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Developing a Decision Model for Joint Improvised Explosive Device Defeat Organization (JIEDDO) Proposal Selection

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THESIS

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Abstract

This research uses Decision Analysis (DA) to develop a structured, repeatable, and most importantly, defensible decision model for the evaluation of proposed IED defeat solutions submitted to the Joint IED Defeat Organization (JIEDDO). Additive value models using Value-Focused Thinking (VFT) and the Analytic Hierarchy Process (AHP) are examined as possible methodologies. VFT is determined to be the "best fit" for JIEDDO's decision situation in which proposals are submitted continuously and must be scored independently of previous proposals. VFT is first used to determine desirable qualities in IED defeat options, and then to generate a hierarchical value model to evaluate these qualities in a selected group of alternatives. The most important criteria for IED defeat proposal evaluation are: Need for the Capability, Operational Performance, and Usability. A group of 30 proposals, previously assessed by the current JIEDDO process, is evaluated using the VFT decision model and the rank ordered results are compared with JIEDDO's previous selection decisions. The VFT decision model results support JIEDDO's past decisions to accept or reject IED defeat proposals, validating the model. Sensitivity analysis is then conducted to allow further insight to the robustness of the model. The resulting effort creates a decision support model that, when consistently applied, provides repeatable and defensible decisions that reflect JIEDDO's priorities for proposal selection.

Dedicated to

Michael Russell Creighton-Weldon, Private First Class, USA

Michael Edward Curtin, Corporal, USA

Diego Fernando Rincon, Private First Class, USA

Eugene Williams, Sergeant, USA

These soldiers were casualties of the first Improvised Explosive Device attack of Operation IRAQI FREEDOM.

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DEVELOPING A DECISION MODEL FOR JOINT IMPROVISED EXPLOSIVE DEVICE DEFEAT ORGANIZATION (JIEDDO) PROPOSAL SELECTION

I. Introduction

JIEDDO

In recent years, improvised explosive devices (IEDs) have emerged as the most significant threat to U.S. forces deployed in Iraq and Afghanistan. IEDs are the primary source of coalition casualties in these countries, accounting for about 2/3 of all combat related deaths in Iraq since 2003, and about 1/2 of combat related deaths in Afghanistan since 2001 (Atkinson, 2007). IEDs are developed, emplaced and detonated by complex and adaptable insurgent networks with extensive practice dating back to the Russian occupation of Afghanistan and the Iran-Iraq War (Global Security Organization, 2007). In addition, the number of IEDs placed by enemy forces, either exploded or discovered prior to detonation, increased six fold between 2003 and 2006 (JIEDDO, 2006). IEDs are the insurgent weapon of choice: They are easy to make, low cost, difficult to defend against, and cause untold death and destruction (Chertoff, 2007).

In October 2003, the Army Chief of Staff established the Army IED Task Force to orchestrate efforts to eliminate the IED threat to ground forces in Iraq and Afghanistan. The goal of the task force was to recommend the best available responses and develop and field the selected solutions for IED countermeasures. Although the Army was the primary force dealing with IEDs in theater, it was necessary to synchronize the Department of Defense's (DoD) response to the IED threat. In July 2004, the task force was transformed into the Joint IED Defeat Task Force. The following year, by DoD Directive 2000.19, the command structure was modified so that the Director of the Joint IED Defeat Task Force reported directly to the Deputy Secretary of Defense and the process for fielding life-saving technologies was further streamlined. In December 2006, the Joint IED Defeat Organization (JIEDDO) was established as a permanently manned entity. The creation of JIEDDO was intended to orchestrate all available resources within the DoD, the private sector, our allies and our coalition partners to combat the IED threat (JIEDDO, 2007).

JIEDDO's mission is to focus (lead, advocate, coordinate) all Department of Defense actions in support of Combatant Commanders' and their respective Joint Task Forces' efforts to defeat Improvised Explosive Devices as weapons of strategic influence (Department of Defense, 2006). JIEDDO's objectives are to:

- Rapidly and systematically reduce the effect of all forms of IEDs against Joint and Coalition forces ahead of enemy innovation.
- Provide senior leaders a single point of contact for counter-IED efforts throughout the Department of Defense.
- Establish a Joint Common Operational Picture (JCOP) of IEDs and their employment in the Global War on Terror.
- Provide a Joint forum to collect and synchronize all applicable efforts of the Department of Defense and other agencies.
- Provide senior leaders a rapid and accountable method for identifying issues requiring interservice resourcing and prioritizing decisions.

- Provide a Joint Forum to identify counter-IED efforts and requirements to be rapidly implemented, accelerated or developed in the long term.
- Provide a forum of interservice, interagency, industry and international coordination of IED defeat (JIEDDO, 2007).

Improvised Explosive Devices (IEDs)

IEDs comprise a wide variety of homemade devices that are designed to cause death or injury by using explosives alone or in combination with toxic chemicals, biological toxins, or radiological material. IEDs can be produced in varying sizes, functioning methods, containers, and delivery methods. IEDs can use commercial or military explosives, homemade explosives, or military ordnance and ordnance components. They are unique in nature because the IED builder has to improvise with the materials at hand. Designed to defeat a specific target or type of target, they generally become more difficult to detect and protect against as they become more sophisticated (Global Security Organization, 2007).

IEDs fall into three types of categories: Package Type, Vehicle-Borne, and Suicide Bomb. Though they can vary widely in shape and form, they share a common set of components and consist of an initiation system or fuse, explosive fill, a detonator and power supply, and a container. IEDs are relatively simple devices, but they are extremely effective as an asymmetric strategy for insurgents (Global Security Organization, 2007).

Current IED Defeat Practices

Defeating IEDs requires a comprehensive approach. In the interest of this, JIEDDO's current counter-IED (C-IED) practices are arranged into three separate lines of operation (LOOs): Attack the Network, Defeat the Device and Train the Force.

- Attack the Network is the offensive portion of C-IED efforts intended to interdict the network responsible for the production and emplacement of IEDs.
- Defeat the Device describes efforts to counter the impact of IEDs after they have been successfully emplaced by the enemy.
- Train the Force: JIEDDO supports individual and collective training programs to prepare units prior to and during deployments.

These LOOs are further subdivided into five tenets of C-IED warfare: Prevent/Predict (Attack the Network), Detect, Neutralize, Mitigate (Defeat the Device) and Train (Train the Force). When new proposals for C-IED technology are submitted to JIEDDO, they are assigned to one of the five tenets within the LOO structure when being considered for funding (JIEDDO, 2007).

JIEDDO is currently in the process of adopting a revised set of six tenets (Bonder, 2008). These new tenets will be used for the purposes of this research paper in the evaluation of the proposal set.

- Predict: Activities to anticipate threat actions by integrating intelligence to provide a clearer understanding of enemy personnel, equipment, infrastructure, processes and actions.
- Prevent: Activities to target, interdict, and destroy key enemy personnel, infrastructure, logistics capabilities, and enemy combat operations involving IEDs prior to emplacement.
- Detect: Activities to identify and locate enemy personnel, explosive devices and their component parts, equipment, logistics operations and infrastructure

through the act of emplacement in order to provide accurate and timely information to military operations and planners.

- Degrade: Activities to disrupt, deceive, and avoid the IED chain of events and reduce public support, and to ideally deter the enemy use of IEDs by increasing the cost (time, dollars, personnel, and risk) of employing IEDs.
- Neutralize: Activities to eliminate the hazards of enemy IEDs once emplaced by destroying them or rendering them incapable of detonating at the time/place of the enemy's choosing.
- Protect: Activities to protect personnel and equipment by disrupting, channeling, blocking or redirecting blast energy or fragmentation. (Bonder, 2008)

The nature of the IED threat requires rapid selection, funding and fielding of C-IED systems. However, JIEDDO faces the same challenges as all DoD services in following federal acquisition rules. JIEDDO's acquisitions are governed by the Joint IED Defeat Capability Approval and Acquisition Management Process (JCAAMP). JCAAMP establishes policy for evaluating C-IED proposals sponsored by JIEDDO and assigns responsibilities for these evaluations (JIEDDO, 2007). The intent of JCAAMP is to rapidly assess and acquire new C-IED capabilities and quickly provide them to the warfighter. The Military Services, the Joint Staff, OSD and the Combatant Commanders, along with teams of scientists and other subject matter experts, provide validation and oversight throughout this process (JIEDDO, 2006).

The selection of a methodology for JIEDDO's decision problem requires an understanding of the current decision process and where the decision model is intended to be used in this process. JIEDDO Instruction 5000.01, *Joint IED Defeat Capability Approval and Acquisition Management Process (JCAAMP)*, is the guidebook for the current proposal selection process. This Instruction defines and implements the rapid acquisition management responsibilities for counter-IED efforts (JIEDDO, 2007).

The existing process for the selection of individual proposals begins with the issuance of a Broad Area Announcement (BAA) via the JIEDDO website. These announcements generate proposals from industry, academia and research and development institutions. In addition, unsolicited proposals may also be received from these sources. These incoming proposals are accepted into JIEDDO's BAA Information Delivery System (BIDS), which aids in the multilayered evaluation process prior to being presented to senior leadership for a decision to accept or reject the proposal.

The BIDS process separates incoming proposals into two groups: those that have the potential to perform the IED Defeat mission, and those concepts that are not feasible. The use of such a filter is especially critical in view of the number of proposals received by JIEDDO--1274 in 2006 and 2007 alone. Of these, only 447 passed the initial review (Jacoby, 2008). Therefore, the focus of this research is to create a decision model to support the initial decision to accept or reject the proposal. The objective is to provide a defensible and repeatable framework that will give added justification and credibility to the decision to push a proposal forward in the evaluation process.

The proposals selected through BIDS enter the JCAAMP process at transition point 1 (TP1), depicted in Figure 1. Proposals that make it past TP1 are endorsed by the Deputy Director of JIEDDO as meeting a current need and being mature enough to enter the rapid acquisition and development process (JIEDDO, 2007).

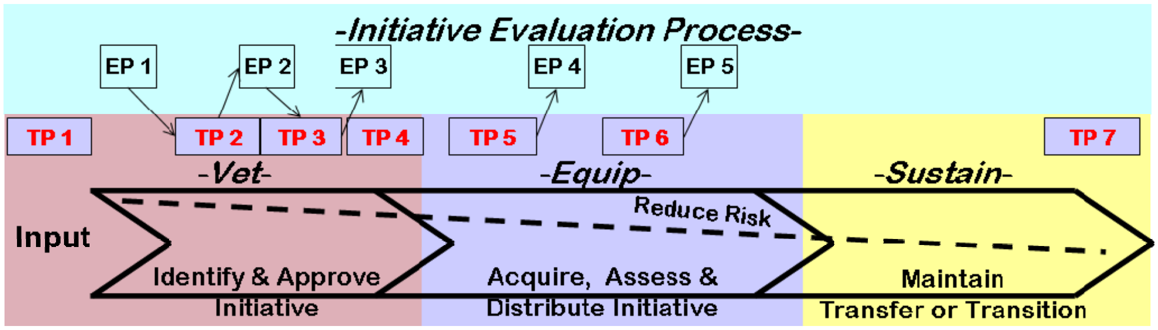


Figure 1. The JCAAMP Process (JIEDDO, 2007)

Research Objective

JIEDDO receives numerous proposals from various sources aimed at reducing the threat posed by IEDs. The importance of focusing the C-IED effort on the right mix of functional areas requires that JIEDDO choose proposals capable of providing the most effective portfolio of C-IED capabilities to the warfighter within budget constraints.

Currently no Decision Analysis model is used to provide traceable, repeatable and defensible scoring of competing proposals submitted to JIEDDO for consideration. A model of this type would use evaluation measures based on JIEDDO's stated operational objectives to accurately represent the value that decision makers place on individual objectives. Use of such a model will enable the JIEDDO to optimize the proposal selection process and ultimately decrease the impact of the IED threat.

The objective of this effort was to develop a repeatable framework to effectively assist JIEDDO in selecting proposals for funding that would provide the most effective C-IED capabilities within budget constraints. Using the Decision Analysis approach of Value-Focused Thinking to elicit the desired objectives of JIEDDO decision makers, a value hierarchy was built. Sensitivity analysis was conducted to identify areas for future refinement and modification of this model according to guidance provided by JIEDDO. The finished product offers useful insight to JIEDDO leadership and ensures that proposal acceptance is based on the value hierarchy developed by the AFIT research team and approved by JIEDDO. The approved model is intended to be used independently by JIEDDO to evaluate incoming proposals.

Research Scope

JIEDDO must consider a widely varied and constantly evolving threat when selecting proposals for funding, so the analysis of submitted proposals is a complex endeavor. Since funds are not strictly divided among the established LOOs (Attack the Network, Defeat the Device and Train the Force), an evaluation tool must encompass the organization’s entire mission. Therefore, the scope of this research is not limited to a particular area of C-IED operations. However, the research is limited to the mission of JIEDDO and the objectives of its decision makers. Lastly, though the focus of this study is IED defeat abroad, the techniques and model created could also be applied to domestic C-IED defense issues.

This research will result in a decision model to be used for selection of C-IED technologies, and application of that model. It is hoped that the study will also offer valuable insight to JIEDDO regarding their process of soliciting proposals from contractors and assigning evaluation experts to incoming proposals.

The remainder of this document is broken down into four chapters. Chapter 2 provides a review of relevant research that has already been conducted in the area of proposal selection along with pertinent information regarding the literature on the Value-Focused Thinking methodology that is used. Chapter 3 provides detailed information on the methodology, step-by-step, as the research is conducted. Chapter 4 displays the results of the analysis done with the process outlined in Chapter 3, and Chapter 5 provides discussion on recommendations based on the results as well as future research that can be done to further explore the issue.

II. Literature Review

Decision Analysis Overview

Decision Analysis is a branch of the Operations Research (OR) discipline. OR lends itself quite readily to addressing decision problems, since the reason for OR in general is to provide decision makers with a scientific method on which to base their decisions (Keeney & Raiffa, 1993). Decision Analysis includes the use of procedures, methods and tools to represent and assess a decision situation, and to recommend a course of action pursuant to the priorities of the decision maker or stakeholders. Unaided decision making works for simple decisions, but may not suffice for complicated decision problems. Decision making relies on the decision maker's intuition, so unaided decision making may result in biases and systematic errors. Several studies have shown how even the simplest Decision Analysis methods are superior to unaided intuition. Currently, DA techniques are successfully used in many private, public and military applications.

Alternative Selection

The selection of alternatives is a decision situation facing every decision maker that is responsible for the allocation of limited resources. It is a common need among these groups to select the optimal solution or package of solutions. Often, there are multiple interested parties and stakeholders for these decisions, so it is important to provide logical decisions in accordance with the organization's stated needs or doctrine. Approaches tend to be either quantitative or qualitative, ranging from rigorous OR methods to social science-based interactive techniques. The family of decision aiding techniques presents a wide range of complexity. Some approaches presented in the literature are so mathematically elaborate that they necessitate the assistance of an expert decision analyst in order to be usable by most real-world managers (Henriksen & Traynor, 1999). Due to the need of this research effort to provide a decision framework that can easily be used by JIEDDO personnel, the focus here will be to select a methodology that provides a "user friendly" product.

