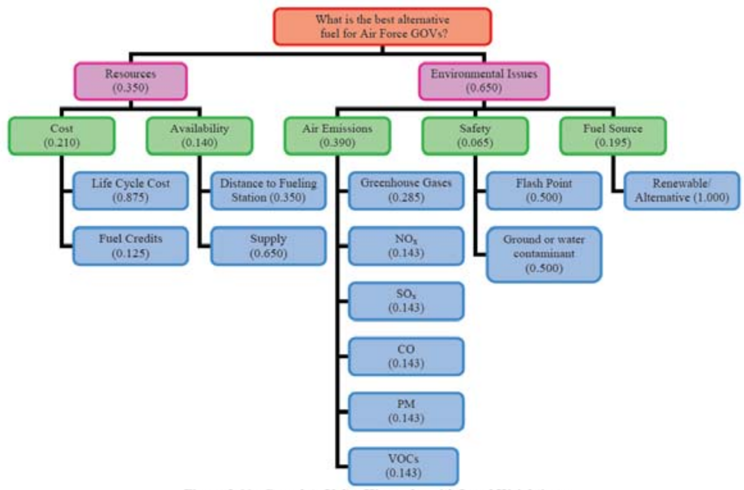
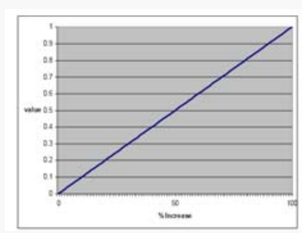
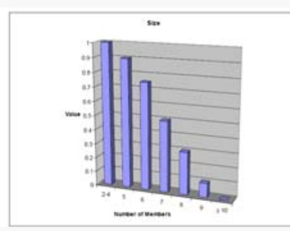


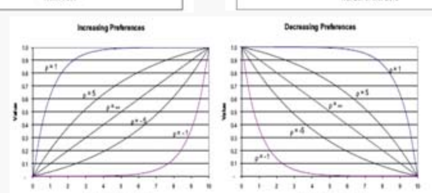
Figure 3-11. Complete Value Hierarchy with Local Weightings

Single Dimension Value Function

Can be linear, piecewise linear, discrete, or exponential







Benefits

- Increases Objectivity
- Provides Continuity
- Implements Strategic Plan
- Repeatable
- Improve Communication
- Validates Leaders Values

Future Uses

- Integration in to ACES and GEOBASE for real-time updates of the prioritization process
- Could be utilized in post-hurricane-exercise
- Integration in to Facility Working Group

Question and Initial Feedback

???

Fundamental Objective

To accurately and objectively prioritize base recovery projects

BRAINSTORMING EXERCISE

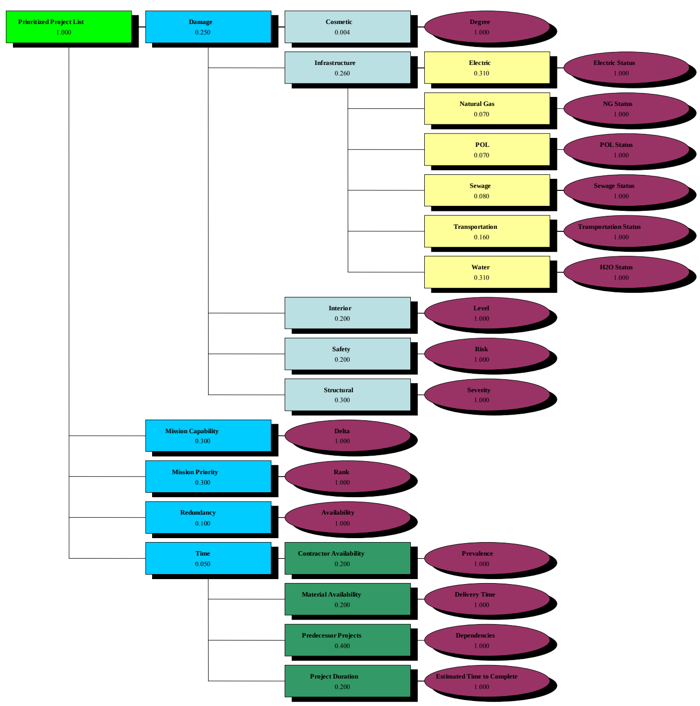
What evaluation considerations (Values) are essential to prioritizing a recovery project?

