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A Value Focused Thinking Model for the Development and Selection of Electrical Energy Source Alternatives at Military Installations

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A VALUE FOCUSED THINKING MODEL FOR THE DEVELOPMENT AND SELECTION OF ELECTRICAL ENERGY SOURCE ALTERNATIVES AT MILITARY INSTALLATIONS

THESIS

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Abstract

Electrical power on military installations is vital for mission accomplishment. Most installations obtain electrical power from a local commercial utility. Although commercial power service has a very low interruption rate, the threat of a sustained power outage resulting from a terrorist act or a natural disaster is of concern. The military should posture itself to prevent such power outages and prepare to mitigate the adverse affects associated with the loss of power.

This thesis presents a Value Focused Thinking approach to the development of a decision analysis model to assist a decision maker at a military installation in the generation and selection of back-up energy alternatives. The model attempts to capture the value to be gained by implementing back-up power systems which utilize fossil fuel powered generators in combination with renewable energy resources and assist the decision maker in selecting an alternative which best suits the needs of the installation. The thesis also includes a case study involving the application of this model to the United States Marine Corps installation in Twentynine Palms, California.

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Chapter 1: Introduction

1.1 Background

Throughout the Department of Defense, electrical service on military installations is primarily purchased through local power companies. Characteristics of this service vary widely between installations including the type of fuel used to generate the power at the power plant and the reliability of this power. Additionally, every installation has unique geographical characteristics, such as climate and renewable energy potential, which affect the reliability of the power supply and each base will suffer some degree of mission degradation as a result of losing power.

The Department of Defense places a high degree of importance on the day-to-day mission performed at each installation. The inability to complete this mission at one installation degrades, to some degree, national defense. The mission performed at a military installation supports military personnel, operations, as well as other military installations. In addition, local communities often depend on military bases to assist them in times of peril. This assistance usually includes emergency services such as medical, fire, and police services, but may also include the sheltering of citizens displaced due to the emergency. The loss of power to a military installation could reduce the ability of the base to provide that support. Two primary threats to the reliability of the electrical service are natural disasters and terrorism. By studying weather patterns, it is possible to predict the likelihood of natural disasters. Terrorism, on the other hand, is an ever changing threat with much less predictability.

In addition to concerns centered on dependability of power supply, there is also a potential cost benefit to be realized through use of cheaper energy sources and reductions in the cost of energy consumed. Self production of electricity can be less expensive than electricity purchased from a public utility company. Therefore, the potential exists in certain parts of the world to capitalize on these cheaper electrical costs.

1.2 Problem Statement

The purpose of this thesis is to develop a mathematical model to evaluate alternative energy opportunities based on the unique characteristics of each military installation. This model will account for the values associated with aspects of power requirements unique to each installation and can therefore be adapted to evaluate proposed energy sources at any military installation. In this thesis, the model is applied to the Twentynine Palms Marine installation to develop alternatives for power generation and to assist the decision maker in selecting from these alternatives.

This model is designed to deal with alternatives consisting of a variety of energy sources. The alternatives will consist of multiple pieces of equipment and infrastructure based on several different energy producing technologies. In other words, an alternative may include photovoltaic arrays, a geothermal plant, and several diesel generators of varying sizes in order to best satisfy the values of the decision maker. In order to be analyzed by this model, the make up of an alternative may be specific or generic in nature. In other words, the alternatives might include detailed information regarding the specifications of each piece of equipment included in the alternative, or it may only contain estimates of wattage and assumed locations. The more specific the alternatives are in regard to their make up, the more beneficial the model output will be.

The United Stated Marine Corps Air Ground Combat Center at Twentynine Palms, California, currently receives the majority of its electrical power requirement from the local electric power provider, Southern California Edison. Twentynine Palms is attempting to reduce its dependence on the utility company by generating its own power in order to reduce cost and to increase the reliability of the electrical service. The potential for natural disasters (primarily earthquakes and severe thunderstorms) threaten the continuity of electrical service. In addition to the threat of natural disasters, terrorism or civil unrest is also a concern. In the event of such an occurrence, the electrical service to Twentynine Palms could possibly be interrupted for extended periods of time during a situation in which it would be most needed. Power would be required to continue life support operations at the hospital, maintain lighting and perimeter security, and provide communications for command and control operations. Decision makers at Twentynine Palms are therefore actively searching for projects to satisfy these needs for dependable and continuous electrical power. This research provides an objective, repeatable, and defendable method for making decisions (Weir, 2003) regarding the selection of alternative energy sources for a military installation. The Value Focused Thinking model developed in this study facilitated the analysis of back-up energy systems by focusing on the values elicited by the decision maker.

1.3 Objective and Scope of Research

Because each military installation is unique, decision makers at each installation will have values associated with aspects of electrical power consumption, cost, ability to self produce, and reliability. A set of values should exist which is common to all installations. However, each installation will perceive each value to be of differing importance in relation to one another. The model is designed to account for the characteristics and requirements of any military installation so that these values can be taken into consideration in the evaluation of the alternatives.

1.4 Summary and Organization

Chapter 2 provides the literature review for this thesis effort. It includes relevant sources regarding energy production and consumption. It also explains the value focused thinking approach. Chapter 3 details the selection of the type of Value Focused Thinking model designed for this model development and how the model can be applied to a specific military installation. It presents the development of values associated with aspects of electricity. Assumptions made within the model are also explained here. Chapter 4 presents the results of the analysis. It provides the results from the case study performed at Twentynine Palms by identifying recommended courses of action based on the decision makers' values input into the model. Chapter 5 provides a summary of the study including insights, recommendations, and suggestions for future research.

Chapter 2: Literature Review

The model developed for this thesis provides assistance in generating and selecting back-up energy alternatives. This literature review discusses back-up power technology, including traditional and environmentally friendly power generation systems. Specifically, it covers those technologies that are anticipated to be included in the alternatives generated for the application of this model. Traditional sources are the diesel and natural gas generators typically found on military installations. Environmentally friendly powers sources such as wind, solar, and geothermal, are continuously becoming more feasible energy options.

The Department of Defense (DoD) places the primary mission of installations above all other functions. The loss of power to the installation would degrade, to some degree, the ability of the installation to complete this mission. Installations have, therefore, gone to great expense to provide a back-up energy system in order to lessen the effects of a power failure. In addition the primary mission, there is also a need to provide support to the local community in times of peril. The requirements of the DoD to assist civil authorities in the event of emergencies are also detailed in this literature review.

Value Focused Thinking was the methodology employed to analyze the decision problem of developing and selecting back-up energy alternatives. Decision analysis methodologies have long been used to provide assistance to decision makers. A discussion of decision analysis and its methodologies are also included in this literature review. The review of decision analysis literature focused primarily on Value Focused Thinking and three procedures developed to implement its concepts.

2.1 Back-up Power Systems

Industrial and commercial organizations traditionally use a variety of redundant power generators. The most common purpose for these generators is to provide back-up power for critical loads. Critical loads are those functions to which the organization cannot afford to lose electrical power. Among other uses, back-up power is commonly provided for emergency lighting within a building, computer servers which are designed to operate continuously, and vital communication networks.

Redundant power systems are also used in order to reduce the commercial power load. Commercial power companies often charge commercial and industrial customers higher rates during peak times (typically during daylight hours) because the demand for power across the entire grid is at its maximum. The power companies must maintain a generation plant and related infrastructure able to meet this peak demand even though the plant very rarely provides this peak power to the users. In order for the utility to be profitable, the cost of maintaining these assets is passed along to its customers.

2.1.1 Traditional Back-up Power Systems

Generators powered by diesel or natural gas are the most common back-up power systems. Although generators require a high level of maintenance, they are attractive options because they tend to have high reliability and a relatively low initial cost. Maintenance is critical to ensure the dependability of these generators and can become burdensome as the number of generators on an installation increases. Additionally, if diesel generators are only to be operated during a power failure, a method of periodically replacing the stored diesel fuel must be considered. Typically, the generator is operated in order to consume the diesel in the holding tanks and the tanks then refilled. However, if there is considerable fuel storage, this can create excessive air pollution.

2.1.2 Environmentally Friendly Power Generation Systems

Environmentally friendly power sources (also referred to as renewables) such as solar arrays, geothermal heat exchangers, and wind farms, share common benefits. Foremost, these power generation methods do not consume fossil fuels and instead rely on a renewable (non-exhaustive) and fuel source. However, the natural and human-influenced geography dictates which of these are available for use at a selected military installation. The climate must be able to support the generation of electricity and the construction of such a power generator must be compatible with the available installation's mission and land use.

Generally speaking, environmentally friendly power sources are not dependable enough to provide back-up power for critical loads. On a cloudy or windless day, there may be no power generated from the respective systems. The capacity factor of an energy source is used to account for this shortcoming. Wind turbines, for instance, have a capacity factor of 0.32 at Twentynine Palms. This capacity factor is multiplied by the rating of the wind turbine to determine the amount of power one can reasonably expect at any given time. Therefore, an installation in a location where wind turbines have a capacity factor of this magnitude can only expect to garner 320kW from a 1MW turbine (Lu, et. al., 2003:33). However, if used to compliment the power supplied from the commercial power source, they can greatly reduce the demand for commercial power during the peak hours (thus reducing overall cost). They can also assist the installation in meeting guidelines requiring military installations to reduce the consumption of fossil fuel generated power by increasing the amount of environmentally friendly power consumed.

Executive Order 13123 mandates that government agencies (military installations included) reduce the amount of greenhouse gas emissions generated by 30 percent from a baseline as measured in 1990 (Executive Office of the President, 1999:1). Reducing the amount of fossil fuel generated electricity used on an installation can assist the installation in meeting these goals. Therefore, aside from the ability of renewables to reduce the cost resulting from the purchase of power, they can also help reduce emission levels of the installation.

Solar arrays are most effective in regions where there is a high degree of sunlight. If the installation depends on them for back-up power, there must be some method of storing the electrical power (such as a flywheel or battery). The high cost of the storage system makes photovoltaic arrays a less attractive choice for dependable back-up power capability. The photovoltaic generators considered in this case study do not possess batteries and only produce power during daylight hours. Solar arrays typically require a large amount of land area and may not be compatible with installations possessing flying missions. The highly reflective surface of the panels must be taken into consideration when locating these assets.

Wind farms also require a large amount of land to provide a usable amount of electricity. Since wind speed is often consistent during day/night time changes, these typically provide a more dependable source of power over the course of a 24-hour day. However, these wind assets may not be compatible at locations near military or civilian airfields. Since wind speed generally increases with altitude, there is more benefit to be gained by elevating the blades of the wind turbines. The height of the individual generators in the wind farm may exceed Federal Aviation Administration or military standards for airfield clear zones.

Geothermal power generators are more dependable than solar arrays or wind farms. Geothermal generators draw heat from the earth and convert it to electricity. The energy produced by geothermal plants is more consistent than energy produced by solar or wind assets. The temperature from which this heat is drawn does not vary and so the electricity produced by the generator can be assumed to be constant. Because of the smaller footprint of a geothermal plant in relation to wind farms and photovoltaic arrays, these can likely be located with other industrial facilities and outside of the airfield clear zones.

2.2 Military Response During Emergencies

As mentioned previously, the primary mission of the Department of Defense (DoD) and its military installations is of higher importance than its auxiliary missions. The DoD has on-going operations worldwide which depend on the support provided by permanent installations. The DoD is committed to providing the best support possible to these missions. However, in the event of an emergency, military installations are required to provide assistance to local communities to help prevent, reduce, or control the adverse effects of catastrophes. For instance, the DoD is required to protect its assets and the families of its personnel from terrorist attacks. It is also required to stop a terrorist act in progress and respond to minimize the adverse effects of a terrorist action (DoD, 1994

(Jun):2). The Stafford Act requires the DoD to lend support to civil authorities in the event of disasters or emergencies as directed by the President (DoD, 1993:3). Civil unrest and disturbances also may require DoD intervention (DoD, 1994 (Feb):3).

The probability that a military installation will lose commercial electrical power during an emergency is increased as a result of the emergency. If a natural disaster strikes in the vicinity of a military installation, it is likely that there will be power outages as a result. If the power failure occurs on an installation without an adequate back-up energy source, the installation's ability to provide support will be severely degraded.

The need for back-up energy is evident. However, many factors need to be considered in selecting an effective back-up energy system. There are characteristics of electricity generation and transmission which must be considered in order to make an educated decision regarding the back-up energy system to implement. In addition, there are geographical considerations that will play a role in determining the availability of certain types of power production technologies. Therefore, there is a need for a reliable method of developing and selecting from back-up energy system alternatives.

2.3 Decision Analysis Models

Most people deal with hundreds of decisions on a daily basis and rarely need to think deeply about more than a handful of them. However, when people are faced with decisions with long term or significant consequences, they often desire additional information or a new perspective in order to make their decision. It is for these decisions that a wide array of decision modeling has been used. Decision models have long been developed as a means of providing insight to decision makers as they provide the decision maker with objective, repeatable, and defendable methods for basing decisions (Weir, 2003). Developing an adequate model based on quantitative measures (such as salary, cost, and temperature) is a fairly straightforward mathematical process. There is a need, however, for quantifying subjective values (such as risk aversion, comfort, entertainment level) in order to apply a model based on the qualitative characteristics of decision alternatives.

In order to meet this need, decision models that capture the subjective aspects of alternatives were created. These models typically focused on the analysis of alternatives and are now termed Alternative Focused Thinking models. These models, however, have a fundamental weakness: they are designed to evaluate alternatives, none of which may be "good." In other words, these methodologies may only assist the decision maker in selecting the best from among a pool of poor alternatives (Kirkwood, 1997:43).

This weakness of AFT set the stage for the development of Value Focused Thinking (VFT). The implementation of VFT promotes the development of additional (and often better) alternatives by focusing not on the evaluation of existing alternatives, but on the values held by the decision maker and alternatives which best satisfy those values. By focusing on the values held by the decision makers, it is possible to view the decision problem from a new perspective and develop alternatives which best satisfy those values (Kirkwood, 1997:11). This is described in more detail below.

2.3.1 Alternative Focused Thinking versus Value Focused Thinking

Values held by a decision maker drive the need to make decisions. After all, decisions are merely a method of improving one's situation. Ralph Keeney, who many consider the father of VFT, encouraged those faced with decisions to view such decisions as opportunities rather than as problems. He argued that this change in thinking would enable the decision maker to improve the decision making opportunity and lead to a better range of alternatives from which to choose (Keeney, 1992:8).

Keeney (1996) developed a four-step process for decision modeling using the VFT approach. The first two steps require the modeler to identify and then structure the values of the decision maker. The decision maker must identify all objectives desired for the given situation. In other words, decision makers should not factor in any external limitations or required trade offs (Keeney, 1996:543). These values should be analyzed to ensure that each is a value in itself and not an objective merely to promote the achievement of other values (Keeney, 1996:544).

Keeney's third step is perhaps the most critical and divergent of his four-step VFT process. This third step instructs the modeler to develop alternatives. It is a tendency for people to have preconceived notions of how to resolve a dilemma before they achieve a thorough understanding of the issues involved. There is a natural desire to eliminate the discomfort created when confronted with a decision and begin the implementation of the "fix." The result of this rush to action is the implementation of an obvious and viable, yet often a flawed, solution. Therefore, it is this third step which promotes deep thinking and facilitates the development of alternatives not immediately apparent to the decision maker (Keeney, 1996:545).

Keeney suggests these alternatives can be created by focusing on one value at a time and developing alternatives to optimize that value, even though the alternatives generated will often fare poorly when judged against a different value. After the analysis of individual values, the decision maker should analyze two values and either create additional alternatives to optimize these values or modify the alternatives which were developed when these two values were analyzed independently so that the revised alternatives better satisfy each of these values. This process is repeated with three objectives, four objectives, and so forth until all values are analyzed together and the list of alternatives is finalized (Keeney, 1996:545).

The fourth and final step in Keeney's process is the seeking out of additional decision opportunities (Keeney, 1996:545). By identifying these decision opportunities before they become decision problems helps the decision maker avoid those situations in which he or she would have to take a reactive role. In short, by seeking out these opportunities, the control of the situation is more in the hands of the decision maker and not the extenuating circumstances (Keeney, 1996:537).

Keeney identified three primary differences between an AFT and VFT approach to problem solving: 1) VFT requires that the values held by the decision maker be identified and analyzed. In the traditional AFT models, this analysis is limited or nonexistent. 2) The identification of values occurs prior to the development of the alternatives (Keeney, 1996:538). If values are analyzed at all in an AFT model, it frequently occurs after the analysis of alternatives. 3) The values identified are utilized to create the list of alternatives (Keeney, 1996:538), rather than merely serving as a basis by which to evaluate previously generated alternatives (as is done in AFT modeling).

VFT focuses on the understanding of the values held by the decision maker. Without the fundamental insight gained by the determination of these values, it is difficult to create an extensive list of options available. By understanding these values, a decision maker is better able to develop alternatives which satisfy these values to varying degrees. In other words, the development of alternatives prior to implementing the decision model eliminates viable, yet previously not considered, options. Because decisions are made in order to satisfy values held by the decision maker, it is these values which should first be analyzed. By eliciting the values and developing a method by which to measure them, the modeler facilitates a thought process on the part of the decision maker which should bring to light previously unconsidered alternatives (Keeney, 1996:537).

Keeney was not alone in developing a stepwise procedure for the implementation of VFT. Kirkwood (1997) introduced his five-step process for developing a VFT model. Kirkwood's first step instructed the modeler to specify the decision makers' values and the scales by which they will be measured (Kirkwood, 1997:3). Kirkwood, who emphasizes the hierarchical structure of values more than Keeney, provides keys to the construction of a working hierarchy: completeness, nonredundancy, independence, operability, and small size (Kirkwood, 1997:16-18).

To satisfy the completeness requirement, each value contained within the hierarchy must include a complete range of concerns (whether they be in the form of measures or additional values) necessary to properly evaluate that value. This must be true of each value contained on each tier of the hierarchy. In addition, each measure must be capable of capturing the degree to which each alternative attains that objective (Kirkwood, 1997:16).

Nonredundancy prohibits the overlapping of any value or measure with another value or measure (Kirkwood, 1997:16-17). This requirement ensures that no alternative will be rewarded or penalized more than once for a single characteristic of the alternative. If, for example, one is creating a model to decide between job opportunities, he or she cannot create a measure to evaluate the base pay of a job and at the same time create another measure which evaluates total compensation which includes base pay among other benefits. Since both of these measures consider base pay, a measure with high base pay would be rewarded twice for this single aspect of the alternative, whereas a job with a low base salary would be penalized twice.

Independence requires that scoring on one measure cannot influence another. Continuing with the employment opportunity example, base salary is often sacrificed as benefits are increased. In other words, people are more likely to accept a lower paying job if more benefits are included in the compensation package. A model which evaluated these two criteria (salary and benefits) in separate measures would violate the independence requirement because salary and benefits are inversely related. In other words, because the scoring of one of these measures would predict a lower or higher score in the other, they are not independent of one another (Kirkwood, 1997:17-18).

For a hierarchy to be operable, it must be geared towards the user. In other words, a hierarchy developed for use by scientists may not be operable to a musician. Operability is simply the ability of the hierarchy to be used by its intended audience (Kirkwood, 1997:18).

Finally, small size refers to the preference to keep the hierarchy as simple as possible. However, the completeness of the model should not be compromised. The decision maker must carefully select those values to ensure that the hierarchy includes all of the decision criteria necessary to make the decision analysis; however, nothing more should be included (Kirkwood, 1997:18).