Decision Analysis Methodologies

There are various techniques and methods available for analyzing decision problems. Most methodologies include the breaking down or decomposing the problem to better understand the situation. The general outline of these methodologies is to define the problem, identify objectives and examine alternatives. Hierarchical representations are used for many processes to illustrate the decision situation. Two of the most widely-used decision making processes are Value-Focused Thinking (VFT) and the Analytic Hierarchy Process (AHP).

Analytic Hierarchy Process

Although it is not a formal subclass of the Decision Analysis discipline (Howard, 1992), the Analytic Hierarchy Process (AHP) is an accepted technique for dealing with complex decisions. AHP consists of decomposing a decision problem into a hierarchy with sub-problems that can be analyzed independently. Flexibility is emphasized as a key capability of this process. AHP allows all things relevant to the decision to be considered whether the aspect is tangible or intangible, roughly estimated or precisely measured, etc. It is readily able to deal with changes to the priorities concerning a problem and interdependence among the elements of a hierarchy, while tracking the logical consistency of judgments used in determining priorities (Saaty T. L., 2001).

Saaty (2001) also asserts that

> An underlying assumption of AHP is that the complete set of possible alternatives is already available for consideration. The first step of the process is the selection from this possible group of alternatives for a decision situation. The selected alternatives form the bottom level of the hierarchy. Once this bottom level is established, the rest of the hierarchy can be constructed. The next level includes the criteria by which the alternatives can be measured. The priorities of these criteria will be judged in terms of their contribution to the overall focus of the hierarchy, or the ultimate decision that must be made.

When the criteria themselves must be measured in detail, a tier of sub criteria can be inserted between the parent criteria and the alternatives. The hierarchy can be broken down into as many levels necessary to adequately represent the situation. Once this initial model is constructed, it can later be changed to accommodate new criteria or to reflect changes in priorities. Figure 2 is a representation of the basic AHP framework.

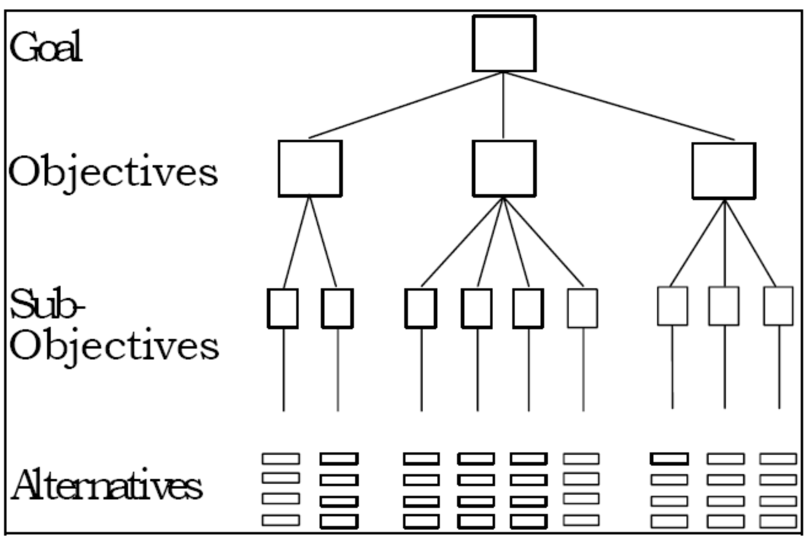


Figure 2. Sample AHP Hierarchy (Colombi, 2007)

The next step of AHP is to establish priorities for the elements of the hierarchy through pairwise comparisons of the alternatives against the criteria. Construction of a matrix (see Table 1) is the preferred process for this analysis. A criterion (C) is selected from the hierarchy, then the alternatives (A_1, A_2,…, A_n) are compared against this property. Numbers are used to represent the relative importance of one alternative over another with respect to the property. The process for determination of these numbers can be seen as subjective, so it is important to implement a systematic practice for this. AHP uses a standard scale of levels 1-9 shown in Table 2 to assign numeric judgments to each element.

Table 1. Sample Matrix for Pairwise Comparison

C	A_1	A_2	A_3
A_1	1	1/2	1/4
A_2	2	1	1/2
A_3	4	2	1
Total	**7**	**3.5**	**1.75**

Table 2. AHP Pairwise Comparison Scale (Saaty T. L., 2001)

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Weak importance of one element over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	Compromise is needed between two judgments
Reciprocals	If activity *i* has one of the preceding numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

After the assignment of numbers, the matrix provides an easily understood representation of the relationship between each alternative and how they fare against each other relative to the criterion. Table 1 is a sample AHP Matrix for pairwise comparisons with nominal data. Note that the diagonal is comprised of "1s" due to the need for unity in representing the comparison of an alternative to itself.

To obtain the set of overall priorities for a decision, the results of the pairwise comparisons must be synthesized in order to get an overall estimate of the relative rank of priorities. To do this, the matrix is normalized by adding the values of each column and then dividing each entry by its column's total. Table 3 illustrates this process with nominal values. For simplicity, the resulting fractions were put into common terms.

Table 3. Normalized Matrix

C	**A_1**	**A_2**	**A_3**
A_1	1/7	1/7	1/7
A_2	2/7	2/7	2/7
A_3	4/7	4/7	4/7

After normalizing the matrix, the new values in each row are averaged. This process reveals the percentages of overall relative preferences:

A_1 = (1/7 + 1/7 + 1/7) / 3 = 1/7 = 0.14

A_2 = (2/7 + 2/7 + 2/7) / 3 = 2/7 = 0.29

A_3 = (4/7 + 4/7 + 4/7) /3 = 4/7 = 0.57

So, in consideration of criterion C, Alternative 3 is about four times more preferable than Alternative 1 in this nominal example.

Another important consideration of AHP is consistency. Judgments should have a relatively high level of consistency, because low consistency can give the appearance of randomness among the scores of the elements. The matrix in Table 1 exhibits good consistency as is evident by the reciprocity of judgment scores for opposite comparisons, e.g. A1 vs. A2 and A2 vs. A1. The consistency index (CI) of a matrix is measured using its eigenvalue. A consistency ratio is then found by comparing the matrix's CI to that of a random matrix of the same size. The accepted ratio of the random matrix CI to the hierarchy matrix CI depends on the size of the matrix under consideration (Saaty T. L., 2001). When the ratio exceeds the maximum acceptable value, the scores within the matrix or even the overall structure of the hierarchy must be revisited. Higher levels of inconsistency can indicate a lack of accurate information and/or understanding of the decision problem.

Value-Focused Thinking

Value-Focused Thinking is another decision analysis method designed to assist in complex decision situations with multiple objectives and priorities. The first fundamental difference between VFT and the previously discussed AHP is the generation of alternatives. Whereas the identification of alternatives is the basis of the AHP hierarchy, alternatives are not considered until the latter steps of the VFT process.

Value-Focused Thinking consists of two overriding activities: first deciding what you want, and then figuring out how to get it. A significant effort is allocated to articulating values in the early steps of VFT. This method incorporates the decision context into values based on what the Decision Maker (DM) wants to achieve. VFT analysis is ideally done with a single DM who is easily accessible and eager to participate in the process. Unfortunately, this is often not possible, and other sources must be consulted for elicitation of values, which is often the most difficult part of the VFT process.

There are three standards of sources for the determination of values: platinum, gold, and silver. Platinum is the most preferred because interviews with senior stakeholders and the actual decision makers are used to determine objectives. Gold is slightly less preferred and uses published policy or strategic planning documents approved by the DMs. The least desirable is silver which is limited to interviews with subject matter experts (SME) and representatives of the stakeholders (Knighton, 2007).

Once the values have been determined, the hierarchy can be created. Whereas the AHP process uses a bottom-up approach for value structuring, VFT employs a top-down approach which starts with an overall value and then subdivides this value into successive levels until measurable values have been reached. Kirkwood (1997) outlines a few desirable properties of value hierarchies that are especially important when using a VFT approach. Hierarchies must be collectively exhaustive and mutually exclusive. That is, the evaluation considerations in each layer must include everything needed to evaluate the decision alternatives, and nothing necessary to do the evaluation can be included in more than one evaluation consideration (Kirkwood, 1997). Unlike an AHP representation, a VFT model must exhibit independence among elements of the hierarchy. This ensures that changing the value of one consideration does not cause a change in a value of another. Since VFT employs an additive value function for the scoring of alternatives, independence among values becomes very important. Finally, complexity and large size should be avoided so that the intended audience can easily understand and use the hierarchy (Kirkwood, 1997). Figure 3 is a representation of the basic VFT hierarchical framework.

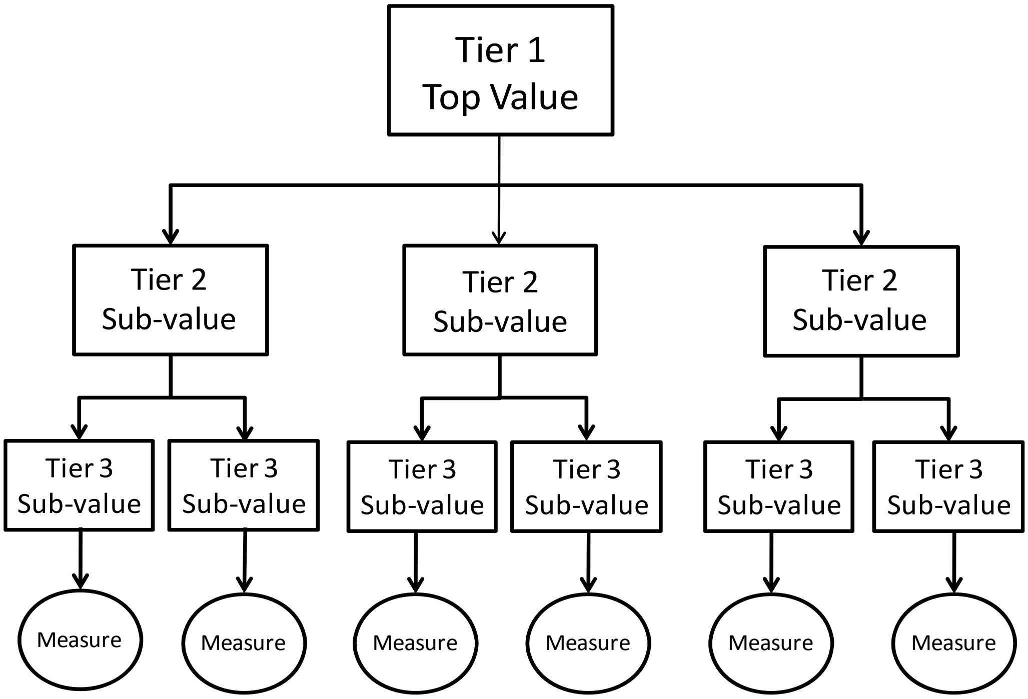


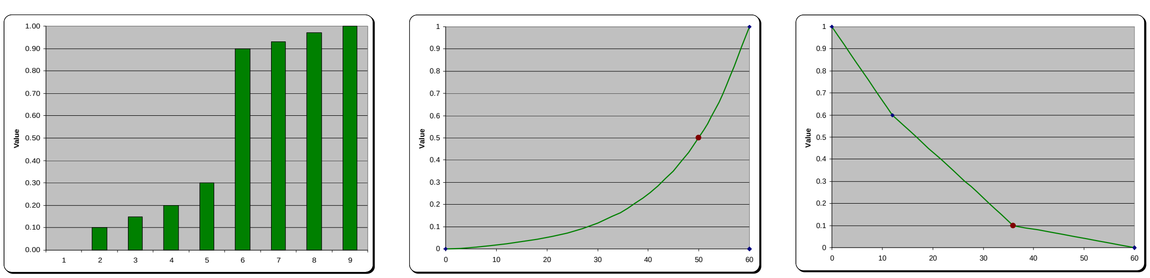
Figure 3. Sample VFT Hierarchy (Kirkwood, 1997)

The next step of the VFT process is to create evaluation measures. Each of the lowest-level values in the hierarchy will be measured for each alternative. Evaluation measure scales can be classified as either *natural* or *constructed*, and also as either *direct* or *proxy* (Kirkwood, 1997). A natural scale is one that is general use and has a common interpretation, for example, time, whereas a constructed scale is developed for a particular decision problem. A direct scale directly measures the degree of attainment of an objective and a proxy scale reflects attainment of the goal, but does not directly measure it. The most desirable situation is to have a natural-direct scale, but this is often not possible in real-world decision situations. Table 4 shows the preferences among the various combinations of scales.

Table 4. Scale Order of Preference

	Natural	Constructed
Direct	Best	Acceptable
Proxy	Acceptable	Least Desirable

Now, the process calls for a mathematical translation of each measure. This is accomplished by using a single-dimensional value function (SDVF) as defined in VFT literature. In the Systems Engineering community, these are referred to as utility curves (Buede, 2000). The benefit of developing SDVFs is that all evaluation measures are transformed into comparable units that can be weighed against each other. SDVFs are either continuous (linear, piecewise linear, or exponential) or discrete (categorical or by value increments), and must be either monotonically increasing or monotonically decreasing (Kirkwood, 1997). This can be seen in the example SDVFs in Figure 4.



Categorical Exponential Piecewise Linear

Figure 4. Single Dimensional Value Function Examples

After SDVFs have been established, the elements of the hierarchy must be weighted. Weighting allows the DM to give relative importance to changes in evaluation measures. For this study, the technique of swing weighting was used. Swing weighting is accomplished by determining the importance of "swinging" an evaluation measure from the least preferred value to the most preferred, placing the "swings" in increasing order of importance, and finally expressing the multiple of all the value swings in terms of multiples of the least important swing. All global weights on the lowest tier must sum to one, as well as all local weights on the same tier.

The next step in the VFT process is the scoring of a set of alternatives according to the following equation:

$$Value(X) = \sum_{i=1}^{n} w_i \, v_i(x_i) \qquad (1)$$

where

Value(X) = the overall score of an alternative
$v_i(x_i)$ = the value of the score on the i^{th} measure
w_i = the weight of the i^{th} measure
n = the total number of measures

Analysis is then conducted by ranking the scores of all alternatives in the set under consideration. Alternatives with higher scores are preferred.

After all the alternatives in the set have been scored, sensitivity analysis is conducted to determine the impact on the ranking of alternatives when changes are made to various model assumptions. A common sensitivity analysis of interest is that of the weights (Kirkwood, 1997). Since weighting of particular values can be a matter of disagreement among stakeholders, it becomes necessary to evaluate the weights on these value to determine whether or not the scores of the alternatives are sensitive based on the weight of a particular value measure. Sensitivity to weighting is measured by ranging the value of a certain measure from zero to one and examining the results in comparison to the original weight. If the overall rankings of the alternatives remain unchanged by varying this weight, then it can be determined that the measure is insensitive. A change to the ranking would indicate sensitivity, and a need to further examine the weighting of the measure in question with the decision makers. Finally, conclusions and recommendations are made to the stakeholders regarding the findings of the model.

Methodology Selection in Published Studies

There are many examples in the literature of the application of DA to the analysis and selection of alternatives. A few will be discussed here with the goal of comparing and contrasting the particular decision situations and examining how they may relate to JIEDDO's decision problem.