Appendix D: Correspondence (Weighting Solicitation)

Weighting Solicitation

Overview

- At this stage of my research we have constructed a value hierarchy for prioritizing natural disaster reconstruction projects
- Now I need to solicit weights for the values from you, the decision maker
- I have already initially weighted all of the values (goals) for each tier
- You can agree or disagree with theses values and I will adjust the model accordingly
- A brief description of each tier and their corresponding values are included in this brief for your convenience



Hierarchy Tiers

- Top tier = The weighting is automatically 1.0
- Second tier = The weighting of all goals in this tier must sum to 1.0
- Third tier = and All goals in each **<u>set</u>** of third tier goals must sum to 1.0
- Fourth tier = The weighting of all goals in this tier must sum to 1.0

Top Tier

- Prioritized Project List
  – Weighting is automatically one because the sum of the second tier value must sum to one
  – The purpose of the hierarchy is to determine the ranked prioritized project list for a natural disaster recovery program

Second Tier

- Damage
  - How much damage a particular project addresses should have a great bearing on the outcome of the prioritized project list
  - I have initially set the weight for this second tier value at 0.250
  - Therefore, damage currently represents 25% of the total value when evaluating a score for a particular recovery project

Second Tier

- Mission Capability
  - To what extent (Delta) a particular project restores the base's mission capability should have a great bearing on the outcome of the prioritized project list.
  - I have initially set the weight for this second tier value at 0.300
  - Therefore, mission capability currently represents 30% of the total value when evaluating a score for a particular recovery project.

Second Tier

- Mission Priority
  - Where or if a particular project falls on the facility mission priority list should have a great bearing on the outcome of the prioritized project list
  - I have initially set the weight for this second tier value at 0.300
  - Therefore, mission priority currently represents 30% of the total value when evaluating a score for a particular recovery project

Second Tier

- Redundancy
  - The availability of facilities for temporarily relocating a function that is currently located in a damaged building should have a fairly significant impact on the outcome of the prioritized project list
  - I have initially set the weight for this second tier value at 0.10
  - Therefore, redundancy currently represents 10% of the total value when evaluating a score for a particular recovery project

Second Tier

- Time
  - The estimated time to complete a project, the estimated delivery time for materials, the availability of qualified contractors, and whether or not a particular project is a predecessor to one or more projects should have a bearing on the outcome of the prioritized project list
  - I have initially set the weight for this second tier value at 0.05
  - Therefore, time represents 5% of the total value when evaluating a score for a particular recovery project

Third Tier

- Cosmetic
  - The cosmetic damage a particular project addresses should have some bearing on the overall second tier damage score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.040
  - Therefore, cosmetic damage currently represents 4.0% of the total damage value when evaluating a score for a particular recovery project

Third Tier

- Infrastructure
  - The infrastructure damage a particular project addresses should have a great bearing on the overall second tier damage score for a particular recovery project.
  - I have initially set the weight for this third tier value at 0.260
  - Therefore, infrastructure damage currently represents 26% of the total damage value when evaluating a score for a particular recovery project.

Third Tier

- Interior
  - The interior damage a particular project addresses should have a great bearing on the overall second tier damage score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.200
  - Therefore, interior damage currently represents 20% of the total damage value when evaluating a score for a particular recovery project

Third Tier

- Safety
  - The level of risk to human life a particular project addresses should have a great bearing on the overall second tier damage score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.200
  - Therefore, safety currently represents 20% of the total damage value when evaluating a score for a particular recovery project

Third Tier

- Structural
  - The severity of structural damage a particular project addresses should have a great bearing on the overall second tier damage score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.300
  - Therefore, structural damage currently represents 30% of the total damage value when evaluating a score for a particular recovery project

Third Tier

- Contractor Availability
  - The availability of contractors to perform work on a particular project should have a significant bearing on the overall second tier time score for a particular recovery project.
  - I have initially set the weight for this third tier value at 0.20
  - Therefore, contractor availability currently represents 20% of the total time value when evaluating a score for a particular recovery project.