Despite Kirkwood's emphasis on the development of the hierarchy, this first step of his VFT process is nearly identical to Keeney's first two steps. Keeney's first two steps, in combination, instruct the decision maker to focus on values and to organize those values prior to development of any alternatives. Kirkwood's second step is to generate the alternatives in much the same method as prescribed by Keeney. The third step of Kirkwood's VFT process is the scoring of each alternative according to the scales developed during the first step (Kirkwood, 1997:3). Although this action was implied in Keeney's procedure, it was not specifically called out in the stepwise procedure. However, it is apparent that each alternative must be scored against the value hierarchy. Kirkwood directs the development of a single dimension value function for each measure and the weighting of the measures and values in order to be able to identify the usefulness of a given alternative (Kirkwood, 1997:53).

Kirkwood then instructs the modeler to analyze the tradeoffs of the alternatives during step four (Kirkwood, 1997:3). This process is required as the modeler did not consider tradeoffs and external restrictions during the generation of alternatives. After the consideration of tradeoffs and external restrictions, the modeler recommends a solution (Kirkwood, 1997:3). During the selection phase, it is important to note that several alternatives may be required in order to satisfy the objectives. He suggests the use of linear optimization to select the best combination of alternatives if more than one is to be chosen (Kirkwood, 1997:206).

The merits of VFT seem obvious. However, few studies have been performed to illustrate the superiority of VFT in contrast to AFT primarily due to the complexities of performing such an experiment (Leon, 1999:215). Leon (1999) performed a study to compare results of decision analysis models using an AFT methodology versus a VFT methodology. The group using a VFT approach was better able to identify desired objectives and to construct them into a hierarchical arrangement than the group utilizing the AFT approach (Leon, 1999:219, 222). Additionally, Leon argues that the group using VFT identified a broader base of values than did the AFT group. This indicates that the AFT methodology creates a narrow viewpoint of the decision at hand (Leon, 1999:220). Both models generated during this experiment were then used in a second study to evaluate the overall usefulness of each model. Overwhelmingly, the VFT model was chosen to be the more useful of the two models (Leon, 1999:223).

2.3.2 Air Force Institute of Technology VFT Process

A 10-step VFT process (Shoviak, 2001:63) was developed at the Air Force Institute of Technology (AFIT). Shown in Figure 1, the steps of this model were derived from the stepwise procedures offered by Keeney (1996) and Kirkwood (1997). Although Shoviak's (2001) modeling approach includes more steps, most of the steps are subtasks within a single step of the others' processes. Steps 2 through 5 focus primarily on the creation of the hierarchy, while Steps 7 through 9 involve the analysis and reporting of results. Due to the insight obtained through all stages of the hierarchy development, VFT is an iterative process. Double arrows have been included between some of the steps in the process to illustrate this. However, once the decision maker has elicited his or her values and measures by which to evaluate alternatives, care should be taken to not modify this set of values based on the available alternatives or in an effort to skew the results of the analysis. In other words, Steps 1 through 3 are fundamental to the decision problem at hand and typically should not be modified based on the insight gained through subsequent steps.

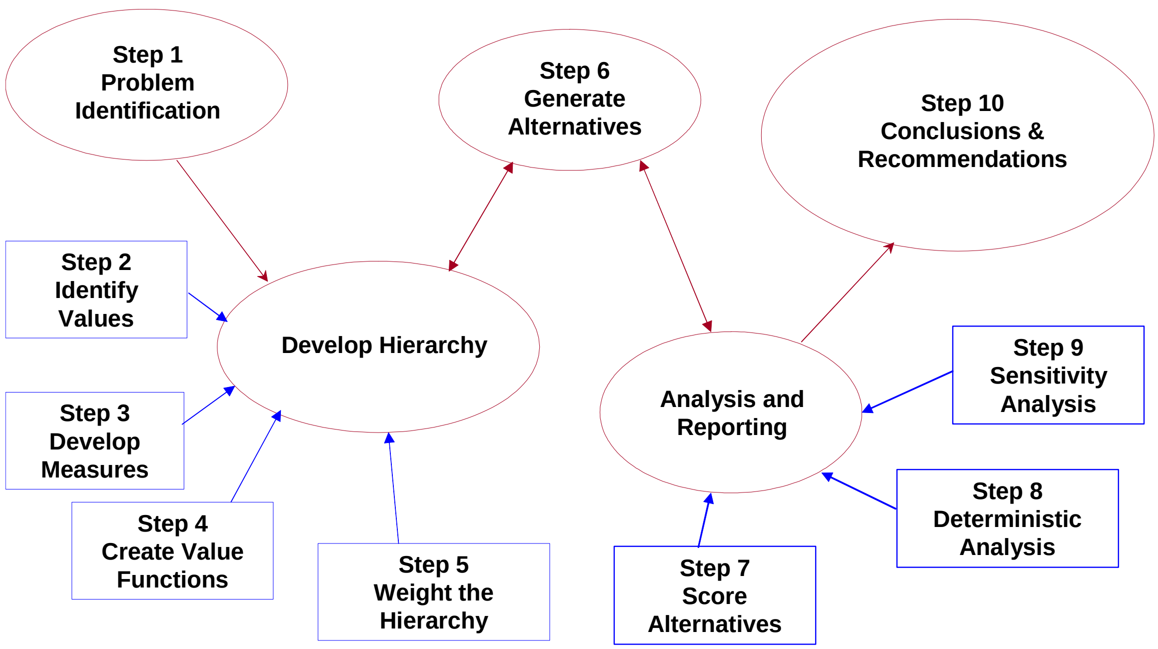

Figure 1 –10-step Value Focused Thinking Procedure (Shoviak, 2001)

Step 1 of Shoviak's (2001) procedure requires a clear articulation of the decision problem faced. The Keeney (1996) and Kirkwood (1997) models detailed above assume the problem is readily identifiable and do not stress the importance of problem identification. However, a thorough understanding of the decision problem to be addressed will focus the modeler and decision maker on the purpose of the model development. In order to maintain focus on the problem, this decision problem becomes the top-tier of the value hierarchy.

Step 2 requires that the modeler develop the values to be included in the value hierarchy. The value hierarchy provides the structure for multi-objective decision analysis and graphically displays the values and categories of values held by the decision maker (see Figure 2). The decision maker is the only one capable of identifying the values relating to the decision problem, so his or her input is crucial in development of a functional hierarchy. The modeler is involved in this step only to ensure that the hierarchy is developed in a "top-down" fashion. The top-down approach ensures that the decision maker identifies values prior to attempting to identify measures (as described in Step 3 below). The graphical depiction of the decision problem further assists those involved in the decision process in remaining focused on the goal of the model development.

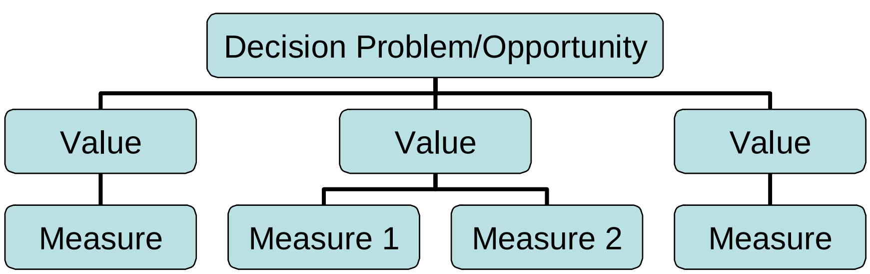

Figure 2 - Generic value hierarchy

Step 3 is the development of the measures. These measures are the criteria that will be used to evaluate the alternatives according to how well the alternatives satisfy the values. Each of the values derived in Step 2 will have associated measures. These measures will be depicted beneath the value on the value hierarchy. For instance, if a decision maker expresses a value of safety, the measures used to gauge the extent to which safety is achieved might be accident rate, worker safety violations, or crime rate. A measure may be capable of directly capturing the value or it may be a *proxy* of that value. For instance, profit would be a measure which could easily be measured directly. However, crime rate may be a proxy measure for a value such as safety. Additionally, each measure can be natural or constructed. A natural measure for crime rate may be simply the number of crimes committed per capita. A constructed measure to capture crime rate may place greater importance on violent crimes, thereby creating an unconventional measure constructed specifically for the decision model under development.

Single dimension value functions are created for each measure in Step 4. The value functions are the method by which each alternative is scored on the measure. First, the decision maker defines the lower and upper bounds for which this measure can be scored. The decision maker then established a function, either continuous or interval, to measure the value associated with an alternative's score in between the limits of the measure. For instance, for a measure defined as accident rate, the lower bound is identified as zero and the upper bound is identified as one per 1000 man hours. The lower bound (zero) in this case identifies the best condition and the single dimension value function should equal one for this score. Whereas, one injury per 1000 man hours is considered high and an alternative which would result in an injury rate this high would be deemed to have no value to the decision maker. The result from the single dimension value function for this alternative would therefore equal zero. In between these two injury rates (zero and one per 1000 man hours), the decision maker must identify the degree to which the value changes as the accident rate increases from zero to one accident per 1000 man hours. In other words, he or she must identify either a continuous function or a set of categories in order to measure the value associated with accident rates between these two extremes. If a continuous function is to be employed, a straight line or some exponential curve linking the two extremes may be used. It may be beneficial or more logical to break out categories within these extremes. In this way, for instance, incremental value may be associated with decreasing accident rate for every 0.1 or 0.25 injuries per 1000 man hours.

The decision maker weights the hierarchy in Step 5. This weighting is performed locally and in a bottom-up approach. In weighting the hierarchy, the decision maker is establishing the importance of each value and measure in relation to one another. Weights are assigned as a percentage, thus the total weight within each value must sum to one. Using the example provided in Step 3, the decision maker may conclude that crime rate constitutes 10 percent of the degree to which the safety value is met. Accident rate may represent 70 percent of the measure, leaving worker violation rate with 20 percent. After weighting each of the measures beneath each value, the decision maker weights the values themselves. He or she does this in the same fashion of determining the importance of the value safety in relation to the other values identified in Step 3. Weighting the hierarchy in this manner is termed local weighting because each measure is weighted against one another "locally," or within the same value.

Another method for weighting is global weighting. In this instance, each measure is assigned a weight in relation to all other measures. All of the weights assigned to all measures in the hierarchy must sum to 1. If a large number of measures are represented in the model, this method can become quite complex. For a hierarchy with 100 measures, for example, it would be difficult to assign weights for all these measures and ensure they sum to 1. However, for a model with few measures, this method of weighting offers an opportunity to visualize the weight of each measure in relation to one another as the weights are being determined. When employing global weighting, only the measures are weighted because the weights of the values are determined by the weights of the measures included beneath the respective value.

Step 6 is the generation of alternatives. This is the fundamental improvement of VFT over previous decision analysis methods. A decision maker will almost always have alternatives in mind at the start of implementing VFT. However, by studying the value hierarchy, the decision maker will gain insight into the decision problem and the desired results that were not apparent before the hierarchy was developed. It may become evident, for instance, that safety is not nearly as important as worker productivity or vice versa. This realization may open the door to alternatives not considered before the hierarchy process was initiated.

In Step 7, each of the alternatives is scored against each of the measures. After an alternative is scored against a measure, the value derived from the value function is multiplied by the weighting of that measure. The sum of the products resulting from the scoring of that alternative against all of the measures is the overall value of the alternative. The formula for calculating the score of an alternative is shown below.

$$Score_i = \sum_{j=1}^{n} a_{ij} w_j$$

where: Score = alternative's total value
n = number of measures
a = alternative's value on the measure
w = global weight of the measure

After each alternative is scored on all measures, they are ranked according to their total value in Step 8, Deterministic Analysis. An alternative's total value provides insight to the decision maker when compared to the scores of other alternatives. A higher score indicates an alternative that better satisfies the values set forth in the VFT model. Depending on the confidence of the decision maker in the validity of the model, this insight may be considered highly valuable.

Sensitivity Analysis, Step 9, provides additional insight. This analysis allows the decision maker to visualize how the ranking of alternatives changes as the weighting of the values and measures increase or decrease. For example, if one desires to examine how the rank order derived in the deterministic analysis changes as the importance of a particular value changes (i.e., the weighting is increased or decreased), the modeler can graphically display the ranking of the alternatives and how that ranking changes as the weighting of the value increases and decreases.

Finally, Step 10 requires that recommendations and conclusions be reported. Rather than stressing the recommended course of action, the modeler should focus on the insight gained into the decision process. The insight acquired throughout the model development and execution is the most valuable result of VFT. The modeler must stress that although VFT provides an objective, repeatable, and defendable basis for making decisions (Weir, 2003), it should not be the sole purpose for making a decision.

Chapter 3: Methodology

3.1 Value Focused Thinking

This chapter describes how Value Focused Thinking was applied to this decision problem. The application is presented in a stepwise fashion according to the 10-step process (Shoviak, 2001:63) described in Chapter 2. Steps 1 through 3 are not installation-specific. That is, these steps were completed without regard to a specific military installation. This ensured that the development of the model would not be installation-specific and would be able to be applied to any military installation. Steps 4 through 10 must be modified according to the installation to which the model is to be applied.

This thesis divides the description of the steps into different chapters in an attempt to best present the stepwise procedure in this thesis format. Steps 1 through 6 are included in this chapter because they relate to methodology more so than do subsequent steps. Steps 7, 8, and 9 are included in Chapter 4, while Step 10 is included in Chapter 5.

3.2 Value Focused Thinking Methodology

The VFT model developed for this thesis was created using the 10-step process (Shoviak, 2001) as described in the previous chapter. After the values were identified, the value hierarchy was constructed. A stepwise description of the application of this methodology follows.

3.2.1 Step 1 – Problem Identification

A reliable back-up power scheme on a military installation is vital to minimize the catastrophic effect of a power outage. The military (as do all government agencies) has a responsibility to the American people to execute wisely appropriated funds. It is therefore good stewardship to employ not only a reliable back-up power scheme, but an efficient one as well. This VFT model was designed to assist military installation decision makers develop and select from among back-up power alternatives for their installation.

3.2.2 Step 2 – Determine Values, Step 3 – Identify Measures

Step 2 requires that the decision makers identify the values they hold in regard to the decision problem at hand. Step 3 requires that measures be identified so that the degree to which each alternative satisfies these values can be measured quantitatively. For measures that are traditionally rated according to qualitative categories, numerical values must be assigned to the categories so that a quantitative analysis can be performed. The values identified for the case study at Twentynine Palms included *Cost, Environmental Compatibility, Geography, Operability,* and *Reliability*. This section provides introductory information regarding each of the measures. Appendix A includes more detail regarding how each measure was developed and how it is scored.

3.2.2.1 Cost

Cost plays a role in determining if military projects ever come to fruition. In order to capture the primary costs associated with a project, it was necessary to consider initial as well as future monetary obligations. In order to quantify these costs, three measures were used as contributors to the *Cost* value. These measures included the initial project cost, the operations and maintenance costs, and the ability to recoup the investment through subsequent cost savings. Figure 3 displays the *Cost* value as it appears in the overall hierarchy.

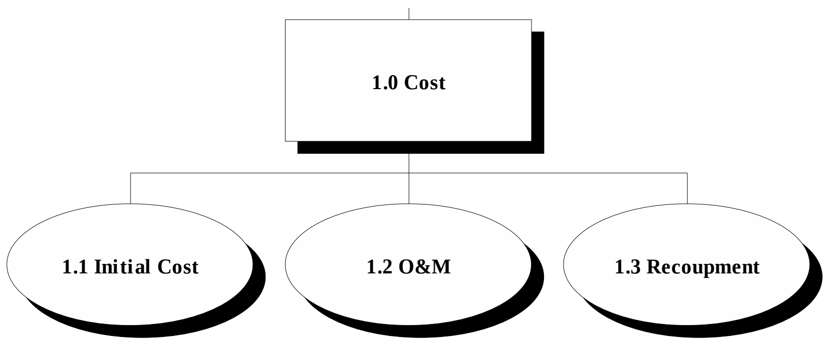

Figure 3 – Cost Value

3.2.2.2 Environmental Compatibility

Environmental Compatibility refers to the environmental “friendliness” of the alternative. The implementation of an environmentally friendly alternative has two primary benefits. The first benefit of using environmentally friendly energy sources is an improved public image which is vital to the long term success of the military. The military promotes that image by being a good steward of the environment. Second, the government has enacted milestones which require that an increasing percentage of the installation’s energy be derived from clean energy sources (Executive Office of the President, 1999:1). Implementing clean energy sources within the alternative helps achieve those goals. The environmental compatibility of each alternative is measured in two ways: the reduction in the amount of greenhouse emissions created by the base as a result of implementing the alternative in question and the renewability of the fuel source. Figure 4 shows the *Environmental Compatibility* value of the hierarchy.

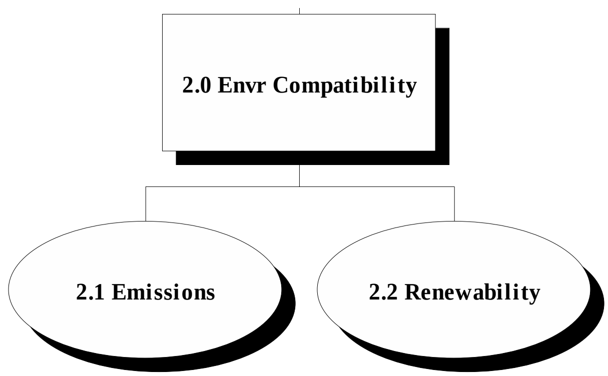

Figure 4 – Environmental Compatibility Value

3.2.2.3 Geography

The values included in *Geography* are the aesthetic appeal and the defensibility of the proposed alternative. This section of the hierarchy is pictured in Figure 5 below. *Aesthetics* has three measures: land valued occupied by the alternative, noise produced by the alternative, and the alternative's visual impact. *Defensibility* has three measures. *Stand Off Distance* is the distance from the equipment to the base perimeter (or to some other location where someone not authorized to be on installation property could situate themselves without being contested by base security). The value added by having additional security measures in place is captured by the *Other Security* measure. These security measures include, but are not limited, to fencing, motion detectors, cameras, personnel radars, or any other device which would alert installation security of a potential breach prior to any sabotage being committed. Depending on the value of the added security features (which will change with technological advances), this measure may require additional categories or a different stratification of the features included. The final measure in *Defensibility* is the response time of installation security upon notification of a security breach at the alternative's location. All of the measures in *Defensibility* are based on a worst case scoring system, which means that the alternative is scored based on the most vulnerable piece of equipment contained in the alternative. Generators designed for a single facility and located in close proximity to that facility are not to be scored since they typically represent a very low value/high risk target to a potential saboteur.