Trumm's 2006 study details the implementation of a decision tool to aid in the Air Force's Source Selection Process. Source selection is an extremely detailed and time consuming course of action used to select the best offeror responding to a specific solicitation. Prior to the study, the source selection process for choosing a contractor did not incorporate a standardized objective decision analysis tool; therefore, the process was extremely subjective and provided little guidance to distinguish between highly competitive contractors (Trumm, 2006).

There was published Air Force guidance on the selection of contractors, but this was largely based on price for the proposed job and the contractor's past performance. A Value-Focused Thinking decision model was developed using the existing documentation and collective source selection expertise of a base civil engineering organization. This organization cooperated with researchers to determine measures for contractor evaluation. In addition to the pre-established price and past performance measures, technical excellence, management capability, financial capability and personnel qualifications were determined to be important enough to include in the analysis. The model was developed, contractors were scored, and the model was refined through several iterations.

Trumm determined at the end of his study that Decision Analysis, using VFT in particular, is a viable and essential tool for the source selection process. There were several problems with the existing source selection process, but VFT was shown to remedy these problems through the objective analysis process described in the research.

Another example of a decision aid methodology as it relates to a selection process is Boeg and Koett's 1998 study conducted for the Air Force Research Laboratory (AFRL). In this case, the Analytic Hierarchy Process was used to aid in requirements analysis and to then evaluate competing system proposals. The development of requirements for a large system is well suited to a top-down hierarchy model. High level mission or system needs are identified and then decomposed into lower level operational requirements for the proposed system. This closely follows the hierarchy construction proposed in AHP. Cost was a driving factor in the study, which produced issues with interdependence within the elements of the hierarchy. AHP is equipped to deal with the interdependency whereas VFT is not (Kott, Boag, & Vargas, 1998). Another reason for the choice to use AHP for the study was its application regarding the comparison of alternatives. Here, a finite set of two alternatives was submitted which could be easily compared to one another as the lowest level of the hierarchy. The two system proposals were compared in terms of their ability to satisfy each of the leaf level requirements. The sum of the contributions determined the overall ranking of the solution.

The focus of the study was a technique that could be applied to the different phases of the requirements definition process, and ultimately aid in the evaluation of alternatives. AHP was selected for this analysis because it provided a consistent and low-effort method for estimating the relative impact of each requirement on the system's overall cost, benefits and risk (Kott, Boag, & Vargas, 1998). Again, given the finite set of alternatives, AHP was well suited to determining the best system proposal for selection.

Henriksen and Traynor's 1999 study focused on the establishment of a research and development project selection process based on the relative value to the organization of the proposed research. This study seems to reflect a combination of the aspects of a few different decision methodologies. After reviewing many existing processes, it was determined that a practical model was needed that would be easy for decision makers to understand and use. This was important for the sake of simplicity as well as to bolster support for the proposed process.

The improved scoring technique realized in the Henriksen study incorporated tradeoffs among evaluation criteria. The resulting figure of merit was then combined with a scaled funds request to obtain a value index for each proposed project. The value index algorithm produced a measure of project value that accounted for value as a function of both merit and cost. It was shown that a combined additive/multiplicative algorithm correctly discriminated the desired characteristics and that proposals were ranked consistently with the institution's intended emphasis. (Henriksen & Traynor, 1999)

Like a Value-Focused Thinking approach, this model was initially based on the values of survey respondents. However, it departs from VFT in the use of an additive/multiplicative function for scoring of proposals. Though this method employs a multiplicative aspect, it is unlike the AHP process in than it does not prescribe the existence of a pre-existing finite set of alternatives. In this respect, the process more resembles VFT. It should be noted, though, that the goal of the research was not to simply rank a list of alternatives, but to promote cost effectiveness and maximum utility in R&D activities. The result of the study revealed the 30 top scoring projects of a candidate group. Of note, only 16 of the 30 had actually been selected for funding. The research determined that decision makers are ultimately responsible for the creation of the best portfolio of alternatives to select for funding, and that there certainly may be added value from various combinations of alternatives that would not be revealed if only the top scoring proposals were chosen (Henriksen & Traynor, 1999).

The current study commissioned by JIEDDO was prompted by a classified study conducted at the Air Force Institute of Technology in 2007. This study used the Joint Capabilities Integration and Development System (JCIDS) to identify and prioritize alternative solutions to C-IED capabilities. JCIDS is the early Department of Defense (DoD) life cycle analysis process that refines warfighting concepts, requirements and evaluation criteria for future defense programs (Chairman of the Joint Chiefs of Staff, 2007). The objective of the 2007 AFIT study was to recommend an optimal combination of technology initiatives to Air Combat Command (ACC) for funding.

As with many other DA methodologies, an objectives hierarchy was created for the 2007 AFIT study. That research effort was scoped to focus on materiel alternatives only, due to the difficulty in assessing materiel and non-materiel solutions using the same evaluation model. (Of note, this assessment challenge was also encountered by the current research effort.) The process for constructing the hierarchy was top-down and alternative based. Values and weights were used to determine a priority and competing technologies were ranked against the priority.

The current research builds on the alternative prioritization developed by the previously mentioned AFIT study. However, rather than follow the JCIDS process to develop a one-time prioritized list, this paper will describe an IED defeat Decision Analysis model that can be used repeatedly to evaluate successive alternative sets.

III. Methodology

Methodology Selection for the JIEDDO Decision Problem

Value-Focused Thinking was determined to be the best fit for the C-IED decision problem. However, there is a vigorous debate in the literature between proponents of AHP and Decision Analysis (of which VFT is a part) as to the effectiveness of each method. Therefore, the key points of the debate are summarized here in order to provide a framework for the selection of VFT as the research methodology.

Decision Analysis practitioners question the theoretical underpinnings of AHP and assert that the application of AHP in certain cases allows decision makers to make politically or economically expedient decisions while still claiming the "pedigree" of a formal decision process (Howard, 1992). Critics of DA, by contrast, claim that it is an outmoded technique of limited usefulness, whose axioms do not adequately take into account the situational constraints faced by decision makers (Brown, 1992).

One of the biggest areas of debate is that of the principle of hierarchical composition—the requirement that evaluation criteria be independent of the alternatives considered. The DA community believes that AHP violates this principle, thus leading to the phenomenon of rank reversal when new alternatives are added to a set of previously scored alternatives (Dyer, 1990).

AHP experts counter this claim by stating that alternatives do in fact impact the criteria, and therefore rank reversal should be expected. Based on Saaty's response (1990) to Dyer's criticism, a JIEDDO-related example of rank reversal might be the portfolio management aspect of fielding C-IED technology—as more systems to counter a certain type of IED threat are fielded, the capability gap narrows and the value of each individual system intended to address that gap decreases. Saaty's position is that the addition of alternatives changes the selection criteria and consequently the ranking. Therefore, rank reversal is a logical outcome of the process and not a fallacy in the underlying theory. AHP addresses the rank reversal problem through the use of an extensive supermatrix that requires a large number of pairwise comparisons on the part of the decision maker (Dyer, 1990).

Of note, it is not feasible for a JIEDDO decision maker to perform large numbers of pairwise comparisons every time a new alternative is considered. However, the proposed decision model handles the supply and demand issue without the aid of AHP by incorporating JIEDDO's existing gap prioritization process into the value hierarchy. As the gaps are reassessed on a periodic basis due in part to portfolio management considerations, candidate technologies are evaluated on their ability to meet the currently prioritized gaps.

There are advantages and disadvantages to the application of every decision analysis tool to any real-world decision problem, and the two presented here are no exception. AHP is a very mathematically structured approach which is desirable for the defensibility of the process, but presents a major difficulty in its application to JIEDDO's decision problem. Since C-IED proposals are submitted to JIEDDO on a continuous basis, there will never be a finite set of alternatives to compare, which is key to the AHP methodology. In addition, while AHP claims a theoretical basis (the supermatrix) for addressing the supply and demand issue of portfolio management, the implementation of the VFT model proposed by this paper in conjunction with periodic gap prioritization will accomplish the same goal.

Ultimately, a VFT hierarchy is preferable since it allows for an unlimited number of alternatives to be evaluated in batch sizes determined by JIEDDO, without the necessity of making instantaneous modifications to the hierarchy as new alternatives enter the evaluation cycle. A possible use of AHP would be at the sustain stage of the JCAAMP process where alternatives are known and need to be evaluated against one another for determining continuation of funding.

Development of the Decision Model

After VFT was selected as the preferred methodology, the first step in building the value hierarchy was the elicitation of DM values, which was performed using three different methods. First, the research team attended JIEDDO's October 2007 Technology Outreach Conference to obtain an accurate perspective of the dynamics of the counter-IED mission area. Then, the team also solicited values directly from JIEDDO personnel and finally researched the organization's source documents.

After obtaining the necessary background information, an affinity diagram grouping exercise was performed and a comprehensive value hierarchy was constructed on a whiteboard. The hierarchy was then developed electronically using Hierarchy Builder software developed by Lt Col Jeffery Weir (Weir, 2008) and is depicted in Figure 5.

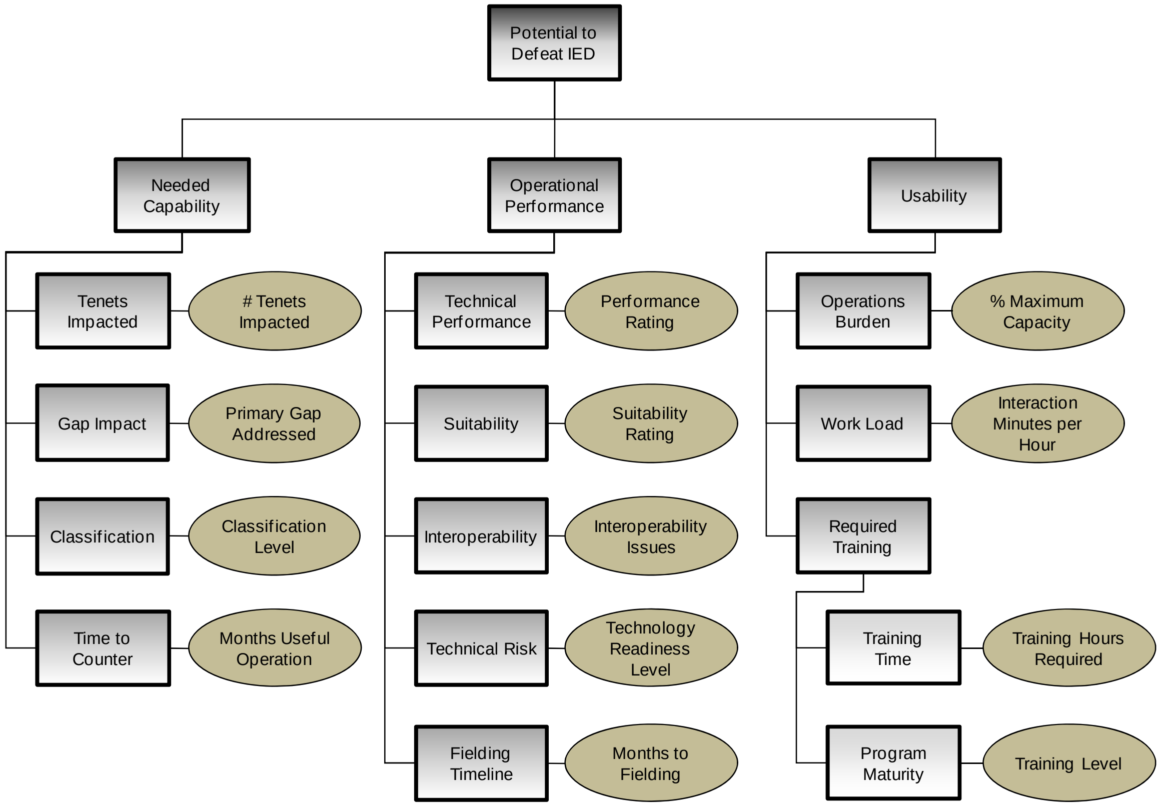


Figure 5. IED Defeat Value Hierarchy

Delineation of Individual Values

Potential to Defeat IEDs was chosen as the overall value for the hierarchy for obvious reasons. The second tier values are Needed Capability, Operational Performance and Usability. Needed Capability addresses how useful the solution will be in the current threat environment. Operational Performance assesses how well the solution meets the criteria for its intended task. Usability, as the name implies, reflects ease of use for the end user. Following are descriptions of the leaf-level values within each of the three branches:

Tenets Impacted ***(Needed Capability)*** answers the question, "Does this proposal impact one or many tenets?" This value allows the hierarchy to capture the synergistic value of a solution that impacts more than one tenet.

Gap Impact ***(Needed Capability)****:* JIEDDO establishes prioritized capability gaps on a periodic basis with input from the Combatant Commands. Thus, the value of a proposal is directly related to the priority of the gap which it targets.

Classification ***(Needed Capability)****:* How easily can this solution be shared among stakeholders within and outside of DoD?

Time to Counter ***(Needed Capability)****:* How long will it take for the enemy to develop a counter-measure for the system?

Technical Performance ***(Operational Performance)****:* The predicted performance of a system while executing its intended mission.

Suitability ***(Operational Performance)****:* How well the system will perform in its intended environment.

Interoperability ***(Operational Performance)*** is the degree to which a system fits into the existing network architecture, whether it can exchange data with supporting and supported systems, and/or whether it can perform its task without negatively impacting friendly assets.

Technical Risk ***(Operational Performance)****:* JIEDDO is a risk-tolerant organization. They are willing to accept technology risk if it is outweighed by other benefits. However, a mature technology will provide more value than an unproven technology for the same performance.

Fielding Timeline ***(Operational Performance)****:* How soon the solution can be fielded. If a solution can't be fielded in a timely manner it becomes much less relevant to JIEDDO—only 10% of their budget is spent on proposals with a timeline of 3 years or longer. "Fielded" is defined as when the first article of a system is delivered.

Operations Burden ***(Usability)****:* The degree to which the system will impact the capacity of its host environment, e.g. bandwidth required by a collaborative software system, weight for a vehicle or soldier mounted system, or rack space required for server enabled analysis system.

Work Load ***(Usability)****:* This value captures the time requirements that the solution places on the user in an operational environment to ensure that the system continues to operate as expected.

Required Training ***(Usability)****:* This value refers to the organic training requirements of each solution and should not be confused with the LOO of "Train the Force". It contains two sub values:

<u>Training Time:</u> How long does it take to train the average user on the solution?

<u>Training Program Maturity:</u> How well does the solution's training capability reflect the actual system when used in its intended environment?

Weighting of Values

After the value hierarchy was constructed, the values were weighted in a process known as swing weighting. This is done considering all values below a single upper tier value and "swinging" each value individually from its least preferred to most preferred levels. The importance of swinging each value is assessed relative to the other values, and the values are ranked from least to most important. The weight of each value is then expressed as a multiple of "k", the weight of the least important value.

Top Tier Weighting

The C-IED mission area is a fluid operational environment. Therefore, the overriding priority is to develop proposals that target the current needs of the C-IED warfighter. A system that does an adequate job and addresses an urgent need is preferable to a system that perfectly fills a low priority or nonexistent capability gap. Therefore Needed Capability was ranked as the most important of the top tier values. Operational Performance was weighted as the next most important because the system needs to be able to do the job it was designed to do in its intended environment.