Third Tier

- Material Availability
  - The availability of material needed to perform work on a particular project should have a significant bearing on the overall second tier time score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.20
  - Therefore, material availability currently represents 20% of the total time value when evaluating a score for a particular recovery project

Third Tier

- Predecessors
  - The number of future recovery projects that rely on a particular project should have great bearing on the overall second tier time score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.40
  - Therefore, predecessors currently represents 40% of the total time value when evaluating a score for a particular recovery project

Third Tier

- Project Duration
  - The estimated duration of particular project should have a significant bearing on the overall second tier time score for a particular recovery project
  - I have initially set the weight for this third tier value at 0.20
  - Therefore, project duration currently represents 20% of the total time value when evaluating a score for a particular recovery project

Fourth Tier

- Electric
  - The amount of electrical infrastructure damage a particular project addresses should have great bearing on the overall third tier infrastructure score for a particular recovery project
  - I have initially set the weight for this fourth tier value at 0.310
  - Therefore, electric currently represents 31% of the total infrastructure value when evaluating a score for a particular recovery project

Fourth Tier

- Natural Gas
  - The amount of natural gas infrastructure damage a particular project addresses should have some bearing on the overall third tier infrastructure score for a particular recovery project
  - I have initially set the weight for this fourth tier value at 0.070
  - Therefore, natural gas currently represents 7% of the total infrastructure value when evaluating a score for a particular recovery project

Fourth Tier

- POL
  - The amount of POL infrastructure damage a particular project addresses should have a significant bearing on the overall third tier infrastructure score for a particular recovery project
  - I have initially set the weight for this fourth tier value at 0.070
  - Therefore, POL currently represents 7% of the total infrastructure value when evaluating a score for a particular recovery project

Fourth Tier

- Sewage
  - The amount of sewage infrastructure damage a particular project addresses should have a significant bearing on the overall third tier infrastructure score for a particular recovery project
  - I have initially set the weight for this fourth tier value at 0.08
  - Therefore, sewage currently represents 8% of the total infrastructure value when evaluating a score for a particular recovery project

Fourth Tier

- Transportation
  - The amount of transportation infrastructure damage a particular project addresses should have a significant bearing on the overall third tier infrastructure score for a particular recovery project
  - I have initially set the weight for this fourth tier value at 0.160
  - Therefore, transportation currently represents 16% of the total infrastructure value when evaluating a score for a particular recovery project

Fourth Tier

- Water
  - The amount of water infrastructure damage a particular project addresses should have a significant bearing on the overall third tier infrastructure score for a particular recovery project
  - I have initially set the weight for this fourth tier value at 0.310
  - Therefore, water currently represents 31% of the total infrastructure value when evaluating a score for a particular recovery project

Summary

- Please forward any changes to the initial weights as you see fit
- The next phase of the research will be to create the measures for the values
- I have already accomplished this initially and will forward a similar briefing to this one in the next two weeks
- Once the measures and their single dimension value functions have been settled upon I will forward you three sets of recovery projects for you to rack and stack independently of the model
  - Each set will represent a different natural disaster event
  - The event location will be Hurlburt Field for reference
  - I will provide a mock Facility Mission Priority List (FMPL) and all other relevant information
- Finally, I will load each event into the model and we will examine its output vs. your prioritized list and then conduct sensitivity analysis to validate or refine the model

Appendix D: Correspondence (Creating Single Dimension Value Functions II)

Creating Single Dimension Value Functions II

(Measures)

Overview

- The following slides represent the single dimension value functions (SDVFs) for each of the infrastructure damage measures
- Each of these SDVFs are Piecewise Linear and continuous.
- Review the Piecewise function and the associated values for level of damage
- Suggest any changes to the values for each Piecewise Linear Function

Overview Cont'd

- These SDVFs, as they are currently composed, allow for data to be expeditiously gathered and are easily understood by anyone assessing them.
- Data for these measures in quantified in % degraded
- This allows almost any airman to collect data on these measures after minimal training. (For instance Saber personnel)
- Simplicity aids in communicating information up the chain of command