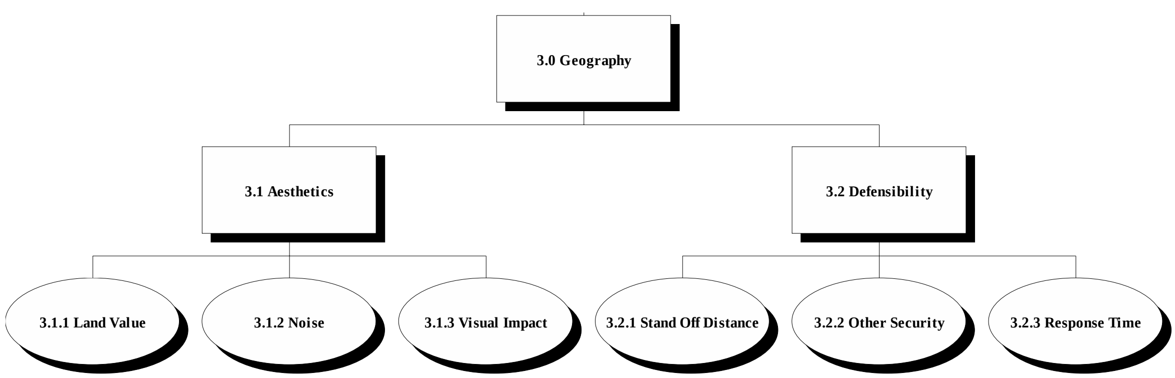

Figure 5 – Geography

3.2.2.4 Operability

Operability captures the alternative's convenience and dependability aspects not contained elsewhere in the model. It includes two measures: the number of fuels utilized by the alternative's assets and the useful life of the alternative. The graphical representation of *Operability* is shown in Figure 6. *Multi-fuel Capability* measures the benefit to be gained from the ability of equipment within the alternative to utilize more than one type of fuel. Typically, only generators capable of operating on different fuel types will provide value to this measure. *Useful Life* is a measure of the useful life of the shortest-lived aspect of the alternative. The lifespan of the shortest-lived unit was the criterion used to score alternatives because once the shortest-lived piece of the alternative is no longer useful, the alternative no longer functions as intended and another decision will be required at that time.

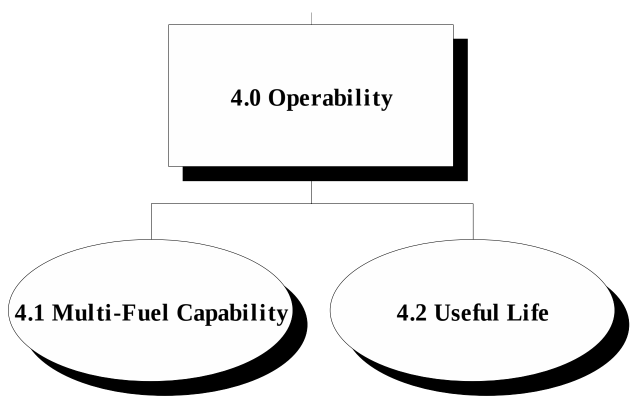

Figure 6 - Operability

3.2.2.5 Reliability

Reliability contains three measures which quantify the benefit to be realized through the reliability of the alternative. These measures are *Critical Load Duration*, *Important Loads*, and *Excess Power*. This section of the hierarchy is depicted in Figure 7.

Each installation has power requirements, termed critical loads, which must remain active or the installation will suffer significant mission degradation, if not mission failure. The duration that the alternative is able to support the critical loads during a primary power outage was deemed to be essential to the decision process. This duration, however, will vary by installation depending on the perceived threat and the anticipated duration of primary power outage. Air Force Instruction 31-301 provides classifications for threat levels (AFI31-301, 5:2002) and could be used as a guide to classify the threat to be considered at an installation where this model is applied. It is required that each of the alternatives generated for the model satisfy the critical loads of the installation. That is, alternatives that do not provide sufficient back-up energy for each of the critical loads on the installation will not be considered in the analysis.

Important Loads assigns value to an alternative based on the alternative's ability to provide power to important loads after satisfying the requirements of the critical loads. An example of an important load might be the installation's dining facility. This would likely not immediately be considered a critical load because military installations have an ample supply of Meals Ready to Eat (MREs) to provide sustenance to the base populace and community during an extended power failure. However, there is a benefit to be able to provide hot meals rather than MREs so the dining facility would be classified as an important load. *Important Loads* measures the percentage of the total important load wattage satisfied by the alternative after meeting the critical loads.

Additionally, there is also a benefit to having additional power available to provide power to loads other than those designated as critical and important loads. These loads are termed other loads and may represent housing areas, recreational facilities, and base services. *Excess Power* was generated to account for this benefit. It measures the percentage of the total non-critical and non-important wattage satisfied by the alternative for the duration the alternative is able to satisfy the critical loads.

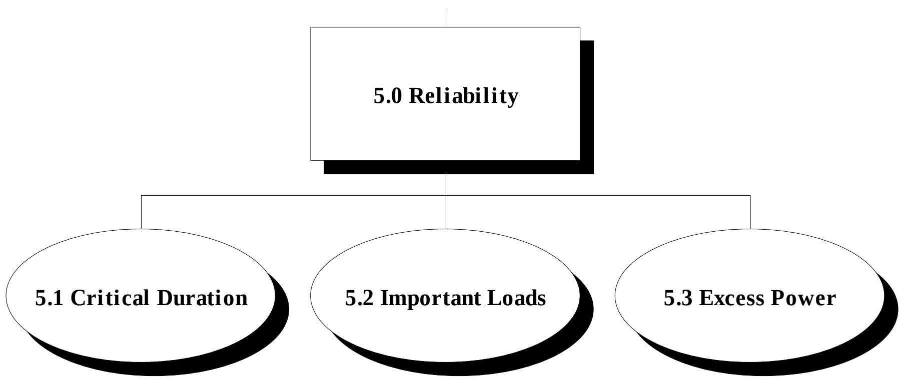

Figure 7 - Reliability

3.2.3 Step 4 – Create Single Dimension Value Functions

The value functions for each measure in the model were created specifically for the case study in Twentynine Palms. Because military installations vary greatly in characteristics such as size, mission, and features, leadership at each installation will need to identify value functions which best represent how they desire these measures to be scored. Additionally, the range of each measure must be relevant to the installation. For instance, the categories developed for the measure *Initial Cost* should reflect the likely range of alternative costs depending upon the size and scope of the proposed back-up energy project. In other words, the *Initial Cost* categories developed for the Twentynine Palms case study would likely not be an effective range for another installation. The entire hierarchy is depicted in vertical format in Figure 8. Appendix A includes the value functions and how they were created.

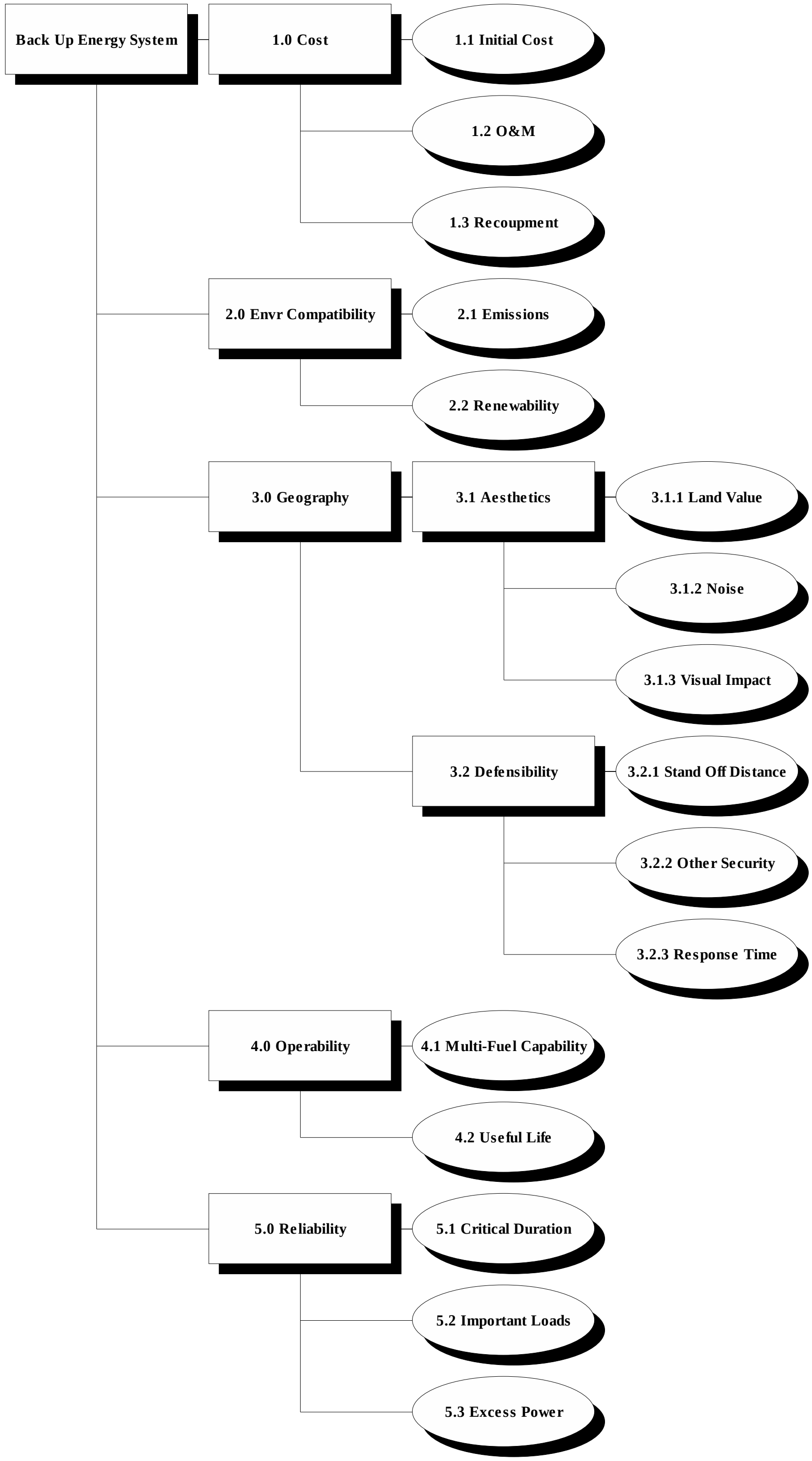

Figure 8 - Value Hierarchy

3.2.4 Step 5 – Weighting the Hierarchy

The hierarchy was weighted using a local weighting approach and was validated by the subject matter experts at Pacific Northwest National Laboratories. The local weighting approach requires that the weights of each measure be assigned in relation to other measures in that value. For example, in *Environmental Compatibility*, *Emissions* is judged to be a little more than twice the importance as the renewability of the fuel source of the alternative. So these two measures were weighted in relation to one another rather than against measures throughout the entire tier. Only after weighting each measure on a tier were the values on the tier above them weighted. Again, this model was weighted with respect to Twentynine Palms. Weights will differ for each installation.

3.2.4.1 Cost

The local weighting for *Cost* and its measures are shown in Figure 9. The initial cost of an alternative was half of the overall weight assigned to *Cost*. Maintenance costs are considered somewhat less important at 30%. Historically, cost recoupment typically does not add significant value to the appeal of a new construction project and is therefore the lowest weighted (at 20%) measure.

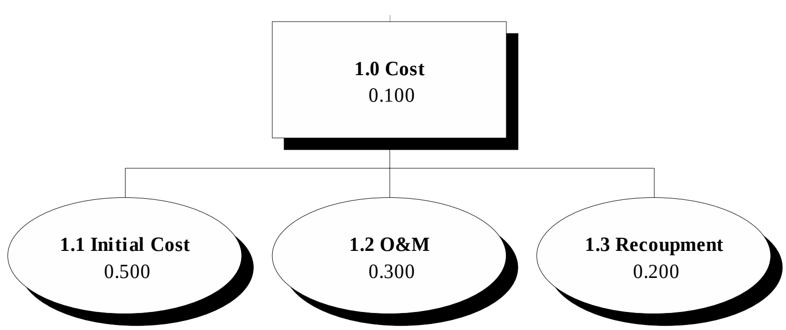

Figure 9 - Cost Weighting

3.2.4.2 Environmental Compatibility

Because of the effort on behalf of the government to reduce emissions on military installations, the *Emissions* measure was weighted more heavily than was *Renewability*, 70% and 30%, respectively. Additionally, emissions are a tangible aspect of energy production; they relate directly to pollution and costs associated with permit costs and fines. People are offended by the odor and the sight of emissions and therefore *Emissions* is weighted more than twice the importance of the *Renewability*. Figure 10 shows the local weighting of the *Environmental Compatibility* value.

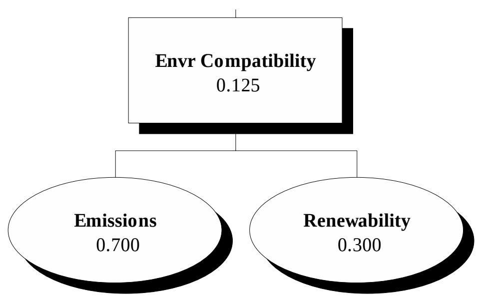

Figure 10 - Environmental Compatibility Weighting

3.2.4.3 Geography

In the *Aesthetics* value, *Land Value* is the most important of the three measures and was assigned 40% of the local weighting. This is because the possibility that land currently used for recreational activities or as a buffer around residential or community centers of the installation may have to be sacrificed to make way for the alternative's assets. This action would have a negative effect on the base populace. The appearance of the alternative is considered to be nearly as important as *Land Value*. Thirty-five percent of the weighting in *Aesthetics* was assigned to *Visual Impact*. Unsightly power producing equipment may present an unpleasant visual impact to the installation populace. Finally, while *Noise* could be a critical factor on a smaller installation, land is plentiful at Twentynine Palms and the assets of an alternative can be spaced such that noise is not a major factor in the decision. Noise, therefore, received only 25% of the total weight assigned to *Aesthetics*.

Because the stand off distance of an asset is widely considered the most beneficial force protection attribute of a military asset, this measure was weighted at 60% of the *Defensibility* weighting. *Other Security* was second most important (35%) because those security measures are targeted at preventing sabotage rather than reacting to the effects of an attack. *Response Time* was assigned the least weight (10%) because this is a measure of a reactionary posture. In other words, *Response Time* is a measure of the reaction time after a breach has already been committed which is not nearly as beneficial as effective preventive measures such as *Stand Off Distance* and *Other Security*.

Defensibility is by far the more important of the two values beneath *Geography*, and was assigned 80% of the weight attributed to *Geography*. Without the ability to defend the power producing asset, it may be compromised and therefore not able to provide any back-up power. Also, because of the vast amount of land on Twentynine Palms, the energy assets could likely be located such that they will not detract from the aesthetic appeal of the installation. Figure 11 shows the local weighting of *Geography*.

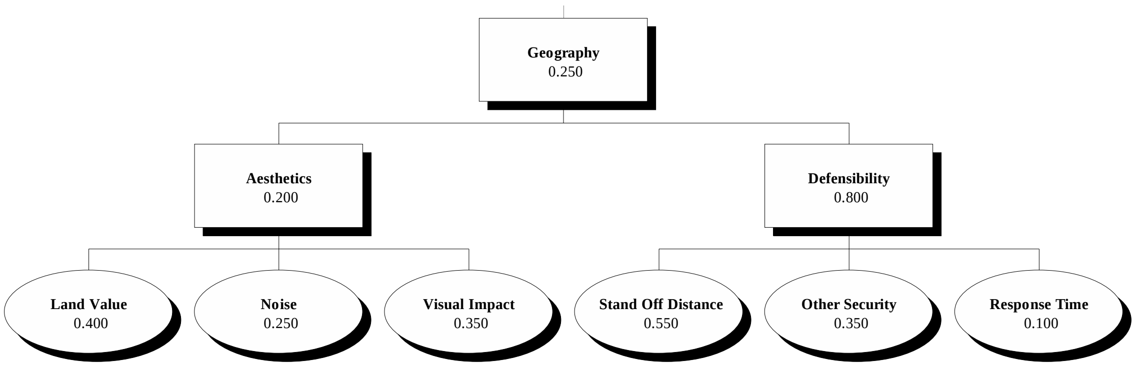

Figure 11 - Geography Weighting

3.2.4.4 Operability

The ability of the alternative to use multiple fuel sources is a benefit. The local weight assigned to *Multi-fuel Capability* was 75% of the *Operability* weight. *Useful Life* is a measure of when the next decision would be required. For these reasons, the weight assigned to *Multi-fuel Capability* was three times that of *Useful Life*. Figure 12 shows the local weighting of *Operability*.

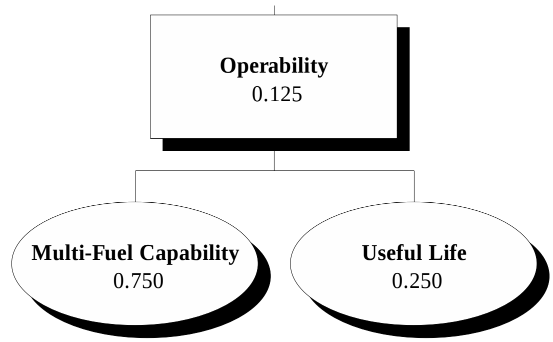

Figure 12 - Operability Weighting

3.2.4.5 Reliability

A failure to provide power to the critical loads is a failure of the back-up energy system and could well result in a failure of the mission. For this reason, *Critical Duration* has a significantly higher weight associated with it than do *Important Loads* and *Excess Power*. *Critical Duration* was assigned 40% of the local weight. Also, it is more beneficial to provide power to the important loads than to other loads, so *Important Loads* receives significantly more weight than does *Excess Power*, 30% and 10%, respectively. The local weighting for *Reliability* is shown in Figure 13.

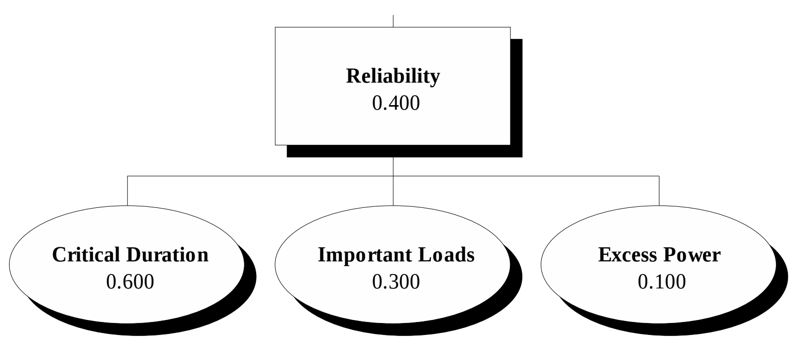

Figure 13 - Reliability Weighting

3.2.4.6 Top-tier Values

Figure 14 displays the weighting of the top-tier values. *Reliability* is the highest weighted value among the top-tier values, receiving 40% of the total weight of the model. The ability of the alternative to provide back-up power to the critical loads should be primary purpose of the system. There is also significant benefit to be gained from the alternative's ability to power the other load categories. These measures quantify the effectiveness of the alternative in powering electrical loads and the duration it is able to do so. This is the primary purpose of having a back-up power system and the single best method of evaluating its performance.

Geography is the second highest weighted value, making up 25% of the decision. The ability of an installation to defend its emergency power assets ensures the effectiveness of the system. Most installations will consider sabotage or terrorism as one of the likely scenarios which causes the loss of electrical power. Without an effective means of preventing sabotage to the assets, the alternative cannot be relied upon to provide power as required. In effect, sabotage could render the alternative useless in its primary function.

Environmental Compatibility and *Operability* are both considered to represent 12.5% of the decision making criteria. In this age of environmental awareness, there is increasing pressure applied on military installations to reduce pollution and the use of nonrenewable resources. In regard to *Operability*, the ability to use multiple fuels increases the effectiveness of an alternative if one of the fuel sources becomes unavailable. The importance of both of these measures was considered to be of equal weight in the decision.

Cost receives only 10% of the weighting. On multi-million dollar projects, costs are typically not the driving factor in approval or disapproval. The merits and value associated with a project (as captured by the other values) are usually the primary reasons for a project to receive approval or rejection. However, the government has an obligation to the American people to execute wisely appropriated funds.