Table 5. Top Tier Weighting

Value	**k value**	**Weight**
Needed Capability	1.6k	.4
Operational Performance	1.4k	.35
Usability	k	.25

Needed Capability Weighting

The fluid nature of the C-IED battlespace places a premium on JIEDDO's ability to fund initiative portfolios that are precisely targeted at the warfighter's most current capability gaps. Therefore, the most weight was placed on Gap Impact. The next most highly weighted value was Time to Counter, because there is relatively little benefit to funding a proposal that will be quickly rendered irrelevant on the battlefield by enemy countermeasures. Lastly, the least weight was placed on Tenets Impacted and

Classification. A proposal can still be of some value even if it does not impact multiple tenets or is highly classified.

Table 6. Needed Capability Weighting

Value	**k value**	**Weight**
Gap Impact	3k	.44
Time to Counter	2k	.28
Tenets Impacted	k	.14
Classification	k	.14

Operational Performance Weighting

Technical Performance was determined to be the most important value within Operational Performance. The most critical aspect of a device or system within this context is that it is effective in the completion of its intended mission. The next most highly weighted value was Interoperability, because one of the most pressing problems in the C-IED environment is the large number of systems that interfere or are unable to communicate with each other (Jacoby, 2008). Suitability and Fielding Timeline value were weighted next due to the requirement to rapidly field systems that can operate effectively in their intended environment. The team assigned the lowest weight to the value of Technical Risk because JIEDDO is a risk-tolerant organization.

Table 7. Operational Performance Weighting

Value	k value	Weight
Technical Performance	3k	.315
Interoperability	2.5k	.26
Suitability	1.5k	.16
Fielding Timeline	1.5k	.16
Technical Risk	k	.105

Usability Weighting

Work Load was determined to be the most important value due to its potential impact on situational awareness in a combat environment. Operations Burden was weighted the next highest because it impacts users every time they use the system over its entire lifetime. By contrast, Required Training was determined to have the lowest value because the timeline of its impact is limited to the initial familiarization phase.

Table 8. Usability Weighting

Value	k value	Weight
Work Load	1.6k	.40
Operations Burden	1.4k	.35
Required Training	k	.25

Required Training Weighting

Training Time was determined to be more important than Training Program Maturity. It is more desirable to use a “good enough” training program to quickly familiarize a soldier with a system than to use a "perfect" program that takes an excessive amount of training time and delays the soldier's deployment to theater.

Table 9. Required Training Weighting

Value	k value	Weight
Training Time	4k	.8
Training Program Maturity	k	.2

Single Dimensional Value Functions (SDVFs) and Evaluation Measures and Methods

SDVFs, evaluation measures and evaluation methods were developed for each leaf level value and are described in detail below. A combination of categorical, exponential and piecewise linear SDVFs was used. All measures were direct measures and used both natural and constructed scales.

Many people and organizations will be involved in determining inputs to the SDVFs for each proposal. The JIEDDO Initiatives and Technology Branch (ITB) can determine inputs for those SDVFs that do not require specific expertise, such as Tenets Impacted. BIDS evaluators are experts in their field and can be used for technology-centric SDVFs such as Technical Risk. Operations subject matter experts are familiar with the counter-IED mission area and current developments in theater and can best assess values such as Technical Performance. The JIEDDO Technical Gaming Team (TGT) is composed of experts in enemy tactics, techniques procedures and capabilities and can assess proposals' Time to Counter.

Tenets Impacted is assessed using a categorical increasing value function based on a natural scale of the number of positively impacted tenets. The JIEDDO ITB could determine how many tenets are targeted by the proposal. Since a proposal must target at least one tenet to be considered, 50% of the value is awarded for addressing this requirement. Some proposals target more than one tenet, so additional value is awarded for addressing two or three tenets. It is not likely that a proposal will address more than three tenets, so the maximum value is awarded at this level.

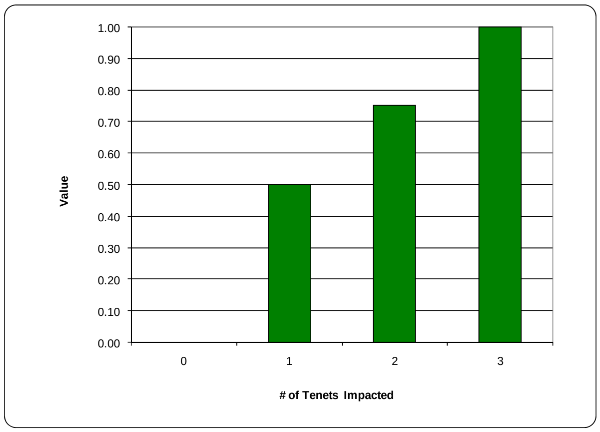


Figure 6. Tenets Impacted SDVF

Gap Impact is represented by a categorical increasing SDVF, with a constructed scale of the prioritized gaps. The JIEDDO ITB could determine which gap is targeted by each proposal, if any, and value assigned to each proposal based on the rank of the gap it targets. Full value is awarded for targeting the highest priority gap, with value measurements linearly decreasing through Gaps #8 and below, which yield a value score of 0.22.

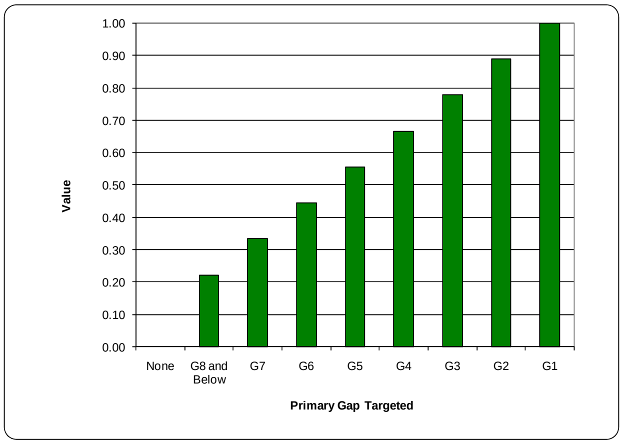


Figure 7. Gap Impact SDVF

<u>*Classification*</u> follows a categorical SDVF using the natural scale of Classification Level, which will be determined by the proponent and validated by the ITB. There is a return to scale of .2 to .5 when moving from the SECRET/NOFORN to SEC/REL levels due to the necessity to share as much as information as possible with our coalition partners, within the bounds of national security. Not being able to share classified information hampers cooperation at all levels of warfare.

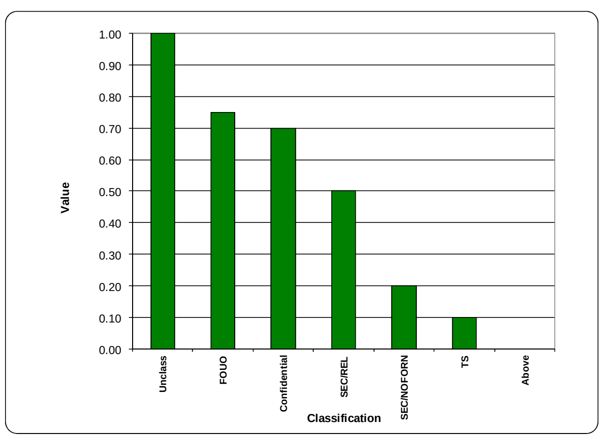


Figure 8. Classification SDVF

Time to Counter is represented by an increasing exponential SDVF measured on a natural scale expressed in months. A proposal must have a projected time to counter of 50 months to get half the available value, because it is desirable to develop and field systems that will provide maximum return on the investment of time and money, and minimize the requirement for end users to learn yet another C-IED system. The SDVF's input would be based on a preliminary assessment conducted by the JIEDDO Technical Gaming Team (TGT). The SDVF exponential is defined by:

$$Value(x) = \frac{1-e^{\frac{x}{15}}}{1-e^{4}} \quad (2)$$

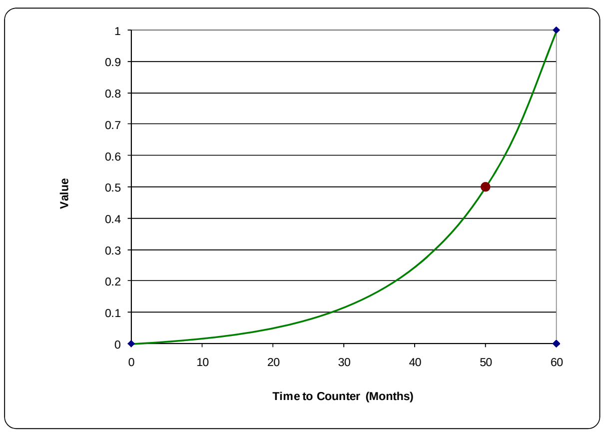


Figure 9. Time to Counter SDVF

Technical Performance is another categorical, linearly increasing SDVF based on a constructed scale (see Table 10). BIDS evaluators could assign a performance rating to a proposal based on how well the system is predicted to meet the requirements of its targeted gap if it functions as advertised by the proponent.

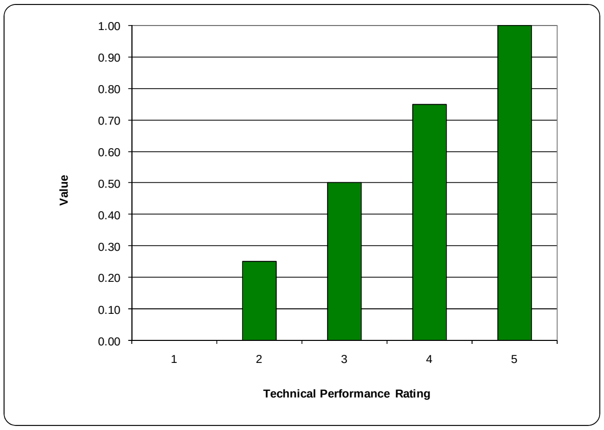


Figure 10. Technical Performance SDVF

Table 10. Technical Performance Assessment Scale

1	Provides none of the capability required by the intended mission.
2	Provides some of the capability required by the intended mission.
3	Provides much of the capability required by the intended mission.
4	Provides most of the capability required by the intended mission.
5	Provides all of the capability required by the intended mission.

Suitability is a categorical, linearly increasing SDVF based on a constructed scale (see Table 11). The suitability rating could be assessed by an operations SME by comparing the system performance parameters provided by the proponent with the conditions likely to be encountered by the system in its area of intended use.

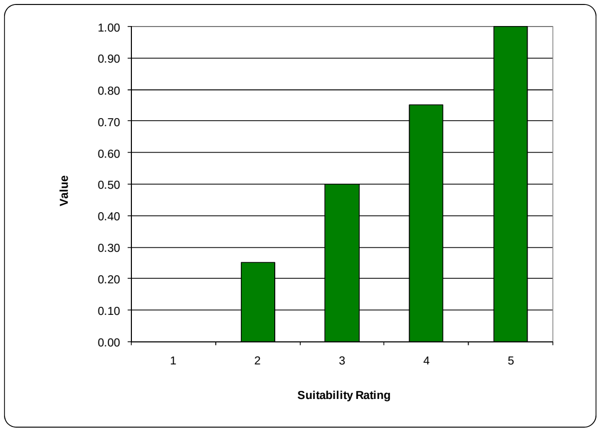


Figure 11. Suitability SDVF

Table 11. Suitability Assessment Scale

1	System performance would be critically degraded in operational environment.
2	System performance would be significantly degraded in operational environment.
3	System performance would be moderately degraded in operational environment.
4	System performance would be slightly degraded in operational environment.
5	System performance would not be degraded in operational environment.

Interoperability is another a categorical, linearly increasing SDVF based on a SME assessment of the level of interoperability issues likely to be associated with integrating the new system into the current C-IED architecture. Selection of a particular SME (electronic warfare, data link, etc.) will be determined by the technology of the system being evaluated. Full value is awarded for those systems that can be seamlessly integrated, while 50% of the available value is awarded for systems with only minor interoperability issues.

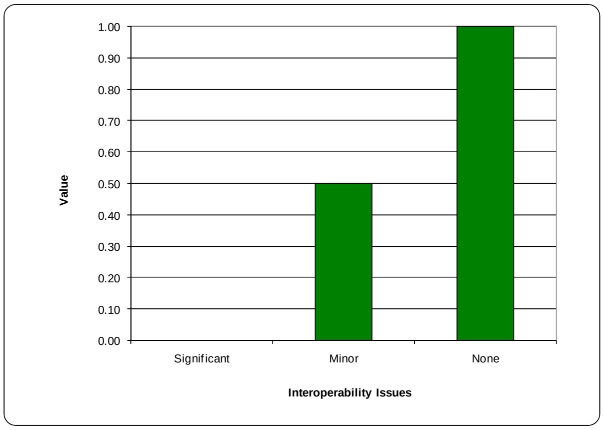


Figure 12. Interoperability SDVF

Table 12. Interoperability Assessment Scale

Significant	Incompatible system links with current architecture, or Electromagnetic Interference (EMI) with other systems that is not easily overcome.
Minor	Incompatibility issues that are easily overcome by minor changes in system design.
None	No issues affecting interoperability of proposal.

Technical Risk is measured using a categorical SDVF based on the constructed but widely used Technology Readiness Level (TRL) scale, located at Appendix A. Since JIEDDO requires that proposals be at a TRL 6 or higher before proceeding from the proposal assessment to initiative evaluation stage, there is a significant return to scale--from 0.3 to 0.9--when moving from TRL 5 to TRL 6. A designated BIDS evaluator could assess Technology Readiness Level.

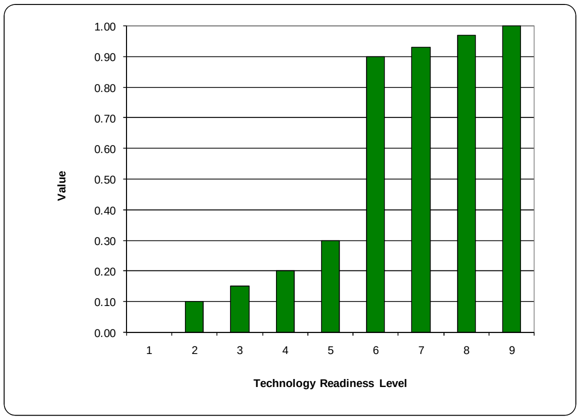


Figure 13. Technical Risk SDVF

Fielding Timeline is assessed by a decreasing piecewise linear SDVF based on a natural scale expressed in months, with breakpoints at 12 and 36 months. Due to JIEDDO's strong preference for proposals that can be fielded within one year (JIEDDO, 2007), 60% of the value is awarded to proposals that meet this criterion. In addition, the return to scale decreases after 36 months because JIEDDO places a very low priority on these long term development efforts. In order to obtain the input for the Fielding Timeline SDVF, an estimated date for delivery of first article could be solicited from the offeror during the BIDS process.