Piecewise Linear Zones

- **Severe** – damage rating given to a project that addresses interior or cosmetic damage that results in the degradation of 50-100% of the facility's original condition. The value in this zone will range from 2/3 – 1.0
- **Moderate** - damage rating given to a project that addresses interior or cosmetic damage that results in the degradation of 25-50% of the facility's original condition. The value for this zone will range from 1/3 to 2/3.
- **Minimal** – damage rating given to a project that addresses interior or cosmetic damage that results in the degradation of 5-25% of the facility's original condition. The value for this range will range from 1/20 to 1/3
- **Nominal** – Little or no significant damage (0-5%) to component value = 0 to 1/20

Electrical Status

- This SDVF says that if a project will repair a systemic electrical problem it has the greatest value for prioritization = 1
- A project with localized damage is 2/3rd as important
- A project that has been temporarily repaired is 1/3rd as important
- A project that does not address any electrical damage = operational = 0 value for prioritization

Label	Value
Systemic	1.000
Localized	0.667
Temporarily Repaired	0.333
Operational	0.000

Natural Gas Status

- This SDVF says that if a project will repair a systemic natural gas problem it has the greatest value for prioritization = 1
- A project with localized damage is 2/3rd as important
- A project that has been temporarily repaired is 1/3rd as important
- A project that does not address any NG damage = operational = 0 value for prioritization

Label	Value
Systemic	1.000
Localized	0.667
Temporarily Repaired	0.333
Operational	0.000

POL Status

- This SDVF says that if a project will repair a systemic POL problem it has the greatest value for prioritization = 1
- A project with localized damage is $2/3^{rd}$ as important
- A project that has been temporarily repaired is $1/3^{rd}$ as important
- A project that does not address any POL damage = operational = 0 value for prioritization

Label	Value
Systemic	1.000
Localized	0.667
Temporarily Repaired	0.333
Operational	0.000

Sewage Status

- This SDVF says that if a project will repair a systemic sewage problem it has the greatest value for prioritization = 1
- A project with localized damage is $2/3^{rd}$ as important
- A project that has been temporarily repaired and is operational is $1/3^{rd}$ as important
- A project that does not address any sewage damage = operational = 0 value for prioritization

Label	Value
Systemic	1.000
Localized	0.667
Temporarily Repaired	0.333
Operational	0.000

Transportation Status

- This SDVF says that if a project will repair a systemic transportation problem it has the greatest value for prioritization = 1
- A project with localized damage is 2/3rd as important
- A project that has been temporarily repaired and is operational is 1/3rd as important
- A project that does not address any transportation damage = operational = 0 value for prioritization

Label	Value
Systemic	1.000
Localized	0.667
Temporarily Repaired	0.333
Operational	0.000

H_2O Status

- This SDVF says that if a project will repair a systemic water problem it has the greatest value for prioritization = 1
- A project with localized damage is 2/3rd as important
- A project that has been temporarily repaired and is operational is 1/3rd as important
- A project that does not address any water damage = operational = 0 value for prioritization

Label	Value
Systemic	1.000
Localized	0.667
Temporarily Repaired	0.333
Operational	0.000

How it works

- Let's say a particular project repairs a *systemic* electrical problem and a *localized* water problem. This project would receive the following score for infrastructure damage.
    - ❑ **Infrastructure Damage Score** = [(Electrical Status Weight * Value of Systemic Electrical Damage) + (Water Status Weight * Value of Localized Water Damage)] *Infrastructure Weight
    - ❑ = [(0.30 * 1.00) + (0.30 * 0.667)]*0.26 = 0.130
    - ❑ The 0.30, 0.30, and 0.26 in the above equation are the weights in the value hierarchy that we determined last time for Electric, Water and Infrastructure damage respectively

Summary

- Please advise me of any changes as you see fit
- The next batch of SDVFs will be sent out Friday
- Thank you for your time and continued support

Appendix D: Correspondence (Creating Single Dimension Value Functions III)

Creating Single Dimension Value Functions III

(Measures)

Overview

- The following slides represent the single dimension value functions (SDVFs) for the structural damage, safety, mission priority, mission capability, and redundancy measures.
- The SDVFs for structural damage, safety and redundancy are categorical; mission priority and mission capability are exponential and linear respectively.
- Review each SDVF and the associated values for each measure.
- Suggest any changes to the values for each SDVF.