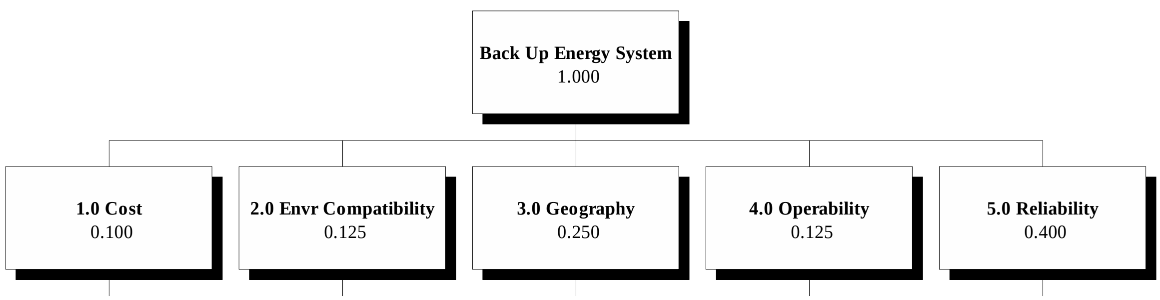

Figure 14 - Top-tier Weighting

3.2.4.7 Global Weighting

Viewing the weights of the measures from a global perspective enables a comparison of the weights of the measures within different values. Table 1 presents a summary of each measure's global weighting and a cumulative total. Interestingly, nearly one half of the decision is based on three measures, two of which belong to *Reliability* and one to *Defensibility*. This kind of insight into the decision process is beneficial when constructing alternatives as outlined in the following section.

Table 1 - Global Weights

	Measure	Percentage Weight	Cumulative Weight
5.1	Critical Duration	24.00	24.0
5.2	Important Loads	12.00	36.0
3.2.1	Stand Off Distance	11.00	47.0
4.1	Multi-Fuel Capability	9.38	56.4
2.1	Emissions	8.75	65.1
3.2.2	Other Security	7.00	72.1
1.1	Initial Cost	5.00	77.1
5.3	Excess Power	4.00	81.1
2.2	Renewability	3.75	84.9
4.2	Useful Life	3.13	88.0
1.2	O&M	3.00	91.0
1.3	Recoupment	2.00	93.0
3.1.1	Land Value	2.00	95.0
3.2.3	Response Time	2.00	97.0
3.1.3	Visual Impact	1.75	98.8
3.1.2	Noise	1.25	100.0

3.2.5 Step 6 – Generate Alternatives

Most of the alternatives for this case study were developed by Pacific Northwest National Laboratory and are summarized in Table 2 (Lu, et. al., 2003:45-47). However, after scoring these alternatives, insight gained from this scoring process drove the creation of a sixth alternative. The geothermal power of Alternative 4 scored exceptionally well on all values, but the 16MW plant was often generating more power than would be required based on the usage characteristics of Twentynine Palms. The sixth alternative includes a geothermal power plant of lower rating combined with the existing diesel assets. By scaling down the size of the geothermal plant, the cost was decreased proportionately.

Table 2 – List of Alternatives

Alternative Number and Description	
1	20MW diesel generated power
2	16MW wind, 4MW diesel
3	10MW solar, 10MW diesel
4	16MW geothermal, 4MW diesel
5	8MW solar, 8MW wind, 4MW diesel
6	10MW geothermal, 4MW diesel

The alternatives analyzed in this test case were fairly generic in nature. None of the alternatives provided specific information regarding the size, type, or location of equipment in the alternative. For this reason, it was necessary to make certain assumptions to score the alternatives accordingly (see Chapter 4 for scoring). More specific alternatives can be developed only after a significant level of analysis of the installation on which the model is to be applied. Many factors (including the amount of power required, the existing power generation capabilities of the installation, the location of various base functions and the proximity to one another and available land, etc...) would need a significant amount of analysis before equipment-specific alternatives could be generated. This level of research was outside the scope of this thesis.

Chapter 4: Results

This chapter presents results obtained through the application of the model to Twentynine Palms Marine Air Command Combat Center in Twentynine Palms, California. As mentioned in Chapter 3, Steps 7 through 9 are presented in this chapter since the products of these steps are specific to the case study. Step 10 pertains to conclusive information and is presented in Chapter 5.

4.1 Step 7 – Score the Alternatives

Each of the alternatives was scored as shown below in Table 3 through Table 7. The tables are categorized according to the top-tier value headings. Appendix B provides an explanation of the scoring. Appendix A provides the value functions and ranges of scoring for each measure.

Table 3 - Cost Scoring

Alternative Number and Description		Cost		
		Initial Cost	O&M	Recoupment
1	20MW diesel generated power	<$10M	$100,000	30+/Never
2	16MW wind, 4MW diesel	$20M-$30M	$244,256	7-12 Years
3	10MW solar, 10MW diesel	>$50M	$550,000	30+/Never
4	16MW geothermal, 4MW diesel	$30M-$40M	$507,757	3-7 Years
5	8MW solar, 8MW wind, 4MW diesel	>$50M	$532,128	20-30 Years
6	10MW geothermal, 4MW diesel	$10M-$20M	$324,848	3-7 Years

Table 4 - Environmental Compatibility Scoring

Alternative Number and Description		Environmental Compatibility	
		Emissions (Reduction)	Renewability (% of Rating)
1	20MW diesel generated power	0%	0%
2	16MW wind, 4MW diesel	30%	56%
3	10MW solar, 10MW diesel	0%	19%
4	16MW geothermal, 4MW diesel	30%	78%
5	8MW solar, 8MW wind, 4MW diesel	24%	52%
6	10MW geothermal, 4MW diesel	30%	69%

Table 5 - Geography Scoring

Alternative Number and Description		Geography					
		Land Value	Noise	Visual Impact	Stand Off Distance (ft)	Other Security (# Items)	Response Time
1	20MW diesel generated power	Industrial	No Effect	Objectionable	500	3	3-5
2	16MW wind, 4MW diesel	Open Space	No Effect	Objectionable	0	2	6-10
3	10MW solar, 10MW diesel	Open Space	No Effect	Objectionable	0	2	6-10
4	16MW geothermal, 4MW diesel	Industrial	No Effect	Neutral	1500	3	3-5
5	8MW solar, 8MW wind, 4MW diesel	Open Space	No Effect	Objectionable	0	2	6-10
6	10MW geothermal, 4MW diesel	Industrial	No Effect	Neutral	1500	3	3-5

Table 6 - Operability Scoring

Alternative Number and Description		Operability	
		Multi-Fuel Capability	Useful Life (Years)
1	20MW diesel generated power	0	15
2	16MW wind, 4MW diesel	0	15
3	10MW solar, 10MW diesel	0	15
4	16MW geothermal, 4MW diesel	0	15
5	8MW solar, 8MW wind, 4MW diesel	0	15
6	10MW geothermal, 4MW diesel	0	15

Table 7 - Reliability Scoring

Alternative Number and Description		Reliability		
		Critical Duration	Important Loads	Excess Power
1	20MW diesel generated power	14 days	0%	0%
2	16MW wind, 4MW diesel	30 days	100%	19%
3	10MW solar, 10MW diesel	30 days	15%	0%
4	16MW geothermal, 4MW diesel	30 days	100%	100%
5	8MW solar, 8MW wind, 4MW diesel	30 days	32%	0%
6	10MW geothermal, 4MW diesel	30 days	100%	38%

4.2 Step 8 – Deterministic Analysis

After each alternative was scored against each measure, these values were summed to obtain a total value for each alternative. The formula below represents this summing of the products. The alternatives can then be ranked according to their total value.

$$Score_i = \sum_{j=1}^{n} a_{ij} w_j$$

a = score for alternative i against measure j

w = weight of measure j

The results of the analysis ranked the alternatives in the order shown in Figure 15. This bar chart shows the total value achieved by each of the alternatives as well as the value received in each of the top-tier value categories. The colors in the bar graph represent the values of the alternatives respective of the top-tier values.

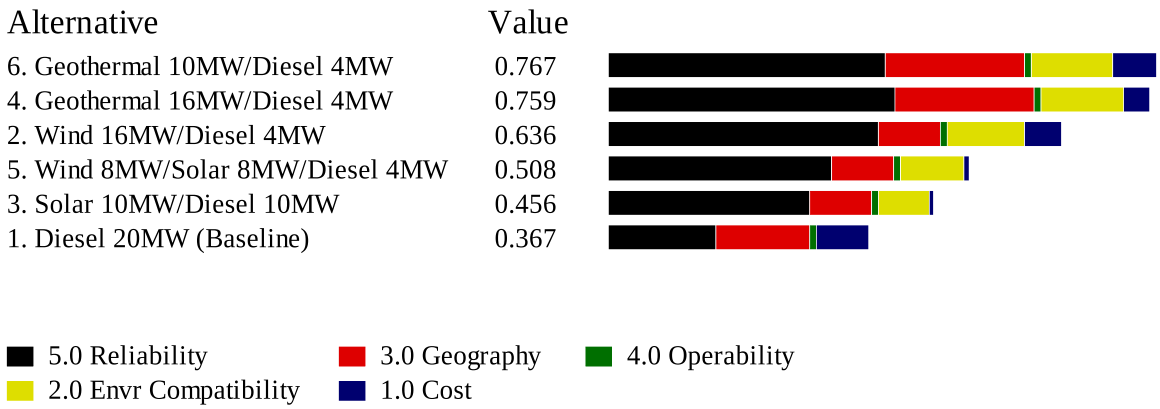

Figure 15 - Alternative Ranking

The results show that Alternative 6 is the best alternative. However, the margin between Alternative 6 and Alternative 4 is small. The graph shows that Alternatives 2, 4, and 6 score significantly better in *Reliability* than do the other alternatives. However, Alternatives 4 and 6 separate themselves from Alternative 2 as a result of the *Geography* value. Although Alternative 4 scores slightly better than Alternative 6 in *Reliability*, the value added to Alternative 6 as a result of cost savings more than offsets this difference in *Reliability*.

The following bar charts illustrate how each alternative scored against each value and in relation to one another. Graphs for both of the values under *Geography* are also included. In the *Cost* value, Alternative 1 scores highest. This is due primarily to the low initial cost of implementing the alternative. Because of the low initial cost of diesel generators, it is not surprising that most military installations rely exclusively on generators for back-up power needs. Also of note is that the high cost of solar options cause Alternatives 3 and 5 to score poorly in the *Cost* value.

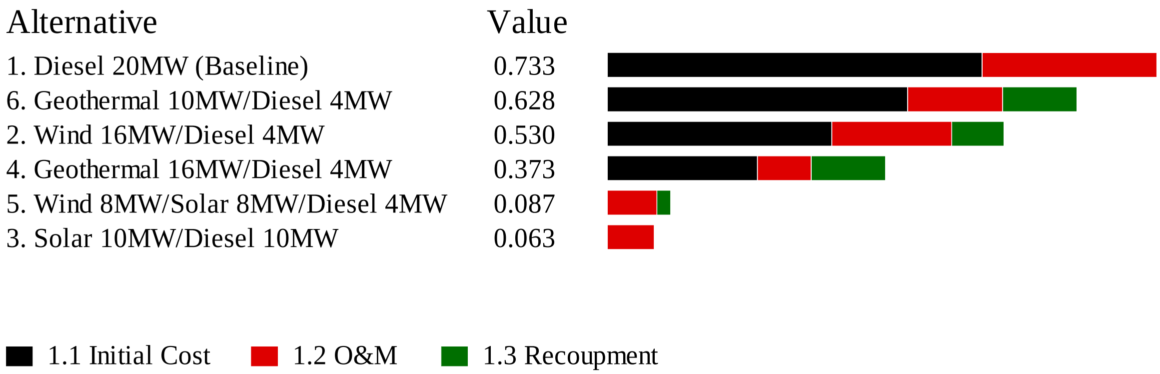

Figure 16 - Ranking for Cost

As expected, Alternative 1 scored far below the others in *Environmental Compatibility* as a result of having no environmental benefit associated with the diesel generators. All of the other alternatives created a reduction in the amount of fossil fuel generated power purchased from the local utility. This resulted in a significant difference in value of the diesel alternative versus the alternatives including environmentally friendly assets.

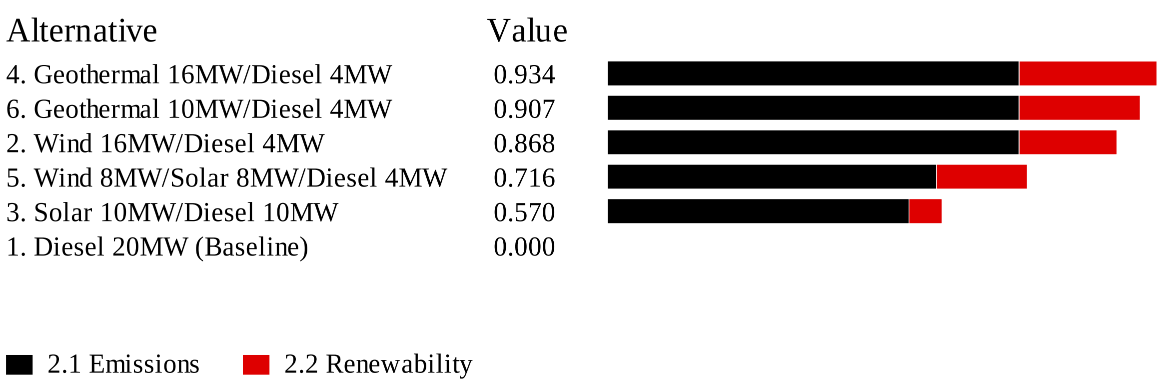

Figure 17 - Ranking for Environmental Compatibility

The geothermal alternatives fared well in *Geography* primarily due to the fact that these power plants require much less acreage and were assumed to be accommodated in the industrial sector of the installation. This provided them with a higher degree of defensibility due to the stand off distance this location afforded them. Alternative 1 also fared well in this value because the decentralized location of the assets afforded the alternative a high degree of defensibility. In *Aesthetics*, again the location of the geothermal plants resulted in a higher score for Alternatives 4 and 6. The ability to locate these plants in the industrial sector of the base enabled them to score relatively high in *Visual Impact* and *Land Value*. The three figures below illustrate the scores for the alternatives in *Geography* and its two values, *Defensibility* and *Aesthetics*.

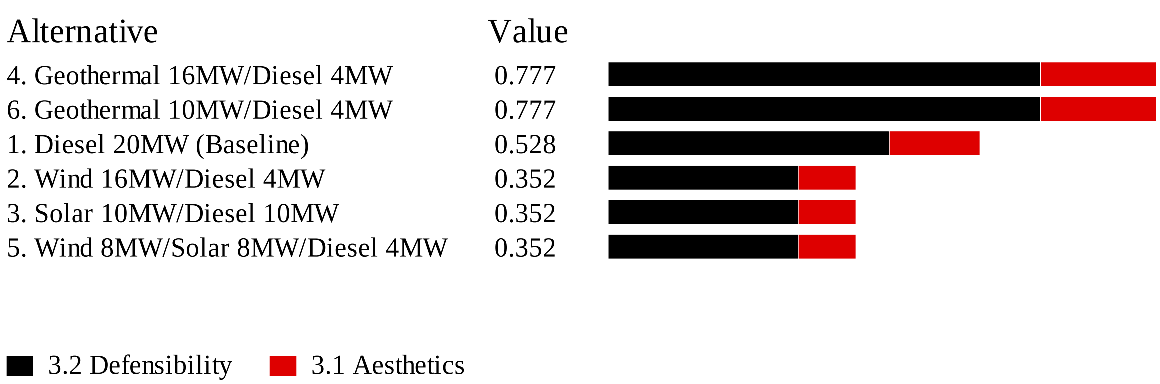

Figure 18 - Ranking for Geography

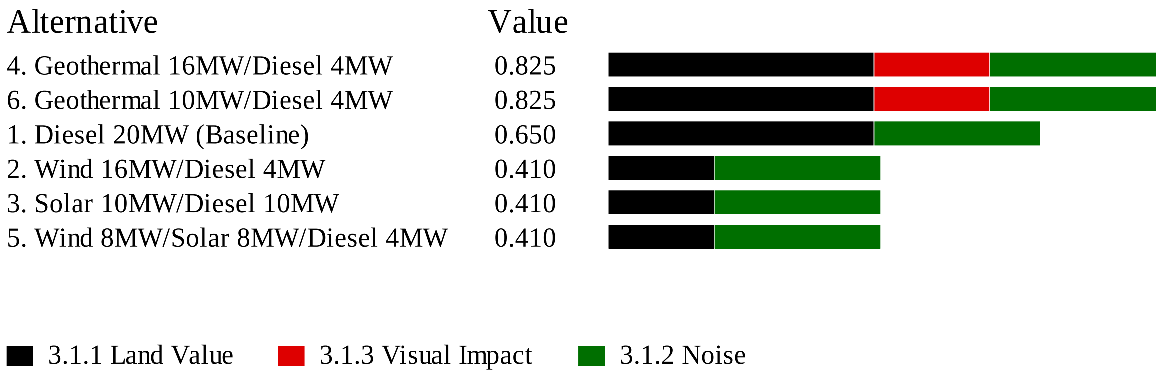

Figure 19 - Ranking for Aesthetics

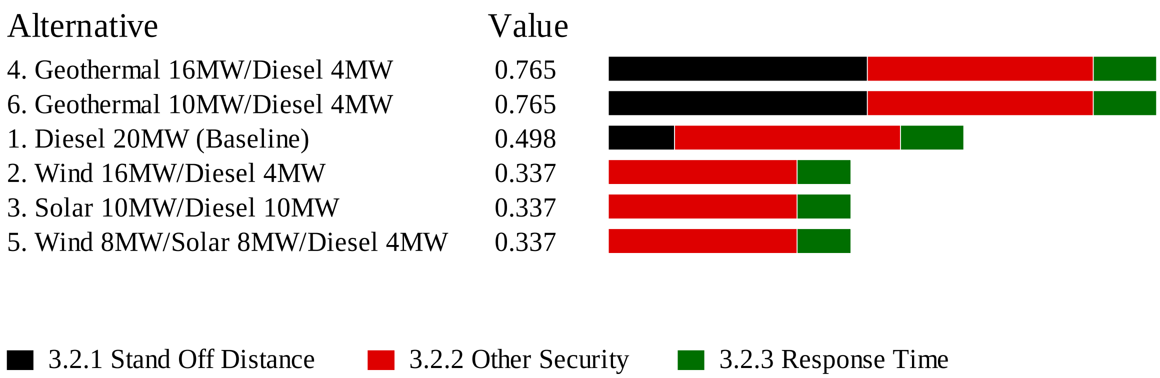

Figure 20 - Ranking for Defensibility

There was no stratification in *Operability* because each alternative scored identically in the two measures. None of the alternatives was determined to utilize multiple fuel types. All of the alternatives included the existing diesel generators. Because these generators are of varying ages, it was assumed that the shortest lived among them would be the shortest lived piece of equipment in each of the alternatives. If this model were applied to another installation, it would be unlikely that all alternatives would score identically in these measures.