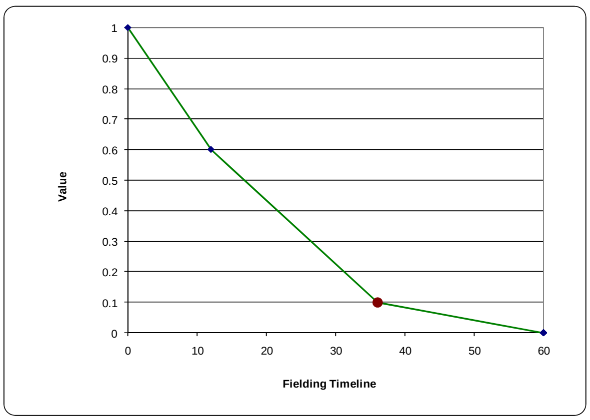


Figure 14. Fielding Timeline SDVF

Operations Burden is a decreasing exponential SDVF using a natural scale expressed in percent of maximum capacity of the equipment or environment in which the system will be employed. A proposed system must be at or below 20% of maximum host system capacity to get half the available value, because most host systems--whether they are humans, vehicles, or communications channels--are already operating near, at or over their maximum capacity. The JIEDDO ITB could compare system data provided by the proponent with the known capacity of the host environment. The SDVF exponential for Operations Burden is defined by:

$$Value(x) = \frac{1-e^{\frac{100-x}{22}}}{1-e^{\frac{100}{22}}} \qquad (3)$$

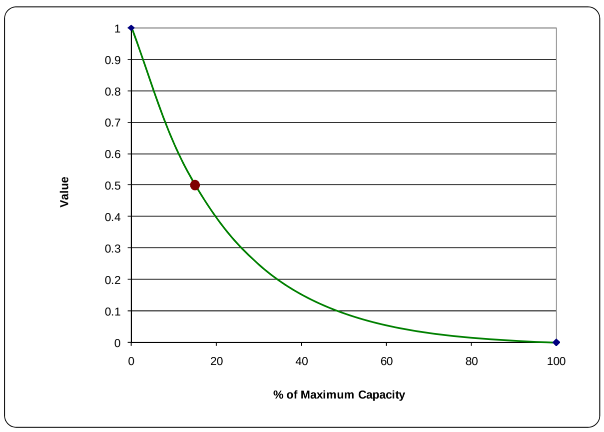


Figure 15. Operations Burden SDVF

Work Load is a decreasing categorical SDVF derived from an exponential curve. It uses a natural scale expressed in interaction minutes per hour in increments of 0-1 minute, 2-5 minutes, 6-15 minutes, 16-30 minutes, and > 30 minutes. A proposed system must require only 5 minutes of user interaction hourly to get a value score of 0.75. End users in mission areas affected by the IED threat are already task saturated, and C-IED is just one of the things they are responsible for. It is critical that C-IED systems not detract from their users' awareness of and attention to the surrounding combat situation.

The underlying exponential for the Work Load SDVF is defined by:

$$Value(x) = \frac{1-e^{\frac{40-x}{7.28}}}{1-e^{\frac{40}{7.28}}} \quad (4)$$

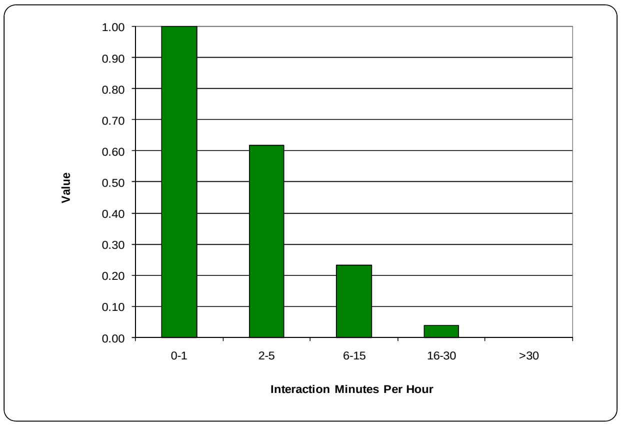


Figure 16. Work Load SDVF

<u>Training Time</u> is another decreasing exponential SDVF using a natural scale expressed in hours. An operations SME could determine the estimated training time required by a proposed system. Since deploying troops already require extensive training before deploying to theater, a system must take eight or fewer hours of training time to get 50% of the available value. The SDVF exponential for Training Time is defined by:

$$Value(x) = \frac{1-e^{\frac{40-x}{12.2}}}{1-e^{\frac{40}{12.2}}} \quad (5)$$

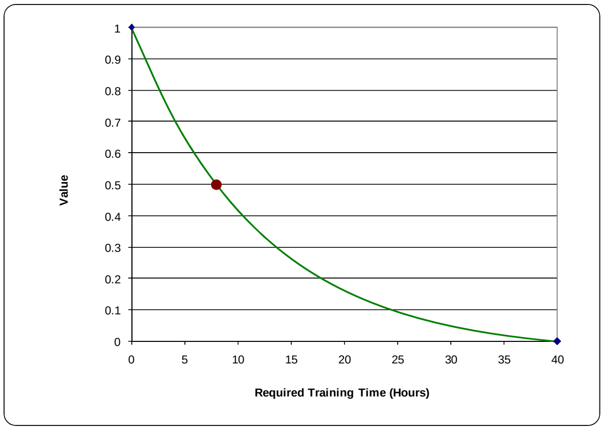


Figure 17. Training Time SDVF

Training Program Maturity is a categorical increasing SDVF based on a constructed Training Readiness Level (TRNL) scale developed by JIEDDO and located at Appendix A. The TRNL of a system could be assessed by the JIEDDO ITB. There is a return to scale from 0.15 to 0.6 when moving from TRNL-2 to TRNL-3 due to JIEDDO's requirement that a proposal be at TRNL-3 before transitioning into the initiative evaluation stage.

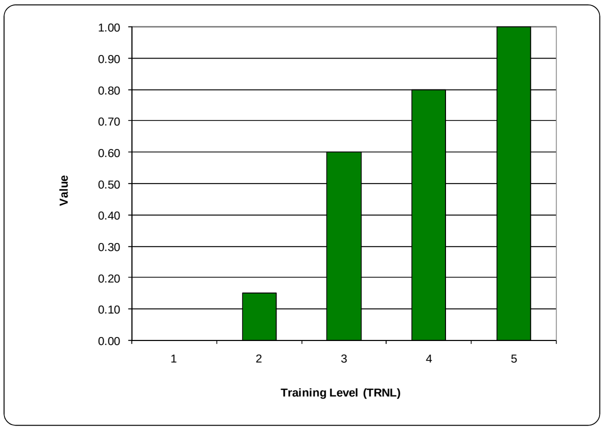


Figure 18. Training Program Maturity SDVF

Additive Value Function

After all SDVF inputs are determined and values calculated for each evaluation measure, the following additive value function will be used to calculate the overall value of each proposal:

$$V(X) = .056v_{Tenets}(x_i) + .176v_{Gaps}(x_i) + .056v_{Class}(x_i) + .112v_{TimeToCounter}(x_i) + .11v_{TechPerf}(x_i) + .056v_{Suit}(x_i) + .091\, v_{Interop}(x_i) + .037v_{TechRisk}(x_i) + .056v_{FieldTime}(x_i) + .087v_{OpsBurden}(x_i) + .1v_{WorkLoad}(x_i) + .05v_{TrngTime}(x_i) + .013v_{TrngMaturity}(x_i) \quad (6)$$

where

X = the proposal under consideration

V(X) = the overall value score of proposal X

x_i = the raw data input associated with proposal attribute i

$v_j(x_i)$ = the score of proposal attribute *i* against its associated evaluation measure *j*.

The complete hierarchy with global weights and evaluation measures is shown in Figure 19. The complete decision model, to include value hierarchy, weights, SDVFs and evaluation measures, was then validated with JIEDDO and appropriate adjustments were made.

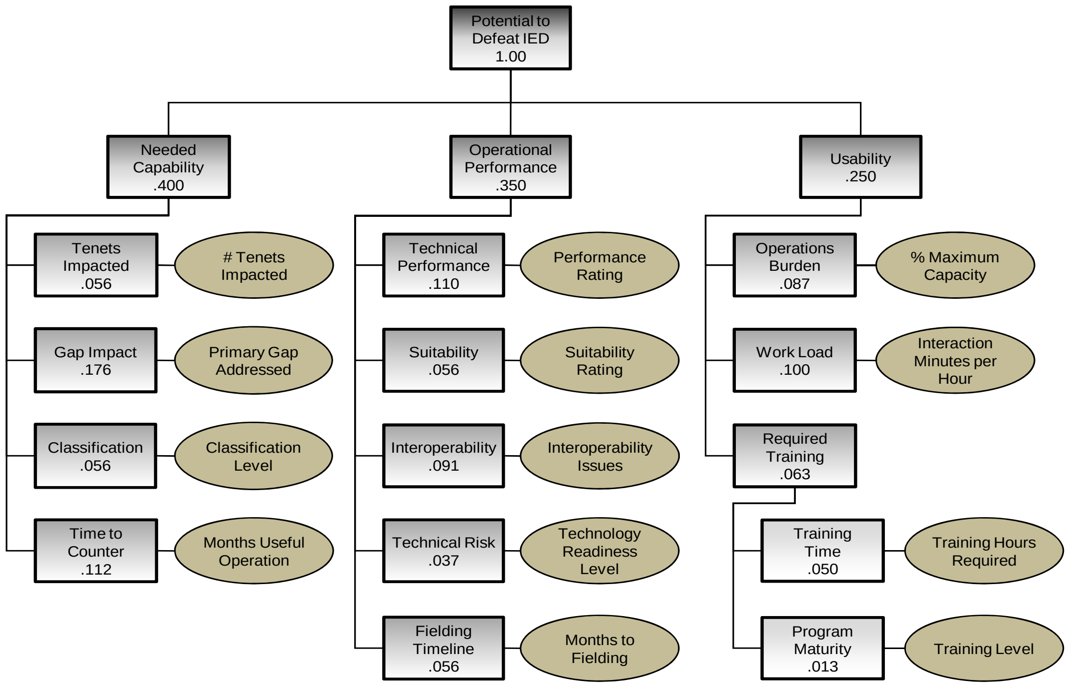


Figure 19. Complete Value Hierarchy

Model Verification

Verification of the completed decision model was accomplished using proposals that have been previously evaluated within the BIDS process. The intent of the verification process was to assess the results of decision model in comparison to the current process and determine what, if any, differences might exist. In fact, slight differences were expected since the decision model, with its increased number of evaluation measures, more thoroughly assesses the merits of a submitted proposal.

In addition to simply assessing the scores and rank order of evaluated proposals, application of the decision model with proposals that have already been assessed within the BIDS process provided significant insight into the current evaluation process as well as highlighting requirements for properly implementing the decision model.

Selection of Proposals for Evaluation

The selection of proposals for use in verification of the decision model was intended to capture a cross section of proposals that have been recently evaluated within the BIDS process. In general there are three categories of proposal evaluation recommendations that emerge from the BIDS process: accept, reject and express reject. Proposals can be express rejected due to improper format or inadequate information included within the submission packet or simply due to obvious lack of technical merit. These proposals were not used in the validation to prevent problems with inadequate evaluation material.

Thirty proposals were selected for use in the verification process with the intent of having an approximately even number that were accepted and rejected. (Due to classification issues associated with the contribution of prioritized capability gaps to individual proposal scores, all proposals are referred to by letters only. The classified key linking the proposals to their letter codes can be obtained by contacting the AFIT Systems Engineering Department, Dr. John Colombi.) The final breakdown included thirteen accepted proposals, all that were available on the BIDS portal at the time of data collection, and seventeen rejected proposals covering all areas of submission for BAA 07-01. Although the intent was to cover both BAA 07-01 and BAA 08-01 in the evaluation, the only proposals that were available for BAA 08-01 were express rejected and therefore not used.

Scoring

In order to validate the decision model while staying within the timeline of the research project, scoring of the individual evaluation measures for each proposal was conducted by the research team. Scores for measures that could be objectively determined from the included proposal information were accomplished first by the entire team by dividing the proposals among the team members. Once this was completed, each member of the research team was assigned two or three evaluation measures, based on background if applicable, and the evaluation measures assigned were scored for all thirty proposals. This was accomplished to ensure consistency in scoring and allow the team members to establish some background for their assigned evaluation measures. The final proposal scoring can be found in Appendix B. Once complete, the scores were entered into the Hierarchy Builder software to calculate and provide a visual representation of the value scores for the proposals, and allow for analysis of the decision model results. Figure 20 illustrates the contribution of individual values to the total score for each of the 30 proposals.

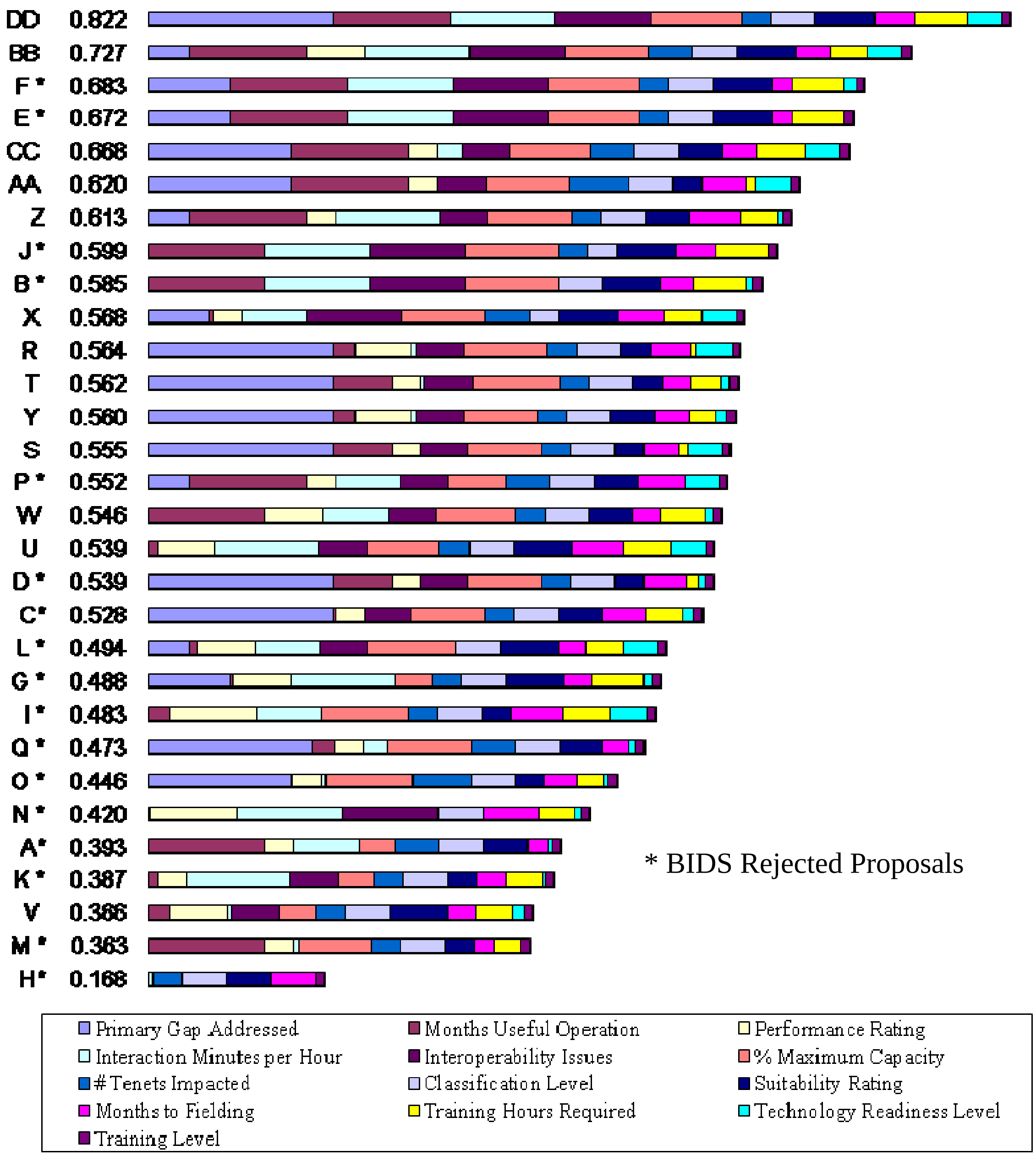


Figure 20. Proposals in Order of Overall Value Score

Sensitivity Analysis

Of particular importance to the evaluation of the decision model performance is the assessment of the sensitivity of each value to changes in the weighting. This analysis provides insight to the impact of changes in weighting and can point out the need for further investigation as to the weighting of particular values within the model. Due to the large number of proposals that were scored in the model, sensitivity analysis was conducted on a reduced set of ten proposals on the expected boundary of accepted and rejected proposals. Evaluation of the sensitivity of weighting for proposals that fell in this area was intended to provide insight into whether weighting changes would potentially adjust scores to more consistently match the results of the current BIDS process.