Overview Cont’d

- These SDVFs, as they are currently composed, allow for data to be expeditiously gathered and are easily understood by anyone assessing them.
- Data for the Structural Damage, Safety, and Redundancy measures is quantified categorically.
- Data for mission priority and mission capability are quantified based on rank and % of mission capability degraded respectively.

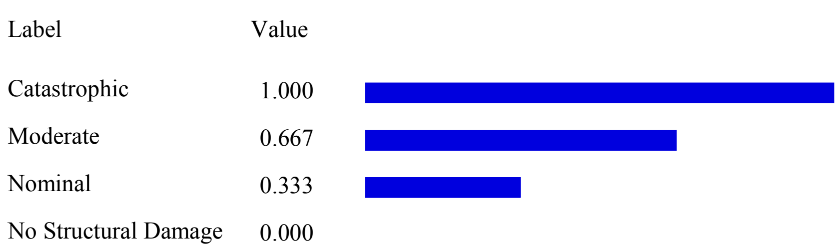
Overview Cont’d

- This allows almost any airman to collect data on these measures after minimal training. (For instance SABER, Engineering Flt, Readiness Flt, Fire Dept, and Wing Safety)
- Simplicity aids in communicating information up the chain of command

Structural Damage Categories

- **<u>Catastrophic</u>** = rating given to a project that addresses extensive structural damage which has rendered a structure unusable.
- **<u>Moderate</u>** = rating given to a project that addresses structural damage that is significant but does not threaten the integrity of the structure; work-arounds are possible.
- **<u>Nominal</u>** = rating given to a project that addresses structural damage that is limited and requires no work-arounds.
- **<u>No Damage</u>** = rating given to a project that does not address structural damage.

Structural Damage SDVF (Severity)



Safety Categories

- The measurement of the estimated risk to human life associated with not immediately undertaking a particular project; high, moderate, low
- Classified by risk assessment code (RAC) = I, II, or III and fire safety deficiency code (FSDC) = I, II, or III.

- **High** = a project that addresses a RAC or FSDC of I.
- **Moderate** = a project that addresses a RAC or FSDC of II or III.
- **Low** = a project that does not address a RAC or FSDC classification.

Safety SDVF (Risk)

Redundancy Categories

- The measurement of how many redundant facilities, routes, or networks are available for a particular project.

- **None** = a project that has no redundancies available must be dealt before others that do receives value = 1.0
- **One** = a project that has one redundancy receives value = 0.667
- **Two** = a project that has two redundancies receives a value of 0.333
- **Three or More** = a project that has three or more redundancies receives a value = 0.00

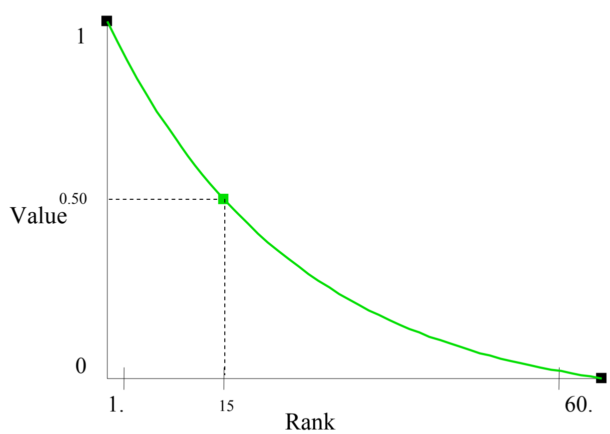
Redundancy SDVF (Availability)

Label	Value
None	1.000
One	0.667
Two	0.333
Three or More	0.000

Mission Priority

- The direct numerical position of a building or network on the mission priority list that a particular program addresses with the higher value being given to the higher rank.
- This measure is exponential and continuous.
- The fifteenth building/network receives 50% of the value. For each increment above #15 the value increases a greater rate than below #15.
- See SDVF for clarification.