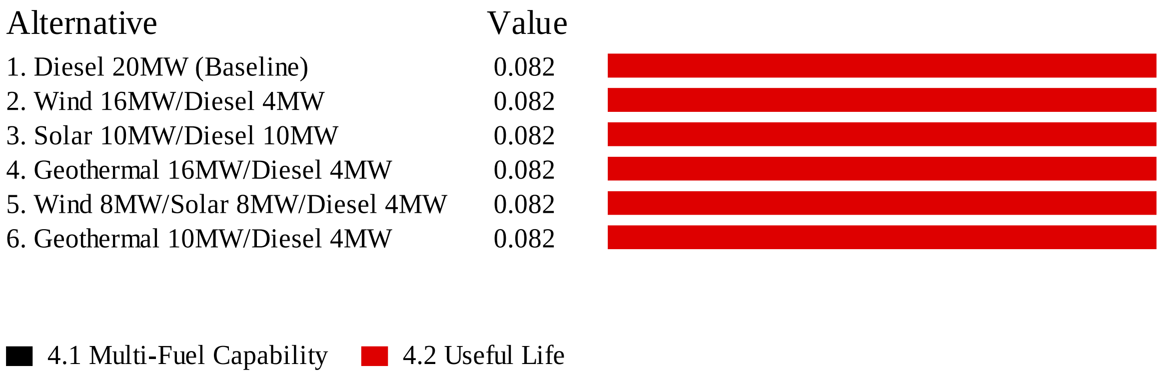

Figure 21 - Ranking for Operability

In *Reliability*, Alternatives 2, 4, and 6 scored exceptionally well. It is of note that Alternative 6, which has a much lower power rating than any other alternative, still scores very well. In fact, all of the alternatives except Alternative 1 score well in this measure. Alternative 1 is the only alternative which is unable to meet the power needs of the critical loads for the 30 day power outage scenario. All of the others were able to meet this 30 day goal and power some of the important loads as well. Three of them, Alternatives 2, 4, and 6, were able to meet all of the important loads and power some of the other loads as well.

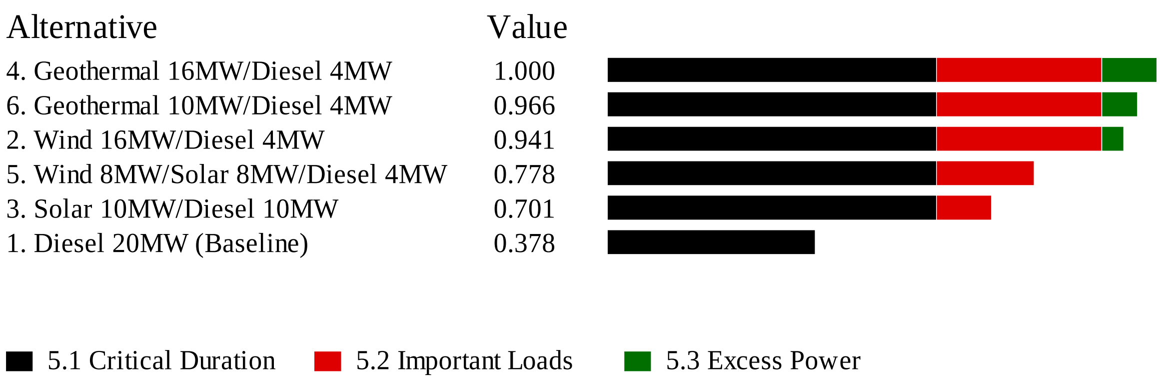

Figure 22 - Ranking for Reliability

4.3 Step 9 – Sensitivity Analysis

The sensitivity analysis consisted of examining the effect that changing the weight of each of the top-tier values has on the overall ranking of the alternatives. By increasing, in turn, each of the weights of these top-tier values, the weights of each of the other values is proportionately decreased. Effectively, this allows the modeler to examine how the alternative ranking changes as one of these weights varies from 0% to 100%.

Cost

The sensitivity graph for *Cost* is shown in Figure 23. The vertical line at 10% corresponds to the weighting used for *Cost* in the deterministic analysis phase. As evidenced from this graph, if the weight of *Cost* were reduced, Alternative 4 becomes the highest ranking alternative. This is as expected since Alternative 4 performs slightly better in *Reliability* and *Environmental Compatibility* due to the larger size of the geothermal plant, but does so at an increased cost. As the weight of *Cost* increases, Alternative 4 worsens in relation to other alternatives. If *Cost* were the sole measure of this analysis, Alternative 1 is the optimum choice because of the low cost to implement.

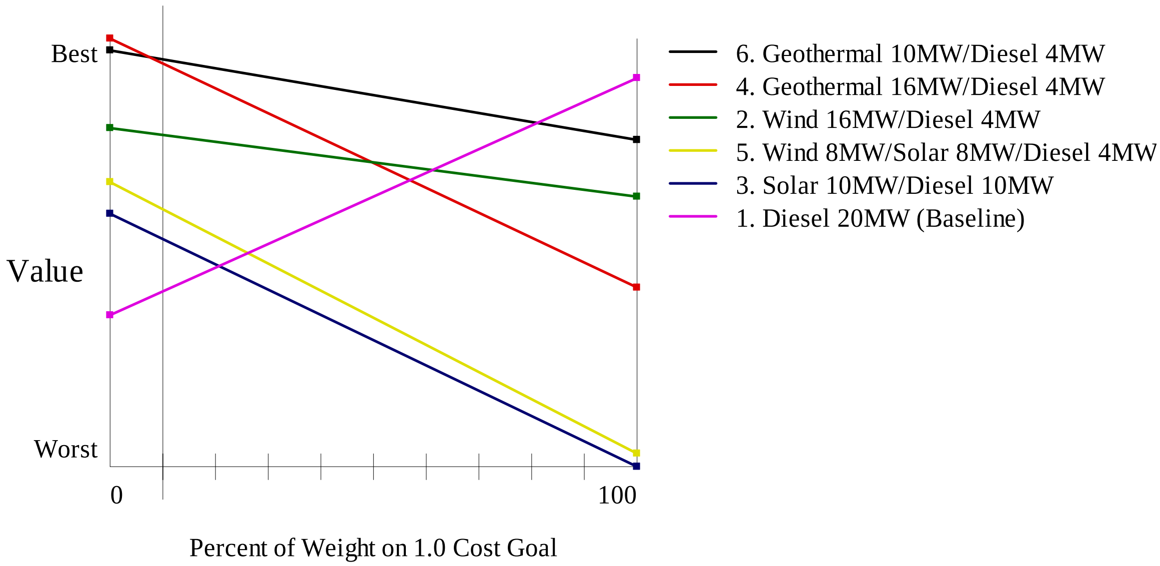

Figure 23 - Cost Sensitivity

Environmental Compatibility

Figure 24 shows the sensitivity graph for *Environmental Compatibility*. This graph shows that little changes in the way of ranking when the weight of *Environmental Compatibility* changes. The only change in ranking occurs when Alternative 4 and 6 swap ranking as a result of the weight of *Environmental Compatibility* increasing to approximately 30% of the decision. Also as a result of increased weighting of this value, the attractiveness of alternative 1 and 3 declines significantly because they rely heavily on fossil fuel generated electricity.

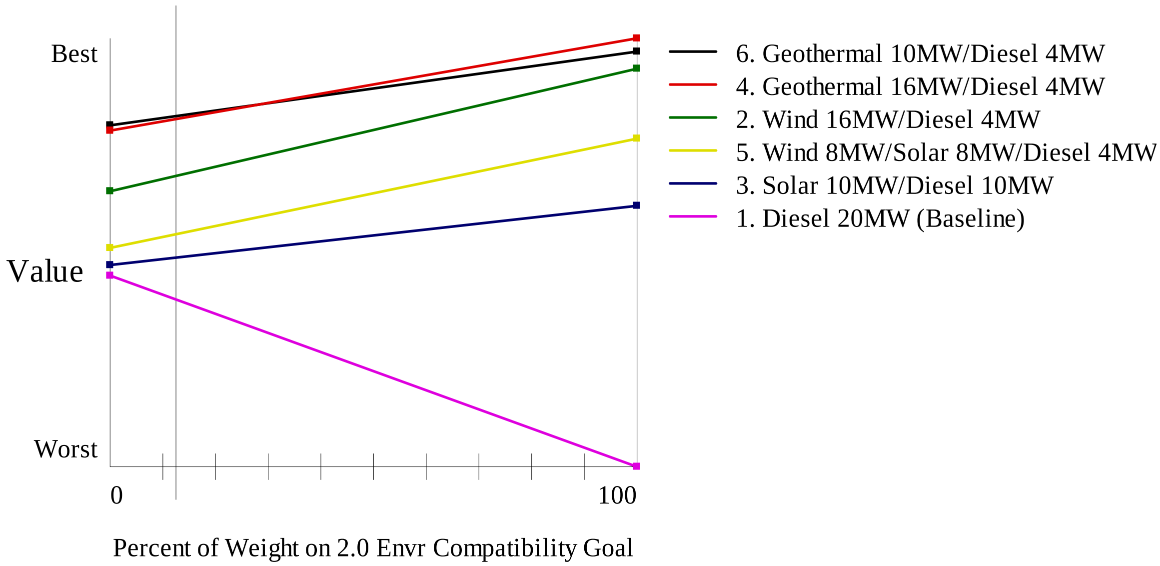

Figure 24 - Environmental Compatibility Sensitivity

Geography

The sensitivity graph for *Geography* is shown in Figure 25. Regardless of the weighting of *Geography*, Alternatives 4 and 6 are very attractive options. At low weighting, Alternative 2 is also attractive. However, due to Alternative 2’s poor scoring in some of the measures in *Geography*, it loses attractiveness as the weighting is increased. Alternative 1 becomes more attractive as weighting is increased due primarily to its high scores on *Defensibility* measures.

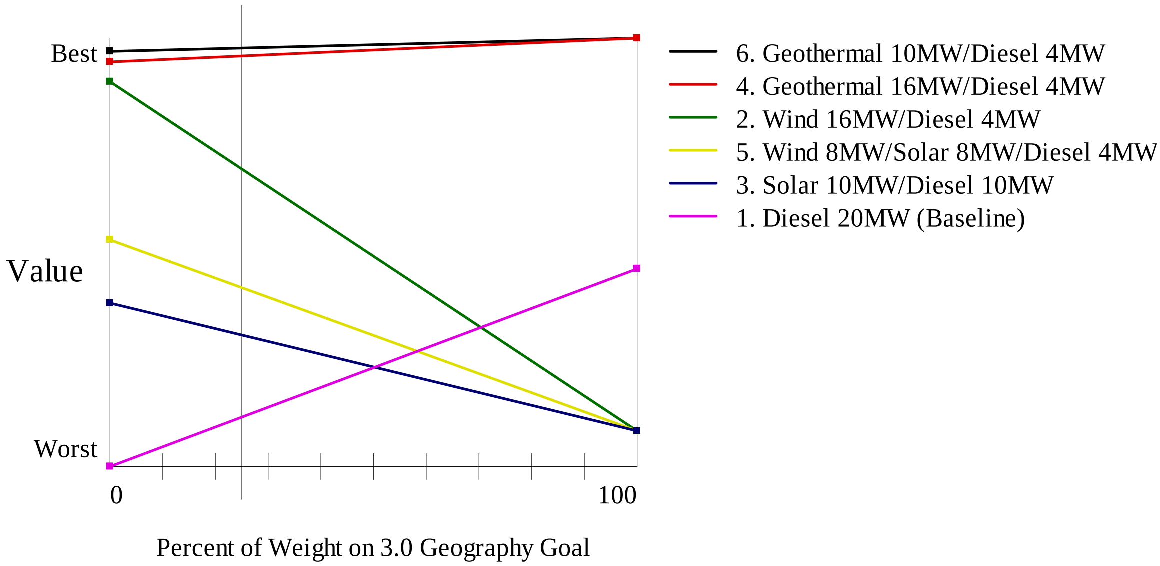

Figure 25 - Geography Sensitivity

Operability

All Alternatives received identical scores on *Operability*. Therefore, changing the weighting did not change the ranking order of any alternatives. Again, application of this model at another installation would likely produce differing scores among the alternatives in these measures.

Reliability

Figure 26 shows the sensitivity graph for *Reliability*. Here one can see that Alternative 6 becomes the favored alternative when the weighting of *Reliability* is increased to approximately 50% of the decision. This is due to the larger electrical output of the geothermal plant in Alternative 6 versus that in Alternative 4. While Alternative 1 is near the middle of the ranking when

Reliability is at a low weight, it becomes less of an attractive alternative when the weight is increased.

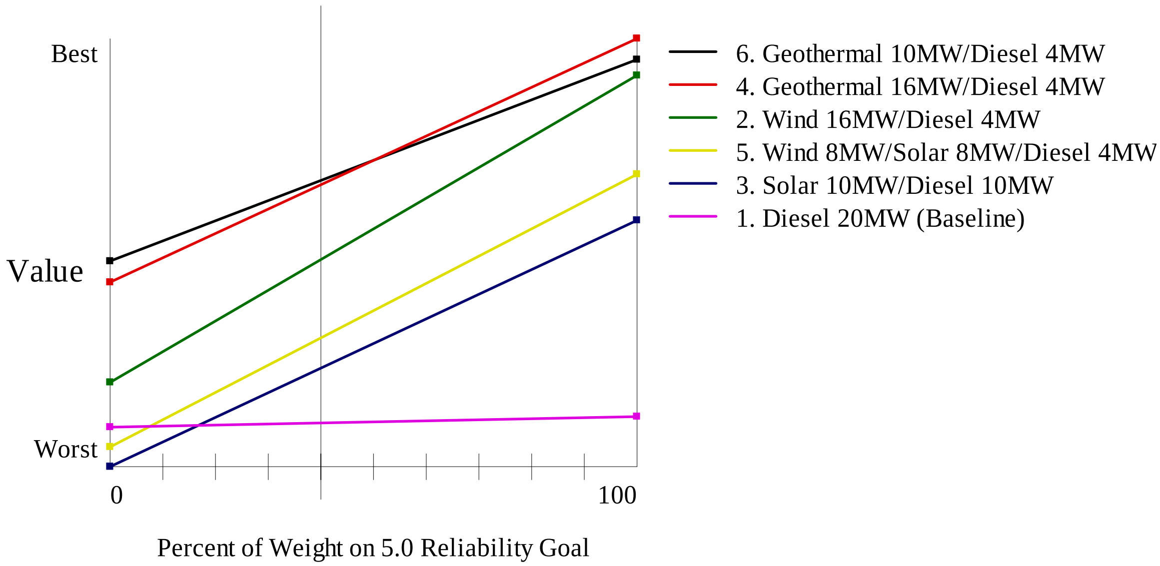

Figure 26 - Reliability Sensitivity

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Chapter 5: Summary and Conclusions

Step 10 of the VFT process directs the modeler to make recommendations and conclusions. This chapter includes the description of this step. This chapter also discusses limitations of this model and recommendations for future research efforts.

5.1 Step 10 – Make Recommendations & Conclusions

Alternative 6 is the recommended alternative in this case study, although Alternative 4 is a close second in nearly every respect. Alternative 4 provides more power due to the larger geothermal plant; however, the power usage characteristics at Twentynine Palms indicate that this additional power would rarely be used. The capacity factor of geothermal power is 0.87, indicating that one might expect to receive nearly 14MW of power at any given time from this 16MW geothermal plant. The assumptions made during the scoring phase dictated that only during summer days does Twentynine Palms experience an electrical demand greater than approximately 10MW. Therefore, a significant portion of the power available from the 16MW geothermal plant of Alternative 4 is rarely used. According to the usage assumptions, the 10MW geothermal plant of Alternative 6 is nearly always capable of providing all of the power demanded by the installation with respect to the load usage characteristics shown in Table 16 on page 86. Therefore, the difference in value assigned to both of these alternatives by *Reliability* is small.

Alternative 6 is less expensive than Alternative 4 with respect to implementation, operation, and maintenance. These cost differences result in a higher value being assigned to Alternative 6 by *Cost*. The difference in value assigned to each alternative from *Cost* exceeds that difference of *Reliability* as discussed above. Therefore, Alternative 6 receives more overall value than Alternative 4 and is the recommended alternative.

The two geothermal alternatives have appeared to be significantly better than the other alternatives. The capacity factor of geothermal power (0.87) is significantly higher than that of any of the other environmentally-friendly alternatives. This results in a much higher score for Alternatives 4 and 6 in *Reliability*. In all other values, the wind turbines of Alternative 3 are very competitive with the geothermal alternatives.

Solar power is very expensive and does not fare well in Cost. In addition, its power generating characteristics do not allow it to score well in other values as well. As mentioned previously, the solar options included in this study did not consider batteries as part of the alternative. Using batteries might well improve the performance of the photovoltaics, but will do so at a significantly higher operations and maintenance cost

5.2 Limitations of Model

As mentioned in Chapter 1, decision analysis models are designed to provide insight to the decision maker. One should not rely on the recommendation of a model as the sole reason for making decisions. This model provides valuable insight to the decision maker and is useful in assisting in the decision making process. However, this study has limitations.

With regard to the case study included in this thesis, many assumptions were made due to the inability to perform a detailed study of the existing conditions at

Twentynine Palms. As with any mathematical model, the better the information input into the model, the better the information received from it. The data input into the model was based partially on assumptions, but could be improved to yield even better results. In order to obtain more accurate results, one might strive to improve the accuracy of the data input into the model. Specifically, one could develop more realistic power usage characteristics of the installation rather than simply averaging the day/night electricity usage.

Additional limitations to this study include the omission of biomass, hybrid, and fuel cell generators. These are emerging technologies in the electricity production field and might well prove to be the energy source of choice in the near future. Batteries to accompany the photovoltaic power generators were not considered in this model. If batteries were included in the photovoltaic alternative, much of the power generated during daylight hours would be routed to the batteries rather than to the installation power grid. However, one might find it interesting to see how the attractiveness of the alternative might have been affected if it had the ability to provide some level of power during evening hours. Additionally, the benefit to be gained from increasing the installation's fuel storage was not considered. An increase in diesel fuel supply would have benefited several of the alternatives in regard to the *Reliability* measures. Each of these measures was based heavily on how long the installation could support critical, important, and other loads during a power failure. By increasing the diesel fuel supply, one could increase the independence on an outside power source.

Finally, the case study did not reflect the minimum electrical usage requirement as set forth by the local utility company. Twentynine Palms' electrical provider requires the installation use a minimum level of electricity in order to justify the expense associated with the utility company maintaining the ability to meet the peak power demand. In other words, the utility company has expensed a significant amount of money in capacity and infrastructure in order to provide Twentynine Palms with their peak power demand. If Twentynine Palms discontinues using this power, the utility company might not be able to recover this investment. Therefore, Twentynine Palms is currently required to maintain this minimum usage.

5.3 Recommendations for Future Work

This model focuses on back-up energy systems, which is one aspect of the security on military installations. A more comprehensive analysis of all security features through the use of a VFT model would further assist installations in preventing and preparing for adversity caused by natural disasters or terrorism. The hierarchy developed within this thesis could be an integral part of the model developed for an analysis of the security of the entire installation.

Cost savings associated with the ability of the alternatives to produce power at a lower cost than can be purchased were included in the study; however, the alternatives were intended primarily for back-up energy. Some installations have considered the feasibility of constructing large scale renewable power generating facilities. The installation would consume the power demanded and then sell the remainder onto the public utility grid. Selling electricity to public consumers was not considered within this thesis. However, a new study which focuses on these large power producing investments might be beneficial to those installations considering the construction of such facilities.

Appendix A: Measures

Initial Cost

Initial Cost captures the cost of implementing the alternative. All military construction (MILCON) projects are approved at the Congressional level. Congress relies on the Department of Defense to evaluate the merits of a MILCON project and to determine the value received. Since all alternatives will likely be MILCON projects, *Initial Cost* is not weighted as heavily as one might expect.

Additionally, it may be possible to fund all or a portion of a back-up energy project through an Energy Savings Performance Contract (ESPC). These contracts allow contractors to evaluate the installations energy needs. Under an ESPC, the contractor can implement changes to the electrical infrastructure which reduce the amount of electricity required on the installation. Payment to the contractor is made out of utility cost savings, so there is no initial cost to the government.