The primary sensitivity analysis effort was conducted for each value by considering a swing of only that value's weight from zero to one. If the preferred proposal changed as weights were moved in modest increments from the current model levels then the value was considered to be sensitive to weight changes. It was expected that measures for which all proposals scored consistently would show little or no sensitivity to weight changes while those with widely varying scores could be sensitive to both increases and decreases in weighting changes. In addition, some values would likely show sensitivity in only one direction of changes in weighting. This information could be used for further investigation with the decision maker to determine if more detailed evaluation of weighting of values was justified. The sensitivity charts for all individual evaluation measures are included in Appendix C.

In addition to the above described "one way" sensitivity analysis, the research team conducted "two way" sensitivity analysis on the second tier of the hierarchy to determine if the method was feasible for this project and if further insight into weighting sensitivity could be obtained. This analysis was conducted by varying the weight of two of the values on that tier at the same time while proportionally allocating the remaining weight balance to the rest of the values. Since this was conducted on tier two with only three values, the third value received the entire balance of weight that was not assigned to the two variable value weights. The results were then plotted to show regions where different proposals would be selected as the most preferred and highlight the boundaries between these areas where weighting is sensitive to changes. Due to the continuous arrival process of the proposal set, the use of sensitivity analysis to alter weights is likely to take a back seat to the use of results to support selection decisions of closely scored proposals. The two way sensitivity helps this effort by highlighting the proposals within a selected set that would be preferred in all weighting scenarios.

IV. Results and Analysis

Overview

This chapter covers the results of the application of the IED Defeat Hierarchy discussed in Chapter 3 to 30 C-IED proposals, and the associated sensitivity analysis. The hierarchical model determined a rank ordered list of 30 alternatives, shown in Table 13, resulting from the scoring process. Sensitivity analysis on the weights determined for the hierarchy was conducted to allow further insight into the validity of the model, and to reveal where further examination may be needed to more accurately represent the decision maker's values.

Table 13. Rank Ordered Alternatives

Proposal	Score	Proposal	Score	Proposal	Score
DD	.822	**R**	.564	**G***	.488
BB	.727	**T**	.562	**I***	.483
F*	.683	**Y**	.560	**Q***	.473
E*	.672	**S**	.555	**O***	.446
CC	.668	**P***	.552	**N***	.420
AA	.620	**W**	.546	**A***	.393
Z	.613	**U**	.539	**K***	.387
J*	.599	**D***	.539	**V**	.366
B*	.585	**C***	.528	**M***	.363
X	.568	**L***	.494	**H***	.168

Evaluation Assumptions and Results

The information available from the JIEDDO BIDS Web portal was used for the evaluation of the 30 alternatives. White papers and quad charts describing the technical aspects, system features, risk, cost and schedule as approximated by the contractor were obtained through the web site. Evaluations completed by JIEDDO subject matter experts were also available for each proposal. While many of the evaluation measures could be readily scored from information contained in the white papers and quad charts, others were more subjective and certain assumptions had to be made to ensure consistent scoring across the set of 30 proposals.

Research and Development Proposals

There were five C-IED proposals (B, E, F, J and DD) that were pure R&D efforts. In other words, their deliverable was a research paper instead of a prototype system. Scoring these proposals was a challenge because many of the hierarchy's values depend on assessing a fieldable product. The team ensured R&D proposals were consistently scored by assigning them the same inputs for the evaluation measures of Time to Counter (60 months), Technical Performance (1), Suitability (5), Interoperability (None), Operations Burden (0%), Work Load (0-1 minutes per hour), and Training Time (0 hours). These input figures were selected because they most closely matched the value definitions as they apply to a pure R&D proposal. The actual figures would clearly be different for a C-IED system or systems developed as a result of the funded R&D effort.

Gap Impact

The value of Gap Impact was assessed using JIEDDO's May 2007 list of capability gaps. Due to the broad scope of one of the gaps ("Improve standoff detection of vehicle borne IEDs, IEDs, suicide bombers and maritime IEDs,") several diverse proposals addressed that gap and as a result received the same score for Gap Impact. Conversely, other gaps such as "Standoff neutralization that preserves forensic integrity" were more narrowly defined. As a result, although many proposals in the study sample fell under the tenet of Neutralize, only one met the requirement to preserve forensic integrity. The remaining Neutralize proposals did not address any gap and were awarded a score of zero for this value.

Comparison of the values of Gap Impact (light blue) and Technical Performance (cream) in the proposal rack and stack at Figure 20 reveals many proposals that scored well in performance but did not rise high in the ranking because they did not address a high priority gap or did not address a gap at all. This amply demonstrates the decision maker's preference for systems that are relevant to the current operational needs of the warfighter over systems that perform well but do not target a gap. It also highlights the need for JIEDDO to maintain a current, prioritized gap list.

Classification

Classification was measured at the level of classification of the white paper and quad chart of the proposal. As a result, all the proposals but two were assessed as For Official Use Only, and the remaining two were SECRET/REL. Many proposals in their final fielded form will have a higher classification that would be a truer representation of this value, but the research team was not able to determine the future classification as this point. This measure is important in that it represents how easily the proposed system will be proliferated among the US Armed forces, Coalition partners, and Host Nation forces during transition.

Technical Risk

Similar to Classification, Technical Readiness Level (the evaluation measure for Technical Risk) was assessed at the current level instead of the expected TRL of the final product that was advertised in some proposals. However, in this case, the current TRL as of the date of submission is the appropriate place to perform an assessment, because it will impact the likelihood of a proposal's development into a viable fielded system.

Time to Counter

One of the more difficult areas for scoring was Time to Counter. This evaluation was intended to estimate the time a particular system would operate in the IED Defeat effort before the enemy developed tactics to counter the system. Proposals that are not directly designed to detect or counter IED devices generally score high in this evaluation. As an example, a network analysis software system will likely not be countered by the enemy as its primary function is data analysis. On the other hand, proposals that are intended to detect and or counter IED devices were scored lower based on an estimate of how long it would take the enemy to determine how their devices are being affected by the proposed system. If the enemy counter tactic was to stop using the targeted IED device then the proposed system was considered to have continuing effectiveness. However, if the enemy counter tactic allowed the continued use of the IED device with modifications that significantly reduced or negated the effectiveness of the proposed system it was considered to be countered. Although an in depth analysis was not conducted for each proposal considering trends of enemy counter tactics development, the Time to Counter score was estimated by a general assessment of how difficult it would be to determine how the IED devices were being targeted and how difficult a counter tactic would be to develop.

Operations Burden

Operations Burden was a complicated field for scoring since it had to be measured in terms of percent of maximum capacity of such a wide variety of platforms. Some, such as soldier or vehicle capacity, were easily calculated. Other solutions, like software upgrades, were more difficult to score. Assumptions were made about the numerical values of available bandwidth and system capacity to allow the scoring of these solutions. Although the range of the evaluation measure was from 0% to 100%, with one exception the highest figure assessed for this value was 20%. (The exception was a hardened shelter system that is not designed to be transported once it is in place.) This indicates there may be some benefit to readjusting the maximum range of the SDVF to reduce the inactive portion of the independent axis.

Work Load

The majority of systems that received low scores for this value (> 30 minutes per hour of required interaction) were sensor systems that required a human operator to monitor some type of display for an indication of a threat. Higher scores were awarded to those systems that had automatic monitoring and could audibly cue the human operator when their attention was required.

Technical Performance

Scores for Technical Performance fell almost exclusively in the 1 to 3 range out of 5. Only two 4s and no 5s were awarded. There was a wide range of expected performance within each of the two groups of proposals that were awarded scores of 2 or 3. This indicates that the assessment scale for Technical Performance could be redefined or expanded to provide greater distinction between proposals.

Other Values

Fielding Timeline, Interoperability, Suitability and Training Time were easily measured in most cases from information provided in the white papers, quad charts and evaluator comments. Since Training Level could not be assessed with the available information, every proposal received a 3.

Overall Scoring Results

The overall rack and stack produced by scoring the selected proposals against the decision model was provided in Figure 20. Proposals that were rejected by the evaluation conducted in the BIDS process are indicated by an asterisk. In general, the priority reflected previous BIDS decisions to either accept or reject a proposal, with a few exceptions.

R&D proposals scored artificially high in the decision model's rack and stack (DD, F, E, J, and B). As previously discussed, scoring was conducted not against the system which might be developed as a result of the R&D, but on the actual R&D deliverable of a research paper. The scoring methodology resulted in overly optimistic scores for many of the evaluation areas that drove the R&D proposals almost to the top of the rack and stack. This scoring discrepancy demonstrates why R&D proposals do not fit well into the decision model. Figure 21 contains a rank ordered list of the non-R&D proposals that were scored in the model.

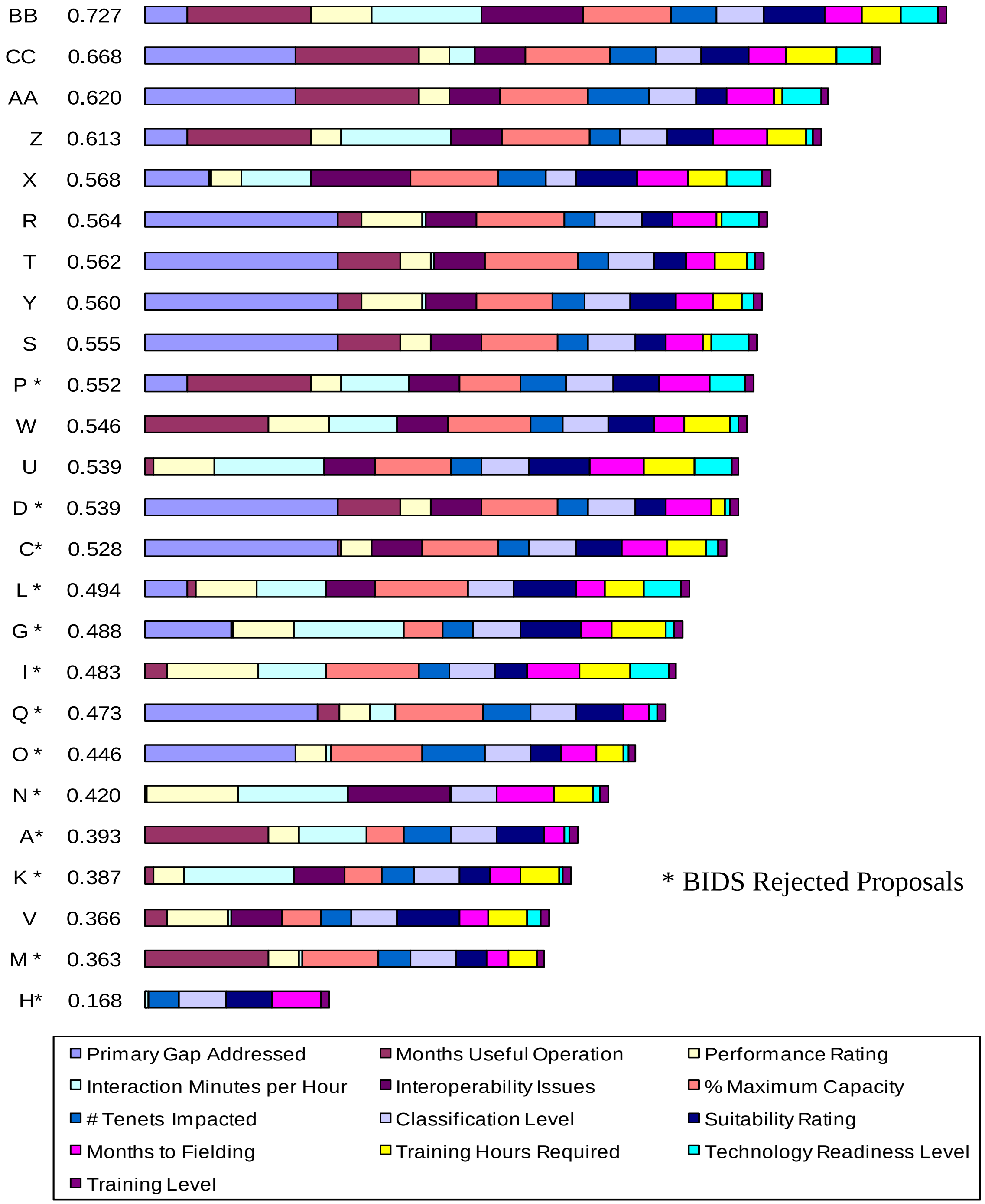


Figure 21. Non-R&D Proposals in Order of Overall Value Score

The two non-R&D outliers were proposal P, which was rejected by the BIDS process but was preferred over two selected proposals by the decision model, and proposal V, which was accepted by the BIDS process but ranked 28th by the model.

Initially the research team was most interested in the BIDS rejected proposals that scored in the upper half of the group as opposed to accepted proposals that scored in the lower half. However, due to the ability of the JCAAMP process to further evaluate and eliminate proposals prior to full funding it is less critical to ensure that some borderline proposals are selected for further investigation as it is to not reject those proposals which have potential to aid in IED defeat efforts. Therefore, the most important outliers to consider for further investigation would be those that fell into the rejected region but could actually provide positive results.

Proposal P was ranked 15th by the decision model. It gained most of its value from Time to Counter, because it is a “behind the scenes” information management system that would not be easily countered by the enemy. However, it scored from mediocre to poor in other areas, and the sensitivity analysis discussion that follows will demonstrate that no combination of weights would make proposal P the preferred alternative.