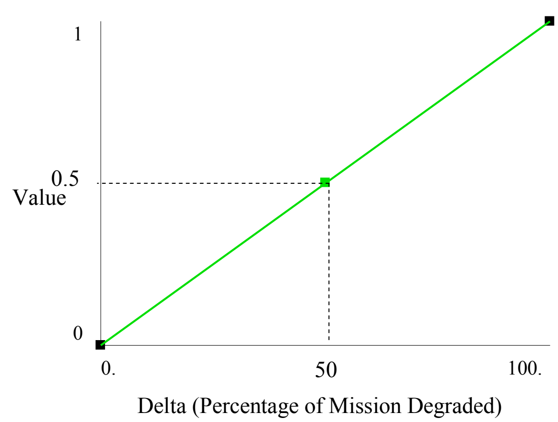
Mission Priority SDVF



Mission Capability

- The measure of the percentage of mission capability brought back on line by the completion of a particular reconstruction project.
- Measured as % of mission capability degraded.
- This measure is linear and continuous.
- See SDVF for clarification

Mission Capability SDVF (Delta)



Summary

- Please advise me of any changes as you see fit
- The final batch of SDVFs will be sent out 27 Nov 06
- Thank you for your time and continued support

Appendix D: Correspondence (Creating Single Dimension Value Functions IV)

Creating Single Dimension Value Functions IV

(Measures)

Overview

- The following slides represent the single dimension value functions (SDVFs) for the contractor availability, material availability, predecessor, and estimated time to complete measures.
- All of these SDVFs are exponential.
- Review each SDVF and the associated values for each measure.
- Suggest any changes to the values for each SDVF.

Overview Cont'd

- These SDVFs, as they are currently composed, allow for data to be expeditiously gathered and are easily understood by anyone assessing them.
- Data for **prevalence** (contractor measure) is measured in # of contractors available.
- Data for **deliver time** (materials measure) is measured in weeks.
- Data for **dependencies** (predecessors) is measured in # of projects dependent on the current project.

Overview Cont'd

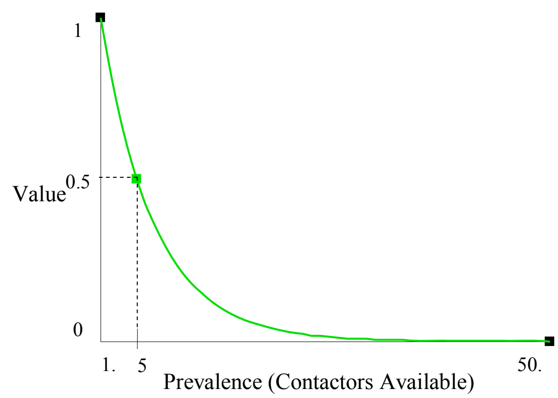
- Data for **ETC** is measured in days.
- This allows almost any airman to collect data on these measures after minimal training. (Project Manager, SABER, Contracting Sq etc.)
- Simplicity aids in communicating information up the chain of command
- Definitions of each measure are presented in the chart on the next slide.

PREVALENCE Contractor Availability	The availability of contractors to perform the work specific to a particular recovery project
DELIVER TIME Material Availability	The availability of material needed to perform work specific to a particular recovery project
DEPENDENCIES Predecessor Projects	How many projects a particular recovery project is a predecessor project for
ETC Project Duration	The estimated construction time of a recovery project

Prevalence

- This measure lets the decision maker know how many general contractors are available to perform work specific to a particular project.
- The SDVF is exponential with 5 contractors receiving a value of 0.5 and the value decreases as the number of available contractors increases.
- The point of this measure is to allow projects that have very few contracting options a higher priority than those with more options. This lets us obligate before someone else does.
- See SDVF on next slide for more clarification.