For each installation, the categories (or labels) associated with this measure will need to be modified to reflect the range of anticipated costs of alternatives. The values derived from those labels may also be modified in order to better reflect the decision maker’s opinion of the importance of the cost. Figure 27 shows the labels and respective values for the case study. This range of costs is representative of the costs of alternatives anticipated for the scope of the project at Twentynine Palms. As the cost of an alternative increases, less value is awarded that alternative for this measure.

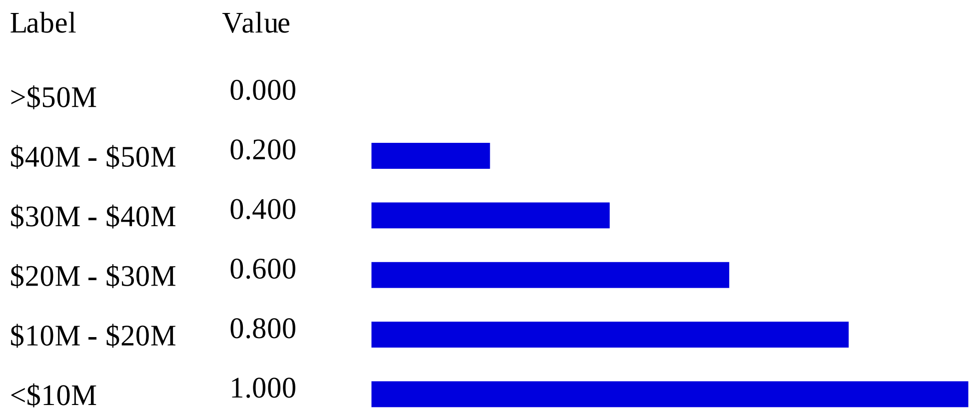


Figure 27 – Initial Cost Single Dimension Value Function

Operations and Maintenance Costs

This measure captures the value associated with operations and maintenance cost if an alternative is implemented. The range of dollar values associated with this measure will need to be modified based on the anticipated range of expected costs of the alternatives. Also, the value function for determining the value of alternatives based on their O&M costs must be based on the impact additional costs would have on the installation.

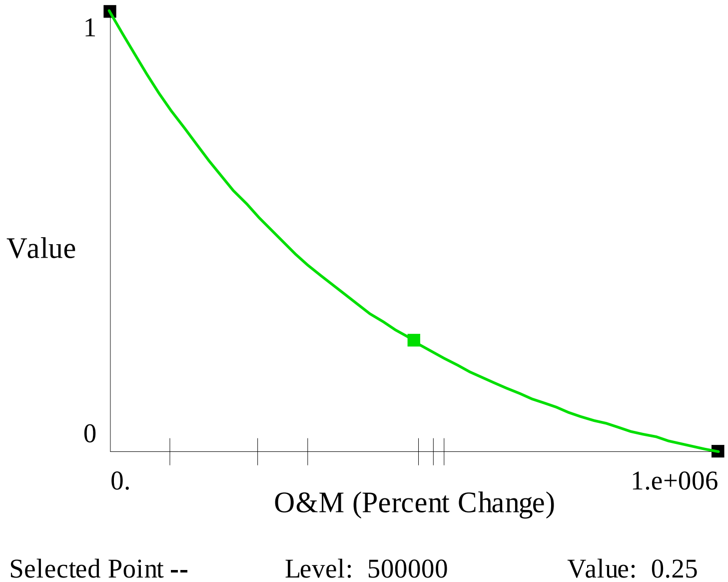


Figure 28 – O&M Value Function

Recoupment

Recoupment assigns value to those alternatives which provide cost payback. The potential for cost payback is derived from the installation's intent to operate the alternative's assets not only during power failures, but on a daily or seasonal basis. Those alternatives which include equipment designed to provide power continuously and at a lower rate than can be purchased from the commercial utility should eventually provide enough cost avoidance to pay for themselves.

Generally speaking, the government rarely considers the benefit of payback of those projects which have a payback period of greater than three years. However, the ability of an alternative to eventually generate a payback is still of some value to the decision maker. Additionally, a lower payback period makes the alternative much more desirable to implement via an Energy Savings Performance Contract. Therefore, a graduating scale is used to determine the value associated with this payback. A value of zero is scored to any alternative which is not projected to recoup the investment. The value function for *Recoupment* is shown in Figure 29.

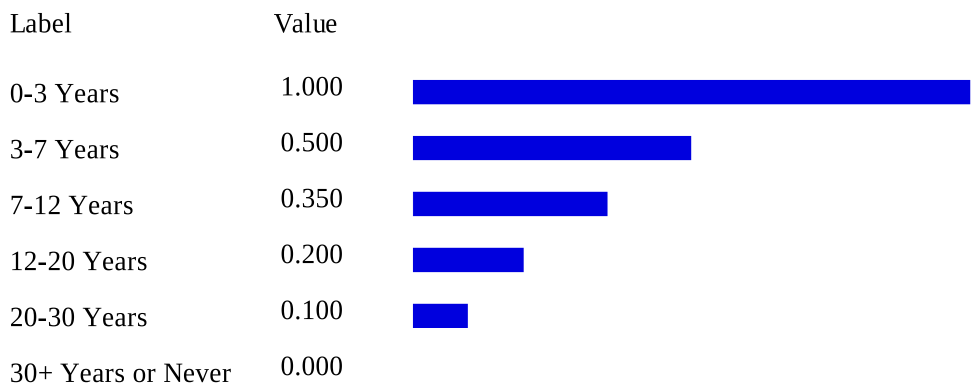


Figure 29 - Recoupment Value Function

Emissions

Section 201 of Executive Order 13123 requires that government agencies reduce their greenhouse gas emissions by 30 percent from their baseline levels of 1990 (Executive Office of the President, 1999:1). Because of this requirement, a project which replaces or improves an installation's back-up energy system is an excellent opportunity to reduce the emissions. This would be achieved primarily through the introduction of environmentally friendly energy sources within their primary energy scheme. These energy sources would be utilized continuously (not just as a back-up energy measure), thereby reducing the installation's air emissions. This measure captures the value of the daily emissions reduction, not merely the emissions reduced during the operation of the alternative's equipment.

While each installation has made some progress towards the reduction of greenhouse gas emissions, each will likely be at differing stages of meeting the requirement. Therefore, each installation will value a level of emissions reduction according to the amount still needed to meet the requirement. There is no value awarded to alternatives which do not reduce the daily emissions level of the installation.

Because the required emissions reduction at Twentynine Palms was not known, a reduction in emissions of 30 percent was deemed the best case scenario and assigned a value of one. The single dimension value function is shown below in Figure 30. Greater value is associated with those alternatives which approach a 30 percent reduction in air emissions as a result of the implementation of the alternative.

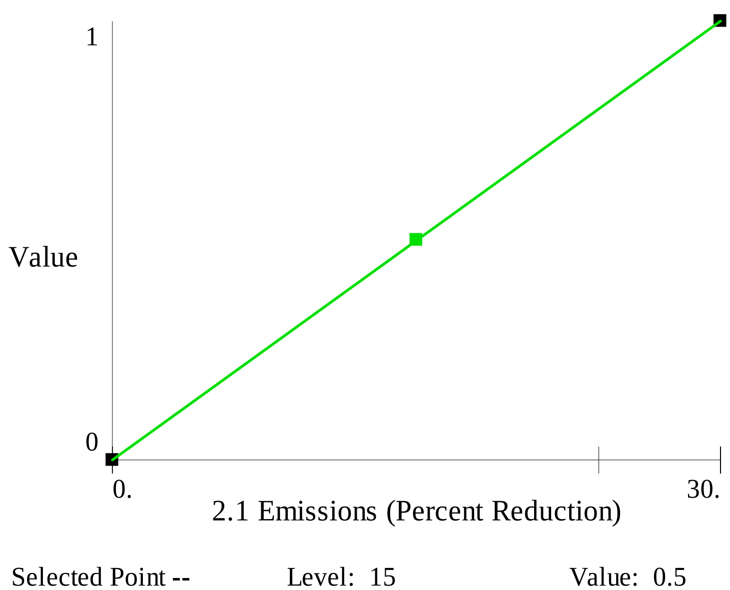


Figure 30 - Emissions Value Function

Renewability

Renewability captures the value received when an alternative utilizes energy which originates from a renewable fuel source. The value awarded to alternatives utilizing renewable fuel source is derived from two primary sources. The first is the fact that the fuel source is unlimited. Second, there is value associated from improved public image and from promoting an environmentally responsible energy program. A back-up energy system which uses completely renewable fuel sources achieves a value of one for this measure. A straight value function was chosen for this measure because value received from using renewable fuels was deemed to be incrementally beneficial. Figure 31 shows the value function for *Renewability* in the Twentynine Palms case study.

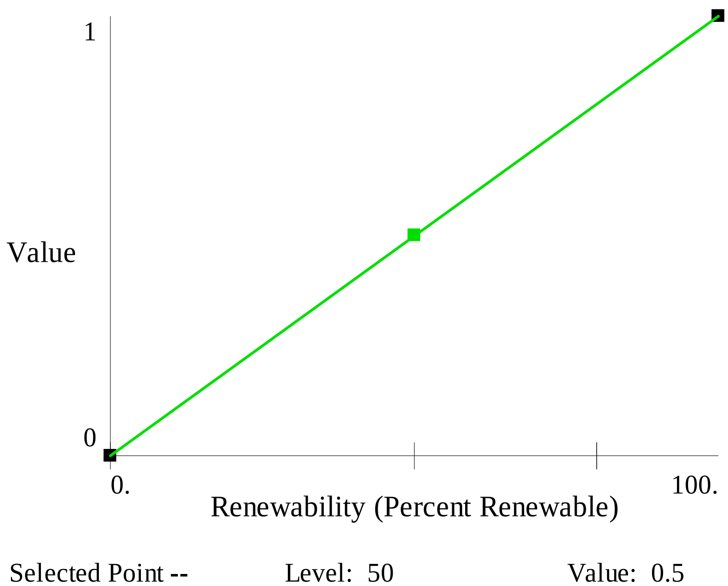


Figure 31 - Renewability Value Function

Land Value

This measure captures the value of the alternative occupying the appropriate land according to the installation's land use plan. In order to facilitate the implementation of an alternative, it may be necessary to locate portions of the alternative in an area of the installation not well suited to an industrial use. This measure captures the value associated with the alternative occupying land suited to power generation. Alternatives are measured according to whether any part of the alternative is required to occupy anything other than land zoned for industrial use. Excluded from the analysis are any generators placed across the installation in order to provide back-up energy to a building in the immediate area. In other words, this measure only considers large scale power sources, not smaller-sized generators designed for a single facility.

There are several categories of land use that receive zero value if an alternative encroaches on that land. It is possible that some of these may be screening criteria. That is, if an alternative is proposed to occupy any of these land uses, it would not be considered as a viable alternative. These include, but may not be limited to, Airfield Operations, Housing/Lodging, Administration, Community, and Medical. For each installation where this model is applied, additional land use categories may need to be created and the values modified in order to reflect the values of that installation's leadership. Figure 32 displays the value function used for Twentynine Palms. It was determined that there was no value associated with an alternative occupying any land other than the three categories in the figure.

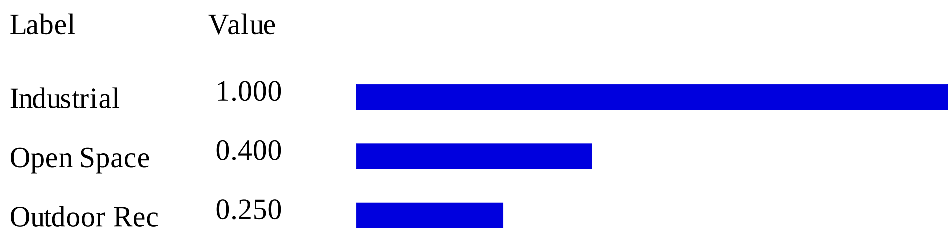


Figure 32 – Land Value Function

Noise

As suggested, this is a measure of the amount of noise generated by the alternative. Military installations with air operations are required to abide by the regulations set forth in the Air Installations Compatible Use Zones (AICUZ) program (AFH32-7084, 1999:3). AICUZ was developed in order to ensure that encroachment around military installations is compatible with the airfield operations conducted on that installation (AFH32-7084, 1999:3). *Noise* is one of several characteristics of an airfield for which the AICUZ program sets standards. Noise generated by a proposed alternative may contribute to the noise generated by activities related to the installation's airfield resulting in a need for an update to the installation's AICUZ plan. AICUZ updates are required if the day-night average noise level increases two or more decibels (AFI32-7063, 2002:5). In the worst case, the noise may be such that it creates an AICUZ violation which cannot be rectified. An alternative resulting in an AICUZ violation will not be considered a viable alternative. An alternative requiring an AICUZ update would be considered a viable alternative, but would receive no value for the *Noise* measure. Those alternatives which require hearing protection of individuals within the immediate area but cause no other significant noise pollution receive a marginal value for *Noise*.

Table 8 below is a reproduction of Table G-16 from the Occupational Safety and Health Administration allowable noise level guidelines. This table indicates that any noise greater than 90 dBs requires hearing protection for individuals exposed to that noise over the course of a typical working day. Decision makers at each installation must determine if their alternatives require hearing protection based on whether or not personnel will be exposed to that noise level and for what duration.

Table 8 - OSHA Hearing Protection Guidelines

Duration per Day (Hours)	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Finally, an alternative which imparts no significant noise problems to the installation receives full value. Even if an alternative creates a high level of noise, but it is isolated and therefore creates no harmful effects, the alternative may still receive full value for this measure. The value function for this measure is shown in Figure 33.

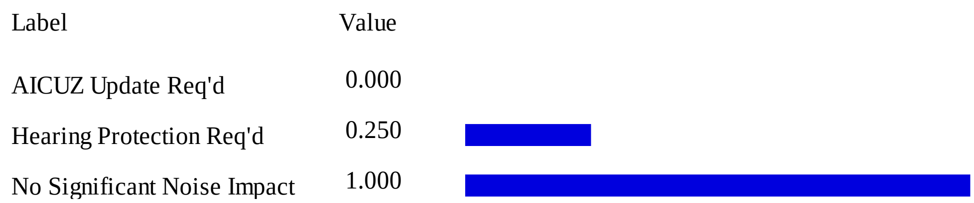


Figure 33 - Noise Value Function

Visual Impact

This is a highly subjective measure of the overall visual appeal of the alternative. Depending on the prominence of the installation, different descriptions of *Visual Impact* may be warranted. For this case study, there are three levels of value associated with this measure. Objectionable alternatives possess equipment or other infrastructure (power poles, lines, etc...) which present an offensive visual impact on the installation. In order to be deemed obtrusive, the alternative requires the equipment to occupy a prominent piece of installation real estate. That is, it must either be located along a main thoroughfare or highly visible from practically any densely occupied portion of the base. Examples of obtrusive alternatives might include those which possess wind generators of significant height which are visible from nearly all of the installation, large scale diesel or natural gas generators (~5MW or greater) which require a prominent location due to the proximity of the facilities they serve, or a large photovoltaic array situated adjacent to a housing area.

An alternative with a neutral visual appeal is one in which the visual impact may be undesirable, but is not considered displeasing. This category might include those alternatives which possess equipment which require extensive amounts of new power lines or other electrical equipment such as transformers. Other neutral alternatives might include equipment such as wind turbine generators which, although visible over a majority of the installation, are not visually offensive.

Unobtrusive alternatives are those which do not possess elements which negatively impact the visual appeal of the area in which they are situated. In other words, these assets are either unseen or do not detract in any way from the appearance of the installation. Examples of unobtrusive alternatives might include those which are primarily located in unoccupied or sparsely populated areas of the installation and are not visible from the populated areas or those with equipment located primarily in industrial areas of the installation.

As mentioned above, this is a subjective measure. The descriptions presented in this thesis relative to each of the categories for this measure may be altered to better reflect a specific installation and its decision maker's values. The value function for *Visual Impact* as applied to Twentynine Palms is provided below in Figure 34.

Figure 34 - Visual Impact value function

Stand Off Distance

The stand off distance of an alternative is the distance between the alternative's assets and the installation perimeter. It may also be the measure from the asset to the closest location in which a potential saboteur could occupy without being challenged by installation security. Stand off distance is widely considered the single best defensive measure available to protect the asset from someone wishing to render it inoperable.

Since installations vary in size and available space, the desirable stand off distance will vary as well. The value associated with *Stand Off Distance* for Twentynine Palms is based on the effective range of most rocket propelled grenades (RPGs). This assumes that RPGs would be a likely form of attack on a power source. Research showed that a typical effective range for an RPG is about 500 meters. Allowing for variance, the maximum value for this measure is approximately 609 meters, or 2000 feet. The value function for *Stand Off Distance* is shown in Figure 35.

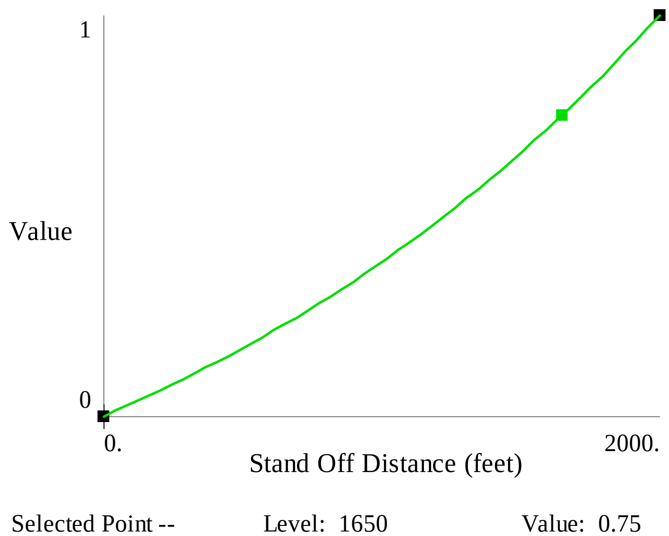


Figure 35 - Stand Off Distance Value Function

Other Security

The value related to other security features utilized in the protection of the alternative's assets is captured by this measure. Security features available to the military include such defenses as cameras, Doppler radar systems, motion detectors and fencing. This is by no means a comprehensive list as new technologies are always in development and being implemented. With each new technology applied in the field, the value associated with these features will change. However, there will always be additional value associated with those technologies which help to prevent attacks rather than detect them after the fact. For Twentynine Palms, each security measure employed was deemed to be of increasing value. This measure assigns value to the alternatives based on the number of these additional security devices utilized to protect the alternative's assets. Each of these security features provides additional value to the alternative. The value function is shown in Figure 36.