The other outlier, proposal V, received an average score (3) for Technical Performance, but did not do well in other areas, particularly in Gap Impact. Proposal V does not address a gap so it was awarded the lowest score. Since Gap Impact is the most heavily weighted value, its overall ranking was significantly lower than it would have been if it had targeted a gap.

Sensitivity Analysis

Sensitivity analysis was conducted on a reduced set of ten proposals (X, R, T, Y, S, P*, W, U, D*, C*) from the thirty used to evaluate the decision model. This group of ten was selected for two reasons. First, they include the transition point from predominantly BIDS accepted proposals to predominantly BIDS rejected proposals. Second, this set of proposals was tightly grouped with only a .04 value difference from the highest to lowest score.

One way sensitivity analysis of weights was conducted to see how the preference of the proposal set changed as each of the value weights was transitioned from 0 to 1. Results of this effort can be seen in Appendix C, Sensitivity Analysis. The graphs show current weighting of the measure and total value for each of the ten proposals for a given range of weights. The sensitivity results can be broken up into four categories of weight changes: sensitive to increases, sensitive to decreases, sensitive to both, and not sensitive.

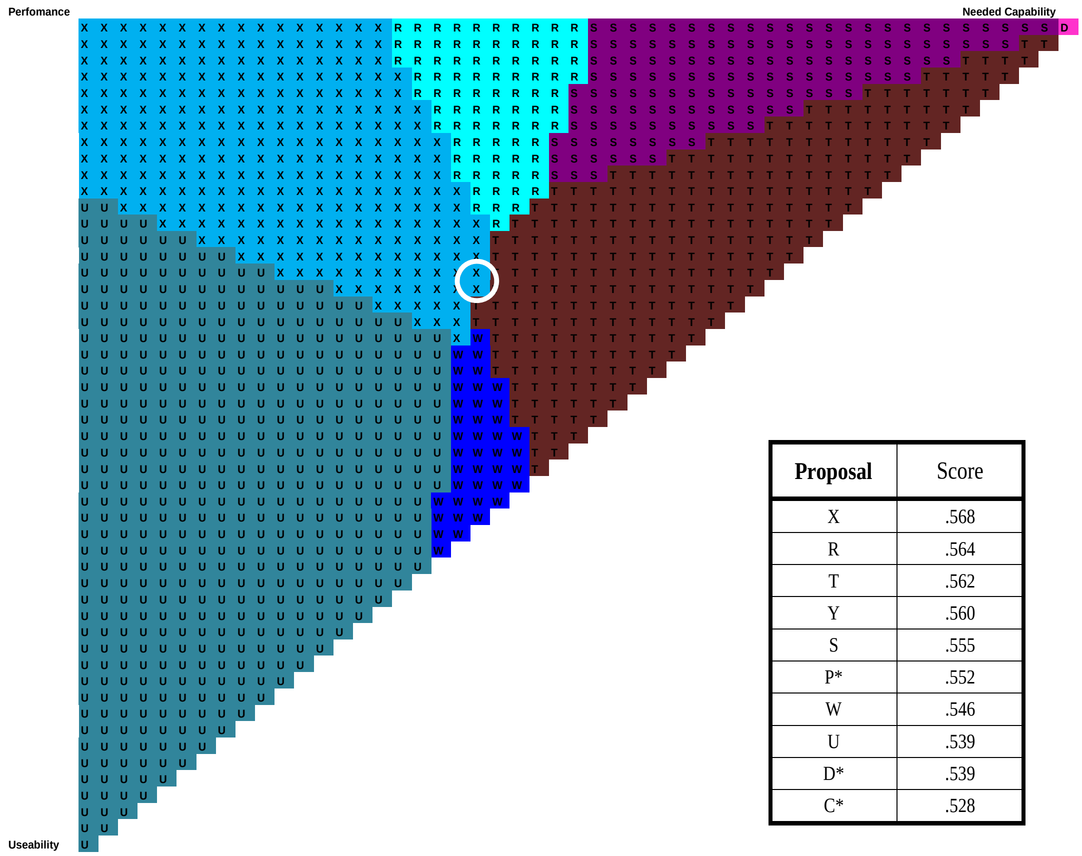
There was a very small delta between the highest and lowest overall score for the proposals, so it was expected that most of the values would have some sensitivity to changes in weights. The values that are sensitive to increases in weight values include Needed Capability, Classification, Time to Counter and Technical Performance. Those which were sensitive to decreases in weight values include Operational Performance, Tenets Impacted, Suitability, Interoperability, Technical Risk, Fielding Timeline and Training Time. Usability, Gap Impact and Work Load were sensitive to both increases and decreases in weight values. Although these values were sensitive to changes in weights, the overall ranking of the proposals indicates that the initial weighting allows the model to match the current BIDS process fairly well. If the R&D proposals are removed from consideration, this model selected 92% of the proposals accepted by BIDS with only one rejected outlier in the top 12 proposals.

The lack of sensitivity to weight changes for Operations Burden and Training Program Maturity can be explained by the scoring of the proposals for these measures. Training Program Maturity could not be evaluated based on the data and resulted in all proposals being scored the same. Operations Burden was also difficult to score and resulted in values that were similar for most of the proposals. Although lack of sensitivity usually indicates the potential to eliminate a value from the hierarchy, in this case it is not justified. An area for further investigation would be to gather high fidelity data for these two measures and reassess the sensitivity of the model to these values.

One way sensitivity analysis is particularly helpful when a fixed set of alternatives are evaluated since changes in the preference order of the alternative set can be observed. The unique situation encountered in this research is the continuous arrival of alternatives which will alter the sensitivity with each newly scored alternative. Since the evaluation of the model was conducted with a discrete set of alternatives, the sensitivity analysis is only useful for initial training of the model. Once the model is in use for continuous evaluation of incoming proposals the ability to adjust the weighting based on sensitivity analysis becomes difficult. One area for further investigation as to the performance of this model with respect to historic BIDS results would be to score all the proposals that have been received to date as a fixed data set. This may provide more insight as to the the sensitivity of the weighting; however, there would be a fairly significant cost in time and effort for this to be accomplished.

In addition to one way sensitivity analysis, the research team explored the usefulness of two way sensitivity analysis where two weights are moved at the same time and all others are adjusted proportionately to their current value. This analysis was conducted on the second tier where there are only three weighted values--Needed Capability, Operational Performance and Usability. Since there were only three values, the group of "others" consisted of the third value, and in essence all three were adjusted at the same time. The results, shown in Figure 22, highlight the areas where one of the ten proposals would be the most preferred if weighting were adjusted to a particular combination of Needed Capability, Operational Performance, and Usability. Each corner of the figure represents where one of the three values has a weight of one and the others have a weight of zero. Needed Capability and Usability both decrease to zero as they move toward the Operational Performance corner, while Operational Performance decreases to zero as it moves toward the hypotenuse of the triangle. The white circle indicates where the current weighting values lie and provides an intuitive presentation of the impact of changing the weights at this level in the hierarchy.

The basic information provided by this analysis does not differ from the one way analysis; however, it does provide some additional insight. Consider the weighting tuple of (Needed Capability, Operational Performance, Usability). If the weighting tuple is moved to increase or decrease one value while maintaining a proportionate relationship between the remaining values, the resulting preferred alternative changes are the same as looking at the one way sensitivity graph. However, if all values are changed simultaneously without maintaining any relationship to the original weight values, this method highlights the resulting change in proposal preference not captured in the one way charts. Finally, the fairly high sensitivity indicated by the one way analysis is supported by the location of the current weighting represented by the white circle.



Proposal	Score
X	.568
R	.564
T	.562
Y	.560
S	.555
P*	.552
W	.546
U	.539
D*	.539
C*	.528

Note 1: This is the location of current weighting indicating high sensitivity to the weights of Needed Capability, Operational Performance, and Usability within this set of proposals.
Note 2: Alternatives D, S and T had the same score for Needed Capability resulting in all three being preferred in this extreme case.

Figure 22. Two Way Sensitivity Region Plot and Proposal List

The insight provided by this analysis comes from its ability to highlight the proposals that would be most preferred for any weighting combination at this tier of the decision model. This information could be used to support decisions of whether to accept or reject those proposals that lie on or near acceptance or rejection boundary. This figure shows six proposals (R,S,T,U,W,X) that would be preferred with only minor changes to the weighting combination which could be used to support selection of this set of six out of the ten compared. Of note, none of the BIDS rejected proposals are highlighted on this figure.

V. Conclusions and Recommendations

The focus of this research effort was to develop a decision model for C-IED proposal selection, not to make change recommendations for JIEDDO's selection process. Following the accepted process of developing a VFT decision model, the student team initially concentrated on JIEDDO's values for IED defeat and the evaluation measures that would best capture those values. Only after the evaluation measures were selected was the JCAAMP process reviewed to determine what was currently being measured and what changes would be needed to effectively implement the model.

Throughout the processes of developing the decision model, reviewing previous evaluations of the sample set of proposals and scoring the same set against the newly developed model, the research team developed several recommendations for JIEDDO's consideration.

Prioritization of Capability Gaps

One of the most critical supporting processes for the decision model is the management of capability gaps. Since the Gap Impact value is the most heavily weighted, scores for this evaluation measure have the most effect on a proposal's overall score. The current portfolio of systems and ongoing evaluations reference a variety of capability gaps and requirements sources including: Joint Urgent Operational Need Statements (JUONs), Multinational Corps-Iraq (MNC-I), emails from units in theater, as well as the requirements cited from the BAA. Given the number of C-IED requirements on record, it is very easy to tie any type of C-IED proposal to a gap. However, since these requirements are coming from many different sources, there is no way to determine the relative importance of multiple targeted gaps. This is where a comprehensive, regularly updated capability gap portfolio will reap the most benefits. The gaps should then be incorporated into the Requirements section of the BAA to ensure offerors clearly understand JIEDDO's priorities at the time of submission.

An additional benefit of a robust gap management process is that it will address the issue of technology duplication addressed in the current BIDS process. As multiple C-IED systems are fielded against a particular need, the associated gap will be demoted on or removed from the master gap listing.

Lastly, gaps should be defined in terms of similar breadth to the maximum extent possible. For example, "standoff detection of IEDs" is much broader than "backtrack vehicles in a rural environment." This leads to many of the proposals being binned into one gap and receiving the full benefit of that gap's priority score, when they are really addressing different pieces of the gap.

Evaluation Process Recommendations

Time to Counter

Currently, JIEDDO's Technical Gaming Team performs an exhaustive assessment of expected "red" (enemy) and "blue" (friendly) actions and reactions regarding specific C-IED systems. However, this assessment is not performed until after a proposal is selected through BIDS and enters the Equip phase (recall Figure 2) of the JCAAMP process. The research team recommends that the TGT support the BIDS process by acting as the subject matter experts for assessing Time to Counter by performing a preliminary, abbreviated assessment of enemy activities that impact each C-IED proposal under consideration.

Classification

Although the classification of a proposal impacts its overall usefulness, most proposals are at a lower classification level during the BIDS process than they will be when fielded. Therefore, the score for this evaluation measure will not return an accurate measure of a proposal's value related to classification. The JIEDDO ITB could resolve this discrepancy by assessing the anticipated classification of the proposal's fielded system.

Training Program Maturity

The BIDS process currently does not require offerors to submit documentation of a training program as part of their proposal. Therefore, there no is no data with which to score proposals against the value of Training Program Maturity. To address this issue, JIEDDO should consider requiring training program documentation as part of the white paper.

Evaluator Assignments

The research team's review of previous evaluator comments for the 30 selected proposals revealed several inconsistencies in the scoring process. Currently, an evaluator scores all measures of a proposal, not just ones on which they have subject matter expertise. For instance, many evaluators input the same comments into their responses for several evaluation measures, or stated that they were not qualified to respond in a particular area. Different evaluator comments also seemed to indicate varying interpretations of the evaluation measures, e.g. one evaluator would comment on technology risk under the "Technology" measure while another would comment on it under the "Schedule Risk" measure.

In order to resolve these discrepancies, it is recommended that the JIEDDO ITB assign specific evaluation measures to individual evaluators according to their area of expertise, as described in Chapter 3. For instance, some measures would require a *technical* expert, while others would require a C-IED *operations* expert or a Red Team analyst. This would preclude evaluators from being asked to assess issues outside their area of expertise.

Evaluator Training

It is further recommended that the value definitions and evaluation instructions contained in Chapter 3 be provided to the evaluators. Proper and thorough evaluator training is the cornerstone of successfully using the value model. Evaluators do not need to be familiar with the single dimensional value function underlying their assigned evaluation measure—they just need to know the value definition and associated instructions and background material. In fact, knowing the form of a value function may actually make it more difficult to make an objective assessment.

A good example of the importance of evaluator training is the most heavily weighted value--Gap Impact. Some capability gaps are narrowly defined, such as "Standoff neutralization that preserves forensic integrity." This means that a proposal must not only be able to neutralize IEDs, but it must be able to do so while allowing for forensic analysis of the detected IED. This rules out predetonation systems and radio frequency suppression systems such as Counter Radio Controlled Electronic Warfare (CREW), which typically neutralize IEDs without detecting them. (Obviously, forensic analysis can not be performed on an undetected IED.) There are many predetonation and RF suppression C-IED proposals that would appear to address the standoff neutralization gap quoted above. An untrained evaluator could easily make a scoring error when assessing a batch of such proposals, leading to an erroneous ranking of the overall portfolio under consideration.

Application to Systems Engineering

Several areas of AFIT's overall research effort--of which this paper is a small part--could be facilitated by the application of system engineering concepts. In particular, an "as-is" architecture could have been developed at the outset of a cooperative research effort comprising multiple teams. The BIDS process that would host this paper's decision model is part of the larger, more complex JCAAMP process. A JIEDDO architecture would have framed the specific C-IED proposal selection decision problem, as well as the other areas of JIEDDO-sponsored research, in a useful context.

In addition to benefiting from the application of systems engineering tools such as architecture, this decision model would also benefit the larger systems engineering effort of developing and fielding the selected C-IED systems. The weights, evaluation measures and single dimensional value functions developed for this paper's value hierarchy could be applied during the requirements development phase of a particular system. For example, they could be used as starting points for the preparation of threshold and objective performance specifications to be applied during operational testing.

Areas for Further Research

Complexity of Technical Risk

After scoring the 30 sample proposals against the decision model in conjunction with reviewing the comments of previous BIDS evaluators, the research team determined that the value of Technical Risk is really the combination of two related values—technical feasibility and technology readiness. Technical feasibility can best be described as the answer to the question "What is the likelihood that this thing will work?" Technology readiness, usually assessed by the widely used Technology Readiness Level (TRL) scale in Appendix A, answers the question "To what fidelity has this system been proven?" Although a TRL can be (and frequently is) used to assess technical feasibility, they are not precisely equivalent. For instance, many proposals received by JIEDDO are highly speculative with little, if any, technical theory to back up their assertions of predicted performance. These systems should be assessed as having both low technical feasibility and low technology readiness. By contrast, another proposed system might be based on the integration of several proven technologies, so it would have a relatively high technical feasibility, but because it is still a "paper-only" idea it should score a low TRL.