Prevalence



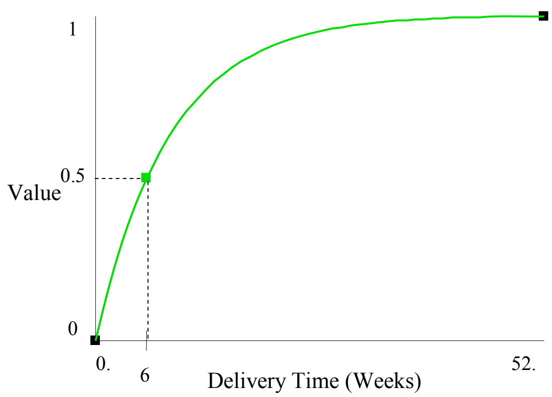
Deliver Time

- This measure lets the decision maker know how many weeks it will take for materials to be available to perform work specific to a particular project.
- The SDVF is exponential with 6 weeks receiving a value of 0.5 and the value increases as the number of weeks to deliver increases.
- Originally we thought that we should prioritize projects with shorter material delivery times first, but then decided against it for contracting related reasons.
- I believe that it makes more sense to fund projects ,such as Hangar Doors, which have a long material deliver lead time first rather than to first fund the close hanging fruit so that the total time to recover the base is decreased.

Deliver Time

- Of course contracting can authorize an emergency multiplier to speed up the delivery process.
- So, this SDVF says that we prioritize projects that have longer material delivery time over those that do not so that they can be completed earlier in the recovery process.
- See SDVF on next slide for more clarification.

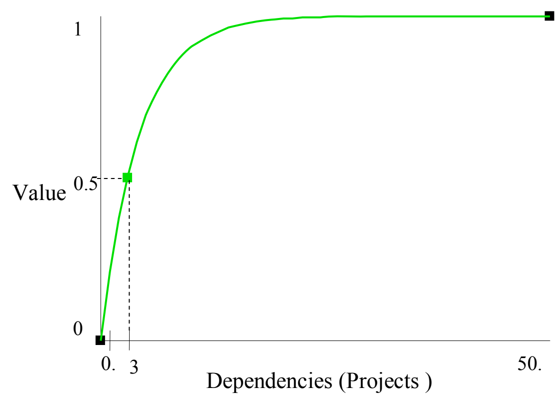
Deliver Time



Dependencies

- This measure lets the decision maker know how many projects a particular project is a predecessor for.
- The SDVF is exponential with 3 projects receiving a value of 0.5 and the value increases as the number of projects increase.
- This measure accounts for the fact that we need to give higher priority to projects that need to be completed in order for other projects to begin.
- See the SDVF on the next slide for further clarification.

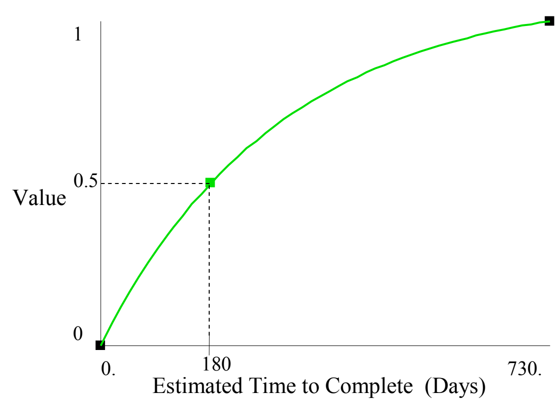
Dependencies



ETC

- This measure lets the decision maker know how many days a particular project is expected to take to complete.
- The SDVF is exponential with 180 days receiving a value of 0.5 and the value increases as the number of projects increase.
- This measure accounts for the fact that we need to prioritize projects that take longer to complete in order to recover in a timely manner.
- See the SDVF on the next slide for further clarification.

ETC



Summary

- Please advise me of any changes as you see fit
- The first set (storm) of disaster recovery projects for prioritization will be sent to you 4 Dec 06.
- Thank you for your time and continued support

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14. ABSTRACT

Prioritizing reconstruction projects to recover a base from a natural disaster is a complicated and arduous process that involves all levels of leadership. The project prioritization phase of base recovery has a direct affect on the allocation of funding, the utilization of human resources, the obligation of projects, and the overall speed an efficiency of the recovery process. The focus of this research is the development of an objective and repeatable process for optimizing the project prioritization phase of the recovery effort. This work will focus on promoting objectivity in the project prioritizing process, improving the communication of the overall base recovery requirement, increasing efficiency in utilizing human and monetary resources, and the creation of a usable and repeatable decision-making tool based on Value Focused Thinking and integer programming methods.

15. SUBJECT TERMS

Value-Focused Thinking, Decision Analysis, Integer Programming, Crisis Management, Project Selection, Natural Disaster Recovery

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