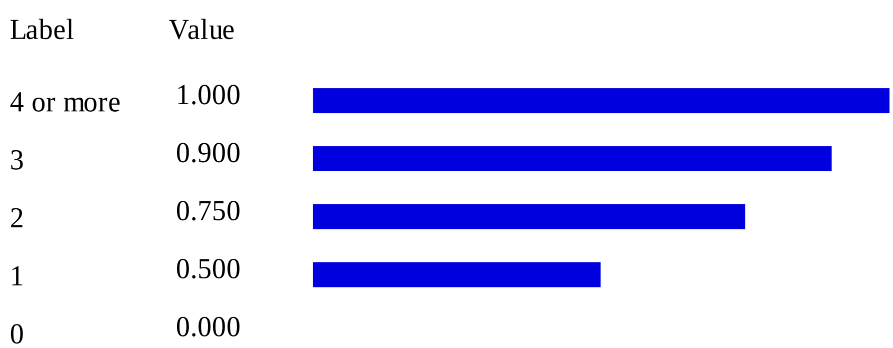


Figure 36 - Other Security Features Value Function

Response Time

This measure captures the value associated with a quick response following a notification of a breach of security. A quick response is necessary in order to prevent an attack or to assist casualties in the event of an attack. In either case, *Response Time* is a measure of how quickly emergency personnel are able to arrive at the scene of a (potential) catastrophic incident. The alternative should be scored against this measure in a worst case scenario. That is, the slowest response time to one of the elements of the alternative is used to score the entire alternative. This does not include small generators which provide power to a single non-critical load. The *Response Time* value function is depicted in Figure 37 below.

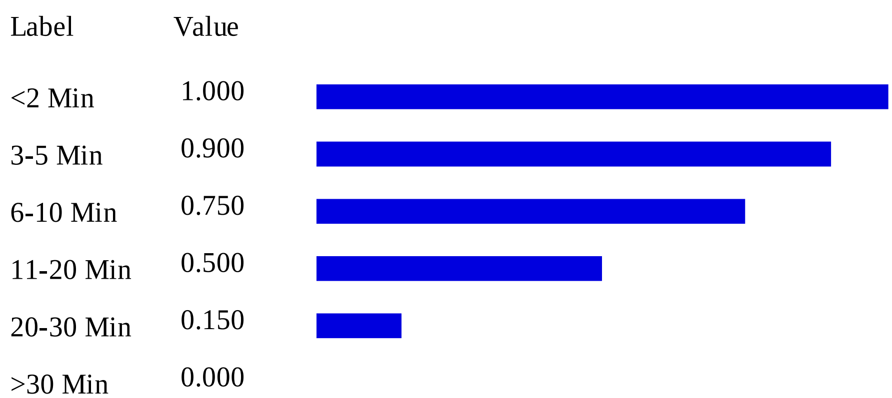
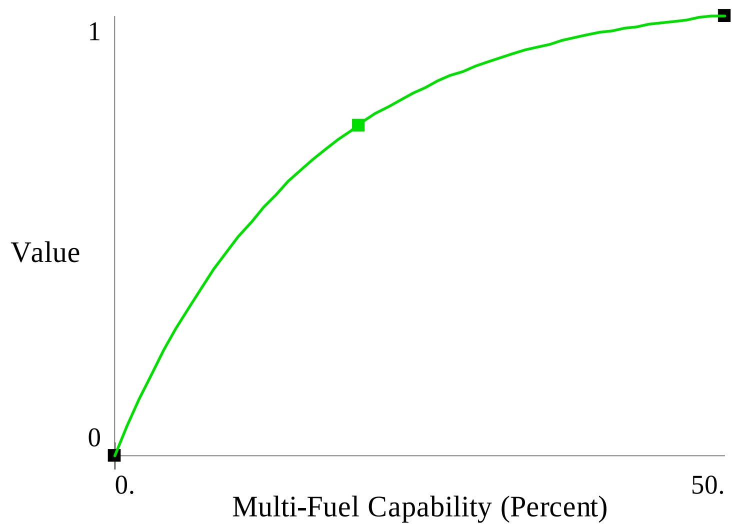


Figure 37 - Response Time Value Function

Multi-Fuel Capability

There is value associated with an alternative's ability to utilize more than one type of fuel. The value is derived from its ability to remain operational despite one of those fuel sources being inaccessible. This measure was designed in order to capture the value of those generators capable of using diesel or natural gas. It is measured according to the percentage of the wattage produced by these multi-fuel systems with respect to the total wattage of the alternative.

An alternative in which all of the wattage is produced by equipment capable of using more than one type of fuel receives full value. Those alternatives which do not have any equipment capable of doing so receive no value for this measure. The value function for *Multi-Fuel Capability* is shown in Figure 38 below.



Selected Point --   Level: 20   Value: 0.75

Figure 38 - Multi-Fuel Capability Value Function

Useful Life

Useful Life, in the context of this model, is a measure of the duration that an alternative will perform as designed. Upon the expiration of the shortest-lived equipment within an alternative, that alternative no longer functions as designed and a new decision will be required at that time. The value function for *Useful Life* is shown in Figure 39.

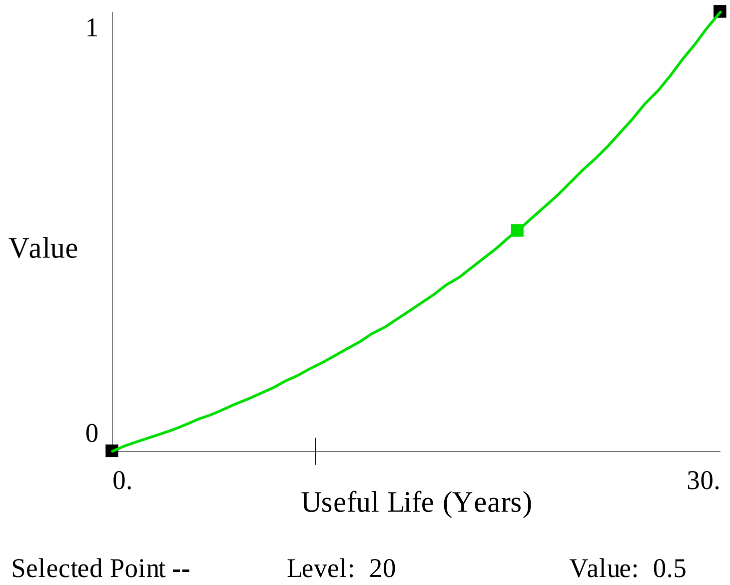


Figure 39 - Useful Life Value Function

Critical Duration

This is a measure of how long a back-up power system is able to maintain the required power to the critical power loads during a power outage. The value achieved on this measure increases with the duration that the back-up system is able to provide for all critical loads on the installation. Pacific Northwest National Laboratory performed a study in which the maximum power outage was assumed to be 30 days (Lu, et. al.), 2003:34). Therefore, a back-up power alternative which provides 30 days worth of power to the critical loads achieves the highest value of one. However, there is value associated with ability of an alternative to support critical loads for less time. For this case study, it was assumed that an alternative capable of supporting critical laods for 20 days still received a high value (0.8). Figure 40 shows the value function chosen for Twentynine Palms.

Leadership at each military installation should evaluate the likely duration of back-up power required and revise the value function accordingly. *Critical Duration* may be determined to be a screening criterion, which would eliminate any alternative that does not meet a minimum allowable back-up power duration capability for critical loads. In this case, this measure would still be effective in quantifying the value associated with exceeding that minimum.

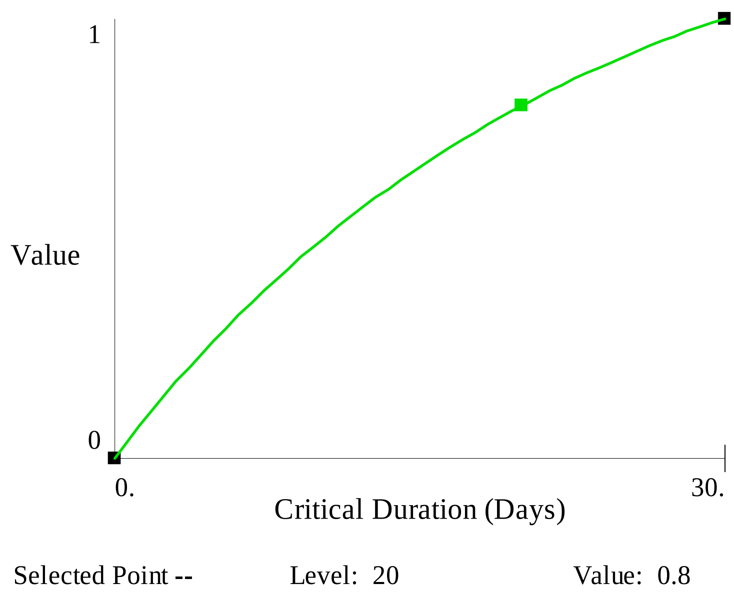


Figure 40 - Critical Duration Value Function

Important Loads

This measure captures the value associated with having power in excess of the demand of critical loads. It is assumed that this power will be provided for important loads for the duration of the outage. This measure assigns value based on the percentage of the installation's important loads that the alternative is able to satisfy concurrently with the critical load requirement. It is anticipated that the most significant important load will be the first load satisfied by the power available after the critical loads are satisfied. The value assigned to the alternative for meeting subsequent important loads is less with each load. The graph of the *Important Load* value function reflects this and is represented in Figure 41.

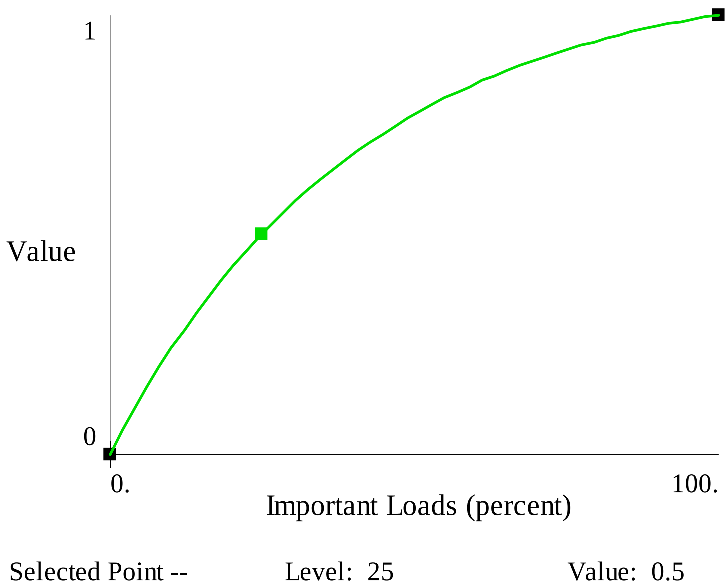


Figure 41 - Important Loads

Excess Power

Installations will have power demands above and beyond that required by important and critical loads. *Excess Power* measures the value of an alternative's ability to satisfy the other loads demanded by the entire base. *Excess Power* is a percentage scale with value increasing at a slower rate as power provided increases. This is due to the fact that installations will have some power requirements for which there is little value or need to satisfy, while some of the other power requirements will have a significant level of value associated with them. Figure 42 shows the value function created for *Excess Power*.

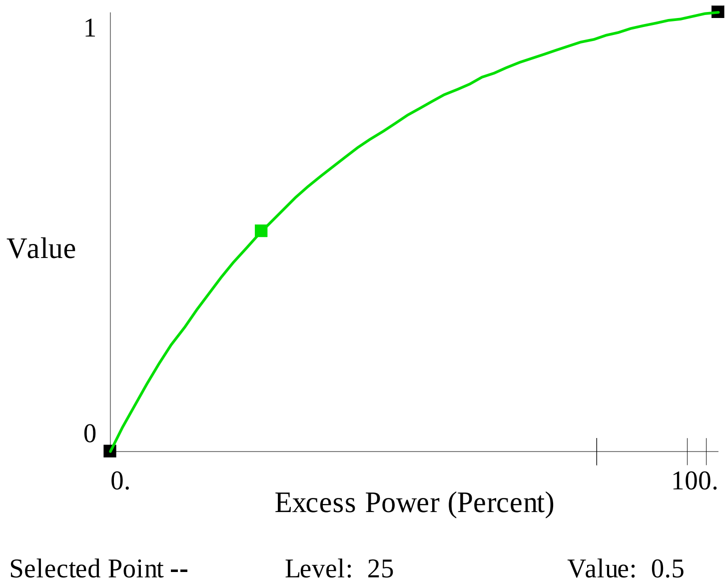


Figure 42 - Excess Power Value Function

Appendix B – Alternative Scoring

Initial Cost

Table 9 summarizes the scoring for the measures within the *Cost* value. Estimates for the initial costs of most of these alternatives were obtained from the Pacific Northwest National Laboratory report (Lu, et. al., 2003:47). These costs are based on typical costs for the power generation resources included in each alternative. Alternative 6 was not included in the Pacific Northwest National Laboratory report and its cost is therefore an estimate based on the cost associated with the other geothermal option, Alternative 4.

Table 9 - Alternative Cost Summary

Alternative Number and Description		Est. Initial Cost ($M)
1	20MW diesel generated power	$7.8
2	16MW wind, 4MW diesel	$23.2
3	10MW solar, 10MW diesel	$73.5
4	16MW geothermal, 4MW diesel	$31.2
5	8MW solar, 8MW wind, 4MW diesel	$68.3
6	10MW geothermal, 4MW diesel	$19.5

O&M Cost

In order to score *O&M,* I gathered data from a wide range of sources and used a representative cost for these liabilities. The cost used to estimate the operations and maintenance costs for diesel generators was $0.005 per kilowatt-hour. Research showed that costs for diesel generators operating continuously required approximately $0.01 per kW-hour produced (not including the cost of fuel). Even though the diesel generators in the alternatives are to be operated only during power outages, the bulk of the maintenance will still be required. Therefore, the O&M cost for diesel generators was assumed to be one-half that amount (or $0.005).

Wind turbines require an O&M cost of $0.005 per kW-hour of energy produced (United Nations Development Programme, 1998:234). Photovoltaic cells require an estimated cost of 1% of the initial investment cost for the operations and maintenance (California Energy Commission). The operations and maintenance cost for geothermal power used in this study was $0.004 per kW-hour produced (Renewable Energy Policy Project). To calculate the total O&M cost for each alternative, these unit costs were multiplied by the rated power or expected power produced. Table 10 summarizes the operations and maintenance costs for all six alternatives.

Table 10 - Operations and Maintenance Scoring

Alternative Number and Description		Diesel O&M	Solar O&M	Wind O&M	Geothermal O&M	Total O&M Costs
1	20MW diesel generated power	$100,000	-	-	-	$100,000
2	16MW wind, 4MW diesel	$20,000	-	$224,256	-	$244,256
3	10MW solar, 10MW diesel	$50,000	$500,000	-	-	$550,000
4	16MW geothermal, 4MW diesel	$20,000	-	-	$487,757	$507,757
5	8MW solar, 8MW wind, 4MW diesel	$20,000	$400,000	$112,128	-	$532,128
6	10MW geothermal, 4MW diesel	$20,000	-	-	$304,848	$324,848

Recoupment

Cost recoupment was calculated for those alternatives which produced power at less cost than Twentynine Palms can purchase power from the local utility. Twentynine Palms currently purchases power from this utility at an average rate of $0.06 per kilowatt-hour (Lu, et. al., 2003:45). The alternatives capable of generating electricity via a renewable energy source at a cost less than that of purchasing it from the local utility company are assumed to produce this electricity as a cost savings measure. However, for diesel and natural gas generators, the installation must determine if the cost savings of producing electricity with fossil fuel burning power generators offsets the adverse environmental effects. At Twentynine Palms, the cost of producing electricity via a diesel generator is greater than the cost from the local utility so self-producing power with diesel generators was not considered in this study.

In order to calculate *Recoupment*, the annual savings in electricity costs for each alternative was identified. The energy usage at Twentynine Palms is not constant and varies between different times of the year and day. A discussion of the variation in energy demand is included in the *Emissions* section below and in Table 16. The model had to account for variations in the installation's energy demand because the average demand is much lower than the peak demand. Therefore, an alternative producing more than the installation's average requirement would not necessarily provide 100% of the total power consumed due to these variations in power demand during the year. After the demand characteristics were identified, they were compared to the expected power provided by the alternative (excluding the portion of the total power rating contributed by diesel generated power) using the capacity factor of the alternative. Capacity factors are described in more detail under the *Reliability* heading below on page 96. The total power contributed by the alternative to the energy demand of the installation and the estimated savings associated with that power was calculated. The energy cost at Twentynine Palms is approximately $0.06 per kilowatt-hour (Lu, et. al., 2003:45). Table 11 through Table 15 summarize the recoupment periods for the alternatives.

Table 11 – Alternative 2 Recoupment Period

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 2			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Equivalent Commercial Power Cost
Summer, Nights	9.5	20,862	5.12	5.12	11,244	$674,611
Summer, Days	19.0	41,724	5.12	5.12	11,244	$674,611
Winter, Nights	4.5	9,882	5.12	4.50	9,882	$592,920
Winter, Days	9.0	19,764	5.12	5.12	11,244	$674,611
		92,232			43,613	$2,616,754
					Project Cost:	$23,200,000
					Payback Period (Years):	8.87

Table 12 - Alternative 3 Recoupment Period

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 3			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Equivalent Commercial Power Cost
Summer, Nights	9.5	20,862	2.30	2.30	5,051	$303,048
Summer, Days	19.0	41,724	2.30	2.30	5,051	$303,048
Winter, Nights	4.5	9,882	2.30	2.30	5,051	$303,048
Winter, Days	9.0	19,764	2.30	2.30	5,051	$303,048
		92,232			20,203	$1,212,192
					Project Cost:	$73,500,000
					Payback Period (Years):	60.63

Table 13 - Alternative 4 Recoupment Period

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 4			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Equivalent Commercial Power Cost
Summer, Nights	9.5	20,862	13.92	9.50	20,862	$1,251,720
Summer, Days	19.0	41,724	13.92	13.92	30,568	$1,834,099
Winter, Nights	4.5	9,882	13.92	4.50	9,882	$592,920
Winter, Days	9.0	19,764	13.92	9.00	19,764	$1,185,840
		92,232			81,076	$4,864,579
					Project Cost:	$31,200,000
					Payback Period (Years):	6.41

Table 14 - Alternative 5 Recoupment Period

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 5			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Equivalent Commercial Power Cost
Summer, Nights	9.5	20,862	4.40	4.40	9,662	$579,744
Summer, Days	19.0	41,724	4.40	4.40	9,662	$579,744
Winter, Nights	4.5	9,882	4.40	4.40	9,662	$579,744
Winter, Days	9.0	19,764	4.40	4.40	9,662	$579,744
		92,232			38,650	$2,318,976
					Project Cost:	$68,300,000
					Payback Period (Years):	29.45

Table 15 - Alternative 6 Recoupment Period

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 6 Max. Power (MW)	Alternative 6 Actual Power (MW)	Alternative 6 Total Power Produced (MW-hr)	Alternative 6 Equivalent Commercial Power Cost
Summer, Nights	9.5	20,862	8.70	8.70	19,105	$1,146,312
Summer, Days	19.0	41,724	8.70	8.70	19,105	$1,146,312
Winter, Nights	4.5	9,882	8.70	4.50	9,882	$592,920
Winter, Days	9.0	19,764	8.70	8.70	19,105	$1,146,312
		92,232			67,198	$4,031,856
					Project Cost:	$19,500,000
					Payback Period (Years):	4.84

Emissions

Several assumptions drove the scoring of *Emissions*. The first assumption was that the commercial power consumed by Twentynine Palms is generated by a fossil fuel-burning power plant. Another assumption was that any alternative capable of producing power at a cost less than that which can be purchased from the local utility would be used to do so. Although geothermal power plants produce a small amount of emissions, this was neglected for the purpose of this study. In order to simplify the calculations, it was assumed that any power generated by an alternative would be consumed on base, rather than sold back onto the grid. In future applications of this model, one might desire to analyze the possibility of implementing an alternative which actually produces more power than is required on the installation and intends to recoup investment costs by selling power to the electric utility. Information such as the selling price per kilowatt-hour would be required in order to determine the cost savings or profit realized through the implementation of the alternative. Additionally, it was assumed that no restrictions are in place by the local utility which sets forth a minimum amount of power that the installation is required to use at any given time. In actuality, Twentynine Palms is required to maintain a minimum level of power usage. Failure to maintain a power usage at or above that minimum level results in significant monetary penalties.

The peak loads at Twentynine Palms are 9MW in winter and 19MW in summer (Lu, et. al., 2003:19). The off-peak load (typically evening hours) during these seasons was assumed to be was half the peak load. This would result in an average loads as shown in Table 16.

Table 16 - Average Power Requirement (Lu, et. al., 2003:19)

Season	Time	Avg Power Req'ment (MW)
Summer	Night	9.5
Summer	Day	19
Winter	Night	4.5
Winter	Day	9

Table 17 through Table 21 summarize the calculations performed in order to determine the percentage decrease in the amount of power required to be purchased from the local utility should the respective alternative be implemented. The calculations are explained in more detail following the tables. Alternative 1 was not considered for this assessment because it consists only of diesel powered generators. Diesel generators are not capable of producing power at a lower cost than can be purchased from the utility company.

Table 17 - Emission Reduction for Alternative 2

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 2			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Percent of Total
Summer, Nights	9.5	20,862	5.12	5.12	11,244	54%
Summer, Days	19.0	41,724	5.12	5.12	11,244	27%
Winter, Nights	4.5	9,882	5.12	4.50	9,882	100%
Winter, Days	9.0	19,764	5.12	5.12	11,244	57%
		92,232			43,613	47%

Table 18 - Emission Reduction for Alternative 3

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 3			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Percent of Total
Summer, Nights	9.5	20,862	2.30	2.30	5,051	24%
Summer, Days	19.0	41,724	2.30	2.30	5,051	12%
Winter, Nights	4.5	9,882	2.30	2.30	5,051	51%
Winter, Days	9.0	19,764	2.30	2.30	5,051	26%
		92,232			20,203	22%

Table 19 - Emission Reduction for Alternative 4

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 4			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Percent of Total
Summer, Nights	9.5	20,862	13.92	9.50	20,862	100%
Summer, Days	19.0	41,724	13.92	13.92	30,568	73%
Winter, Nights	4.5	9,882	13.92	4.50	9,882	100%
Winter, Days	9.0	19,764	13.92	9.00	19,764	100%
		92,232			81,076	88%

Table 20 - Emission Reduction for Alternative 5

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 5			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Percent of Total
Summer, Nights	9.5	20,862	2.56	2.56	5,622	27%
Summer, Days	19.0	41,724	2.56	2.56	5,622	13%
Winter, Nights	4.5	9,882	2.56	2.56	5,622	57%
Winter, Days	9.0	19,764	2.56	2.56	5,622	28%
		92,232			22,487	24%

Table 21 - Emission Reduction for Alternative 6

Season, Time	Power Req'd (MW)	Total Power Consumed (MW)	Alternative 6			
			Max. Power (MW)	Actual Power (MW)	Total Power Produced (MW-hr)	Percent of Total
Summer, Nights	9.5	20,862	8.70	8.70	19,105	92%
Summer, Days	19.0	41,724	8.70	8.70	19,105	46%
Winter, Nights	4.5	9,882	8.70	4.50	9,882	100%
Winter, Days	9.0	19,764	8.70	8.70	19,105	97%
		92,232			67,198	73%

In these tables, power required is the electrical demand of the installation as calculated in Table 16. Total power consumed is the power required × 12 hours × 183 days (one half year). Specific to the alternative in question, the maximum power is the power rating of the energy producing portion of the alternative (this excludes the diesel generators) × the capacity factor. Since it was assumed that no alternative would produce power in excess of that required by the installation, actual power is the amount of power the alternative will generate. Actual power is equal to the lesser of the maximum power output of the alternative or the power demanded by the installation. The total power produced is the actual power generated by the alternative × 12 hours × 183 days. After summing the power consumed and the total power produced, the percentage of the total demand of the installation produced by the alternative was calculated. This percentage was used to represent the emissions reduction related to implementing environmentally friendly power generation in lieu of purchasing power generated from the consumption of fossil fuels. Table 22 summarizes the emissions reduction for the relevant alternatives.

Table 22 - Emissions Reduction Summary

Alternative Number and Description		Emissions Reduction
2	16MW wind, 4MW diesel	47%
4	16MW geothermal, 4MW diesel	88%
5	8MW solar, 8MW wind, 4MW diesel	24%
6	10MW geothermal, 4MW diesel	73%

This method of determining emission reduction may not be viable for an installation which purchases power from a utility which does not create emissions in the production of power (nuclear, renewable energy, etc...). It may also not be valid for an installation which has other sources of air emissions. The decision maker and subject matter experts of future applications of this model would need to determine an appropriate method of calculating emissions reduction. The method included in this study is just one approach

Renewability

Renewability is a measure of the percentage of total wattage of an alternative produced by renewable fuel sources as described in Appendix A. To score *Renewability*, the expected power output of the alternative was determined by multiplying the renewable energy rating of each alternative by the respective capacity factor (as described on page 96). Table 23 summarizes the scoring for this measure.

Table 23 - Renewability Scoring

Alternative Number and Description		Renewable Energy Rating (MW)	Capacity Factor	Expected Power of Renewables (MW)	Total Expected Power (MW)	Renewability
1	20MW diesel generated power	0	-	-	-	0%
2	16MW wind, 4MW diesel	16	0.32	5.12	9.12	56%
3	10MW solar, 10MW diesel	10	0.23	2.30	12.30	19%
4	16MW geothermal, 4MW diesel	16	0.87	13.92	17.92	78%
5	8MW solar, 8MW wind, 4MW diesel	16	0.28	4.40	8.40	52%
6	10MW geothermal, 4MW diesel	10	0.87	8.70	12.70	69%

Land Value

The alternatives generated for this case study were vague in regard to the location of the assets contained within them. It was therefore necessary to make assumptions in order to score this alternative. In future applications of this model, more specific alternatives will improve the value of the information provided by this model.

Alternative 1 is made up exclusively of relatively small sized diesel generators. Many of these generators are to be sized in order to provide back-up energy to a single load. Therefore, they are assumed to be scattered around the installation in close proximity to the loads which they serve. *Land Value* does not score these small generators. Therefore, Alternative 1 receives full value for this measure.

Because of the large amount of space required by photovoltaic arrays and wind farms, Alternatives 2, 3, and 5 were assumed to require some of the installation's open space in order to accommodate the large footprint. Therefore, these alternatives were assumed to be located along the perimeter of the installation or immediately adjoining it. Because geothermal plants typically have a much smaller footprint, it was assumed that the industrial section of Twentynine Palms would be capable of accommodating the geothermal power plants of Alternatives 4 and 6.

Noise

Geothermal power plants and photovoltaic arrays produce very little noise due to the nature of their power generation. Diesel generators produce an exceptional amount of noise. However, that noise is only produced during operation, which only occurs during a power failure. The inconvenience of noise is minimized due to the other concerns expected to be facing an installation without power. Therefore, noise produced exclusively during a power failure is determined to be insignificant.

A collection of wind turbines is capable of producing a significant amount of noise. However, due to the vast amount of land on and abutting Twentynine Palms, it is assumed that the wind farms can be located far enough away from the population center of the base so it will not negatively impact the employees or residents. Therefore, none of the alternatives analyzed for this case study produce enough noise to negatively impact the installation.

Visual Impact

Alternative 1 was deemed obtrusive in this measure due to the large number of diesel generators required to be scattered around the installation. The overall visual appeal of the installation would suffer should a large number of generators be in plain sight. Wind farms were also deemed to be obtrusive because of their high degree of visibility from large distances. Alternatives 1, 2, and 5 were therefore scored obtrusive in this measure because they present this appearance.

Photovoltaic arrays typically do not present the same visual problems that wind farms create. These generators were assumed to be located in such a way as to prevent most of the base populace from being exposed to them. However, since Alternative 3 has a large number of diesel generators, it was assumed that these would present an obtrusive visual appeal as described above for Alternative 1. Therefore Alternative 3 was also deemed obtrusive.

The geothermal plants, as mentioned previously, would be located in the industrial section of the installation. This would provide shielding from sight for most of the residents and employees on base, but would likely present some visual degradation. Therefore, these alternatives were deemed neutral.

Stand Off Distance

As mentioned above, only the geothermal alternatives are projected to be located in the industrial sector of the installation. This industrial sector of Twentynine Palms is located approximately 1500 feet from the perimeter fencing. This location provides ample stand off distance, thus Alternatives 4 and 6 received a high score for *Stand Off Distance*. The diesel generators of Alternative 1 are scattered around the installation and have a varying degree of stand off distance from the perimeter of the installation. This alternative was scored assuming an average of 500 feet of stand off distance. The photovoltaic and wind generators, on the other hand, would likely be located outside of the main camp of Twentynine Palms. Therefore, these alternatives would have their primary assets not included inside the perimeter fencing of the main camp and have no stand off distance.

Other Security

It is not common practice to provide security measures for small diesel generators due to their high risk/low reward value of attack. Therefore, Alternative 1 is assumed to have no added security features associated with it. However, it does have several inherent security features. Because it is decentralized and scattered in many locations, it can be assumed that this is a security feature of the alternative. Additionally, because they are primarily located among the population center of Twentynine Palms, this also can also be considered deterrence due to the installation employees who will be able to observe any suspicious activity. Finally, roving police patrols will also help protect these assets. Therefore, Alternative 1 is considered to have three additional security features.

The wind and solar assets are assumed to have certain security features due to their location off the main camp of Twentynine Palms. I assumed that Alternatives 2, 3, and 5 will have a roving security patrol and motion detectors scattered throughout the area where they are located. Therefore, each of these assets includes two additional security features.

The geothermal alternatives, 4 and 6, also have additional security features. Because these are located in the main camp, it is assumed that military and civilian personnel will be in close proximity and serve as a deterrent. There will also be roving military police patrols. Also, these power plants will also likely be monitored by an employee. This gives the geothermal plants three additional security features.

Response Time

The location of the alternatives is the primary factor in determining *Response Time*. Because those assets located within the main camp of Twentynine Palms are closer to the police headquarters, these will have a shorter response time. It was assumed that the diesel generators and geothermal plants (Alternatives 1, 4 and 6) would be 3-5 minutes, while those alternatives with assets outside the main camp (Alternatives 2, 3, and 5) would be slightly higher at 6-10 minutes.

Multi-Fuel Capability

None of the alternatives for this study were projected to operate on multiple fuel sources; therefore, none of the alternatives receive a value associated with this measure. The existing diesel generators common to all alternatives operate solely on diesel fuel. Due to the initial cost, maintenance, and related infrastructure improvements required to install and operate multi-fuel generators, it was assumed that no alternative would include them.

Useful Life

The useful life of each asset included in an alternative must be considered in order to score the alternative against this measure. Because the alternatives generated for this case study are vague, definite life expectancies of the assets contained within them cannot be ascertained. Therefore, it was assumed that the shortest lived assets in each alternative are the diesel generators because they are existing assets of varying age. The useful life remaining on them was assumed to be 15 years. Since each alternative makes use of these existing diesel generators, each alternative received the same value on this measure.

Critical Duration, Important Loads, Excess Power

In order to score the alternatives against the measures in *Reliability*, there were several assumptions including the following: critical loads require power 24 hours per day and important and other loads require power only 12 hours per day. Twentynine Palms has a diesel supply capable of powering the critical loads for 15 days. This is the equivalent of 4MW × 15 days, or 60MW-days of power. None of the photovoltaic options included battery usage.

Each of the energy sources in an alternative has a capacity factor. The capacity factor is the fraction of the rated power expected to be generated by an energy source based on the nature of the energy source and the geographical region in which it is located. All energy sources typically produce an amount of power lower than their maximum rating due to these considerations. Photovoltaic arrays, for example, only produce power during daylight hours and produce less power on cloudy days than on sunny days. The angle of the sun also impacts the amount of power generated. Based on these factors, a capacity factor of 0.23 was used to estimate the amount of power derived from photovoltaic sources. This means that at any given time, one may depend on receiving 2.3MW from a 10MW photovoltaic array. The capacity factors for all of the power sources considered in this study are included in Table 24 (Lu, et. al., 2003:33). Diesel generators were assumed to have a capacity factor of one because Twentynine Palms has 1.5MW worth of additional diesel generators dedicated to replacing any diesel generators which are not operational. It is assumed that they will continue to reserve these generators for this purpose.

Table 24 - Capacity Factors

Energy Source	Capacity Factor
Solar (Photovoltaic)	0.23
Wind	0.32
Geothermal	0.87
Diesel Generator	1.00

As an example, the calculations used to score the Alternative 2 against the three measures in *Reliability* are described below. The calculations for the other alternatives were performed in a similar manner. First, the amount of power expected from the alternative's assets was determined. This involved multiplying the capacity factor by the power rating of the asset. In this example, the capacity factor for wind (0.32) was multiplied by the rating of the wind farm in the alternative (16MW) to derive the expected power of 5.12MW.

Since the critical loads at Twentynine Palms total 4MW (Lu, et. al., 2003:22), the power provided by the wind generators was deemed sufficient to power the critical loads indefinitely. Since 30 days receives maximum value on this measure, any alternative which scores greater than 30 days is assumed to support critical loads for 30 days. Subtracting the 4MW of critical load from the expected power of 5.12MW yields an excess of 1.12MW which can be utilized to provide power to the important loads.

The total power required by the important loads at Twentynine Palms also totals 4MW (Lu, et. al., 2003:24). This is the peak power requirement and it was assumed that important loads require no power during the evening, the expected amount of power required at any given time is 2MW. Obviously, the 1.12MW is not sufficient to support all of the important loads in addition to the critical loads. By deducting the amount of wind power not used by the critical loads from the 2MW important load requirement, there is a need for 0.88MW.

Multiplying this 0.88MW shortfall by 30 days (0.88MW × 30 days), the need for 26.4MW-days of diesel power to support the remaining important loads is realized. As mentioned before, Twentynine Palms has a 60MW-day supply of diesel to provide this power. Therefore, this alternative is capable of supporting 100% of the important loads for the expected maximum required duration of 30 days. It also leaves 33.6MW-days remaining in the diesel fuel supply which can be used to support other loads.

The peak power required by the other loads is 12MW. Again, it is assumed that other loads require power only during daylight hours, so an average of 6MW is demanded by these other loads. By multiplying 6MW by 30 days, a demand of 180MW-days is required to supply power to all of the other loads. Since Twentynine Palms has only 33.6MW-days worth of diesel, the alternative can only power 33.6 ÷ 180, or 19% of the other loads for the 30 day duration. This method of calculating the *Reliability* measures was applied to all alternatives and the results are summarized in Table 25.

Table 25 - Reliability Scores

Alternative Number and Description		Reliability		
		Critical Duration	Important Loads	Excess Power
1	20MW diesel generated power	14 days	0%	0%
2	16MW wind, 4MW diesel	30 days	100%	19%
3	10MW solar, 10MW diesel	30 days	15%	0%
4	16MW geothermal, 4MW diesel	30 days	100%	100%
5	8MW solar, 8MW wind, 4MW diesel	30 days	32%	0%
6	10MW geothermal, 4MW diesel	30 days	100%	38%

Alternative 3 (10MW photovoltaic, 10MW diesel):

As mentioned previously, Twentynine Palms has diesel fuel storage capacity capable of powering 4MW for 15 days. Since photovoltaic power sources do not produce power during nighttime hours, all of the diesel power generated was assumed to be required to power the critical loads during evening hours. This effectively stretches the diesel fuel supply from 15 to 30 days. The photovoltaic array will power the critical loads during daylight hours.

The capacity factor of photovoltaic during daylight hours (0.46) was multiplied by the rating (10MW) to derive the expected power of 4.6MW. Subtracting the amount required by the critical loads (4MW), this leaves 0.6MW of power to be used by the important loads. This amount of power only provides for 0.6MW ÷ 4MW, or 15% of the important loads for the 30 day duration. Obviously, there is no power available to power any of the other loads.

Alternative 4 (16MW geothermal, 4MW diesel)

Multiplying the capacity factor of geothermal power (0.87) by the rating (16MW) yields 13.92MW. This is sufficient to power all of the critical and important loads and leave 5.92 MW of power available to power other loads. Since Twentynine Palms' other loads require 6MW average load, only 6MW – 5.92MW, or 0.8MW of diesel power is required to provide for 100% of these loads. This consumes 0.8MW × 30 days, or 24MW-days of the 60MW-days available. This alternative provides for all critical, important and other loads for the entire 30 outage scenario and has 36MW-days of diesel-generated power remaining available.

Alternative 5 (8MW wind, 8MW photovoltaic, 4MW diesel)

Because of the photovoltaic element within this alternative, it was necessary to distinguish between day and night power generation/consumption similar to the calculations performed on Alternative 3. To calculate the power generated in the evening, the capacity factor of wind (0.32) was multiplied by the rating of the wind power generator (8MW) which resulted in a power generation of 2.56MW. Since this is less than the 4MW required by the critical loads, diesel generators were assumed to make up this difference. The amount of power generated by wind (2.56MW) was subtracted from the total amount of power required at night (4MW), indicating that diesel generators would need to provide 1.44MW. Multiplying 1.44MW by 30 days yields 43.2MW-days. Subtracting 43.2MW from the 60MW-days available in fuel storage leaves 16.8MW-days available to power loads during daylight hours.

The power produced by the photovoltaic array during daylight hours was found to be 0.46×8MW, or 3.68MW. The wind farm produces the same amount of power during day as it does during the evening, 2.56MW. Taken together, renewable power sources would produce a total of 3.68MW + 2.56MW, or 6.24MW during daylight hours. This is more than sufficient to power the critical loads and leaves 2.24MW to power the important loads.

Subtracting 2.24MW from the 4MW required to power all of the important loads yields 4MW-2.25MW, or 1.76MW. Multiplying this power by 30 days equals 1.76MW $\times$ 30 days, or 52.8MW-days. Since the amount of diesel remaining after powering the important loads during evening hours is equivalent to 16.8MW-days, 16.8MW is divided by 52.8MW-days, indicating that this alternative is capable of powering 32% of the important loads for the 30 day outage scenario.

Alternative 6:

The capacity factor of the geothermal plant was multiplied by the maximum power rating which resulted in a power supply of 0.87×10MW, or 8.7MW. This power is sufficient to provide power to all of the critical loads and important loads. In addition, it makes 0.7MW (8.7MW – 4MW critical load – 4MW important load) available for powering of other loads. This 0.7MW was subtracted from the other load power requirement of 6MW, yielding a power demanded of the diesel equipment of 5.3MW × 30 days, or 159MW-days. The diesel supplies are able to meet 60MW-days ÷ 159MW-days, or 38% of the other loads.

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14. ABSTRACT

Electrical power on military installations is vital for mission accomplishment. Most installations obtain electrical power from a local commercial utility. Although commercial power service has a very low interruption rate, the threat of a sustained power outage resulting from a terrorist act or a natural disaster is of concern. The military should posture itself to prevent such power outages and prepare to mitigate the adverse affects associated with the loss of power.

This thesis presents a Value Focused Thinking approach to the development of a decision analysis model to assist a decision maker at a military installation in the generation and selection of back-up energy alternatives. The model attempts to capture the value to be gained by implementing back-up power systems which utilize fossil fuel powered generators in combination with renewable energy resources and assist the decision maker in selecting an alternative which best suits the needs of the installation. The thesis also includes a case study involving the application of this model to the United States Marine Corps installation in Twentynine Palms, California.

15. SUBJECT TERMS

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