Handling of Non-Materiel Solutions

While the decision model is flexible enough to handle different classes of materiel C-IED solutions such as vehicle mounted, soldier-borne or software solutions, it is not a good fit for non-materiel or R&D only proposals. Evaluation measures such as Operations Burden, Interoperability, Suitability, Technical Performance and Technical Risk are not effective measures for non-materiel proposals. As a result, proposals that focus on important theater requirements such as training or influence operations would not score well in the model even if they have significant potential for successful implementation. JIEDDO should evaluate these proposals as a separate group using another decision model.

Investment Analysis

The focus of this paper has been the determination of the value of C-IED proposals. However, as the proposals continue through the JCAAMP process they will become initiatives upon leaving the "Vet" phase, and then be presented to JIEDDO leadership for a funding decision upon entering the "Equip" phase (recall Figure 1). In order to perform an investment analysis of a group of initiatives, the relative cost-value ratio of each initiative must be considered in the context of the funding constraints in place at that time.

Conclusion

Comparison of the results of the research team's rack and stack of the 30 sample proposals with JIEDDO's binary accept or reject process reveals a positive correlation between the two. This indicates that the current selection process reflects the values of JIEDDO decision makers at a macro level.

This decision model will provide traceable, repeatable and defensible scoring of IED defeat proposals in support of JIEDDO's funding decisions. Effective implementation of the model will rely on its use in conjunction with the other process recommendations in this thesis. The scoring information will provide data for trend analysis and responses to external inquiries about JIEDDO's selection decisions. Ultimately, the decision model will provide support and justification for JIEDDO's critical, highly visible and potentially life-saving decisions regarding acceptance or rejection of IED defeat proposals.

Bibliography

Atkinson, R. (2007, September 30). The IED problem is out of control. We have to stop the bleeding. *Washington Post* , p. A13.

Bonder, S. (2008, March). Revised Tenets. (S. Knighton, Interviewer)

Brown, R. V. (1992, December). Response to: Heathens, Heretics, and Cults: The Religious Spectrum of Decision Aiding. *Interfaces* , pp. 24-27.

Buede, D. M. (2000). *The Engineering Design of Systems.* New York: John Wiley and Sons, Inc.

Chairman of the Joint Chiefs of Staff. (2007). *Joint Capabilities Integration and Development System. CJCSI 3170.01E.* Washington DC: Department of Defense.

Chertoff, M. (2007, October 19). *Homeland Security Leadership Journal*. Retrieved December 12, 2007, from Department of Homeland Security: http://www.dhs.gov/journal/leadership/2007/10/preventing-ied-attacks.html

Colombi, J. M. (2007, June). Class handout, SENG 520, Systems Engineering Design. Wright Patterson AFB, OH, USA: Air Force Institute of Technology.

Department of Defense. (2006). *Joint Improvised Explosive Device Defeat Organization (JIEDDO). DODD 2000.19E.* Washington DC: Department of Defense.

Dyer, J. S. (1990, March). Remarks on the Analytic Hierarchy Process. *Management Science* , pp. 249-258.

Global Security Organization. (2007). *www.globalsecurity.org*. Retrieved December 10, 2007, from GlobalSecurity.org: http://www.globalsecurity.org

Henriksen, A. D., & Traynor, A. J. (1999, May). A Practical R&D Project-Selection Scoring Tool. *IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT* , pp. 158-170.

Howard, R. A. (1992, December). Heathens, Heretics, and Cults: The Religious Spectrum of Decision Aiding. *Interfaces* , pp. 15-27.

Jacoby, G. A. (2008, February 14). Senior Research Scientist and Professor, West Point Military Academy. *JIEDDO Briefing* . Wright Patterson AFB, OH, USA.

JIEDDO. (2007). *Joint Improvised Explosive Device Defeat (IEDD) Capability Approval and Acquisition Management Process (JCAAMP). JIEDDOI 5000.01.* Arlington: JIEDDO.

JIEDDO. (2006). *Joint Improvised Explosive Device Defeat Organization (JIEDDO) Annual Report.* Arlington: JIEDDO.

JIEDDO. (2007). *Joint Improvised Explosive Device Defeat Organization About Us*. Retrieved November 5, 2007, from Joint Improvised Explosive Device Defeat Organization : https://www.jieddo.dod.mil/ABOUTJIEDDO/AJHOME.ASPX

JIEDDO. (2007). Technology Outreach Conference. Baltimore: JIEDDO.

Keeney, R. L., & Raiffa, H. (1993). *Decisions with Multiple Objectives Preference and Value Tradeoffs.* New York: Cambridge University Press.

Kirkwood, C. W. (1997). *Strategic Decision Making.* Belmont: Wadsworth Publishing.

Knighton, S. (2007, October 20). Assistant Professor. *Value-Focused Thinking Course Instruction*. Wright-Patterson AFB, OH, USA.

Kott, A., Boag, W., & Vargas, L. (1998). *Application of AHP to Requirements Analysis.* The Carnegie Group.

Saaty, T. L. (1990). An Exposition of the AHP in Reply to the Paper 'Remarks on the Analytic Hierarchy Process'. *Management Science* , 259-268.

Saaty, T. L. (2001). *The Analytic Hierarchy Process for Decisions in a Complex World.* Pittsburgh: RWS Publications.

Trumm, J. R. (2006). *A Decision Analyis Tool for the Source Selection Process.* Wright-Patterson AFB: Air Force Institute of Technology.

Weir, J. D. (2008). Decision Analysis Excel Add In. Wright-Patterson AFB, OH, United States.

Appendix A: JIEDDO Assessment Scales

Technology Readiness Levels (JIEDDO, 2007)

TRL	Description
1	Basic principles observed and reported. Lowest level of technology maturation. At this level, scientific research begins to be translated into applied research and development. Cost to achieve: Very low "Unique" cost (investment cost is borne by scientific research programs).
2	Technology concept and/or application formulated. Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be "invented" or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture. Cost to achieve: Very low "Unique" cost (investment cost is borne by scientific research programs).
3	Analytical and experimental critical function and/or characteristic proof-of-concept. At this step in the maturation process, active Research and Development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute proof-of-concept validation of the applications/concepts formulated at TRL 2. Cost to achieve: Low "Unique" cost (technology specific).
4	Component validation in laboratory environment. Following successful proof-of-concept work, basic technological elements are integrated to establish that the "pieces" will work together to achieve concept-enabling levels of performance for a component. This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is relatively "low-fidelity" compared to the eventual system: it could be composed of ad-hoc discrete components in a laboratory.
5	Component validation in relevant environment. At this, the fidelity of the component being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level or system-level) can be tested in a simulated or somewhat realistic environment. From one-to-several new technologies might be involved in the demonstration. Cost to achieve: Moderate "Unique" cost (investment cost will be technology dependent, but likely

	to be several factors greater than cost to achieve TRL 4.
6	System/subsystem model or prototype demonstration in a relevant environment. A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model, prototype system or system –would be tested in a relevant environment. Of course, the demonstration should be successful to represent a true TRL 6. Not all technologies will undergo a TRL 6 demonstration: at this point the maturation step is driven more by assuring management confidence than by R&D requirements. The demonstration might represent an actual system application, or it might only be similar to the planned application, but using the same technologies. At this level, several, to many new technologies might be integrated into the demonstration. Cost to achieve: Technology and demonstration specific.
7	TRL is a significant step beyond TRL 6, requiring an actual system prototype demonstration. It has not always been implemented in the past. In this case, the prototype should be near or at the scale of the planned operational system and the demonstration must take place in an operational environment. The driving purposes for achieving this level of maturity are to assure system engineering and development management confidence (more than for purposes of technology R&D). Therefore, the demonstration must be of a prototype of that application. Not all technologies in all systems will go to this level. TRL 7 would normally only be preformed in cases where the technology and /or subsystem application Is mission critical and relatively high risk. Cost to achieve: technology and demonstration specific, but a significant fraction of the cost of TRL 8.
8	Actual system completed through test and demonstration. Actual system qualified through test and demonstration. By definition, all technologies being applied in actual systems go through TRL 8. In almost all cases, this level is the end of true ‘system development’ for most technology elements. This might include integration of new technology into an existing system. Cost to achieve: Mission specific; typically highest unique cost for a new technology.
9	Actual system proven through successful mission operations. By definition. All technologies being applied in actual systems go through TRL 9. In almost all cases, the end of last ‘bug fixing’ aspects of true ‘system development’. This TRL does not include planned product improvement of on going or reusable systems. Cost to achieve: Mission Specific; less than cost of the TRL 8.

Training Levels (JIEDDO, 2007)

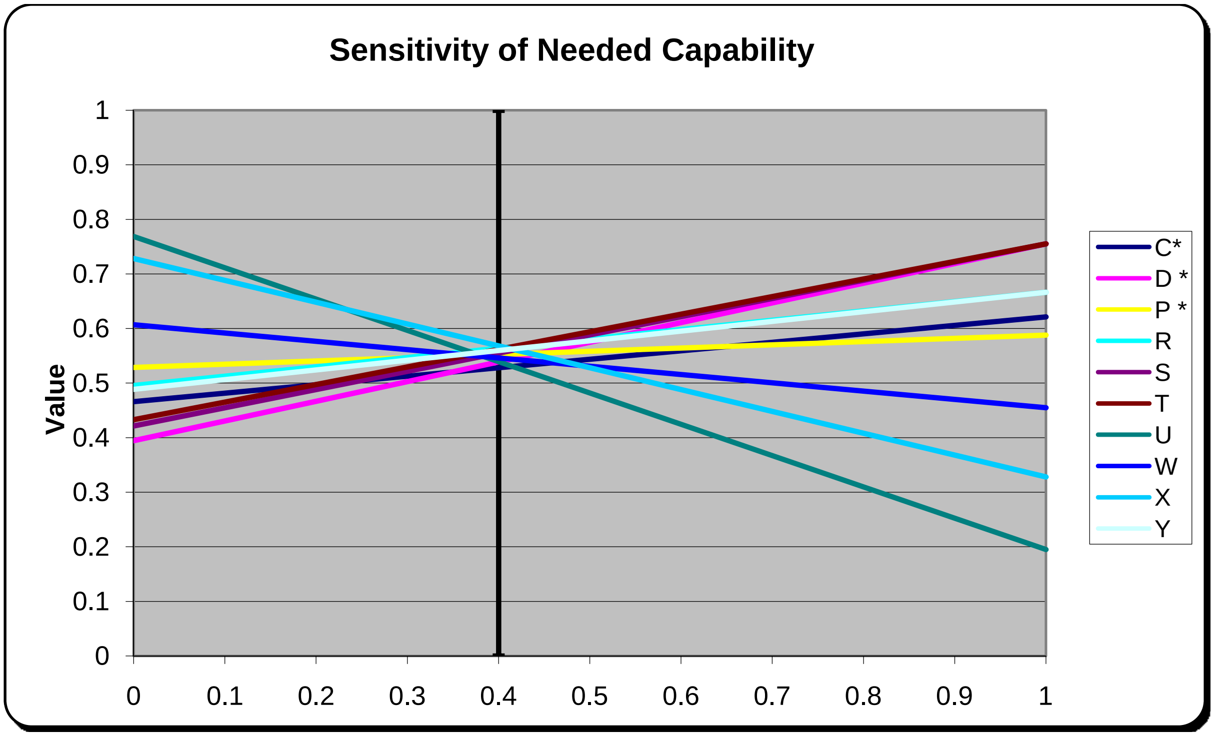
TRNL	Description
1	Initial – Training Program does not exist or…Potential training program is considered but lacks any formal documentation. Cost, distribution, schedule, functionality and maintenance have not been defined.
2	Repeatable – All appropriate items in TRL 1 are satisfied. Training program is defined with some form of documentation. Cost, distribution, schedule, functionality and maintenance (all) issues have been considered to the point of initial written definition.
3	Defined – All items in TRL 2 are satisfied. Long-term management issues (such as PM and FM) have been considered. Hand-off to future Service sponsor has been considered and initial liaison has shown potential concurrence by that sponsor. Prototype hardware/software has been produced and demonstrated in an equivalent environment. Standards for production have been defined.
4	Managed – All items in TRL 3 are satisfied. Actual hardware/software has been produced and demonstrated in an actual environment. Standards for production have been achieved.
5	Optimizing – All items in TRL 4 are satisfied. Processes to update and improve the system are in place and demonstrated. System is considered ready to transition to a Service.

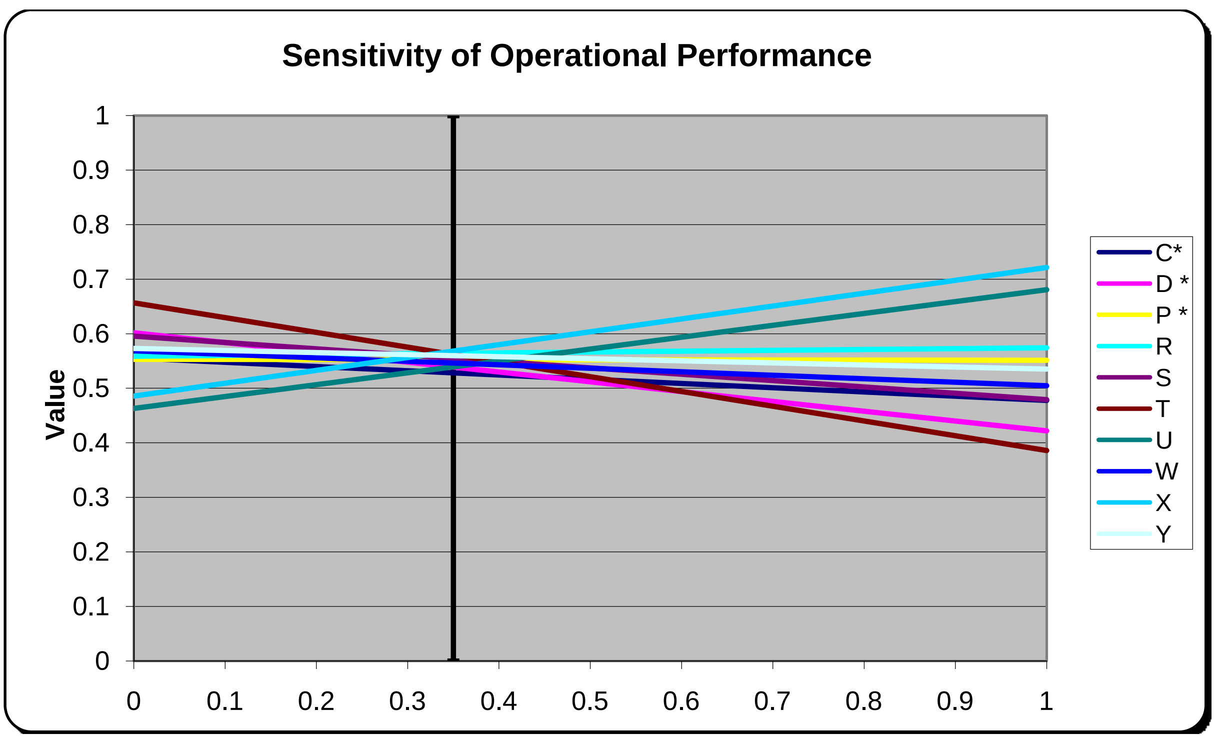
Appendix B: Proposal Scoring

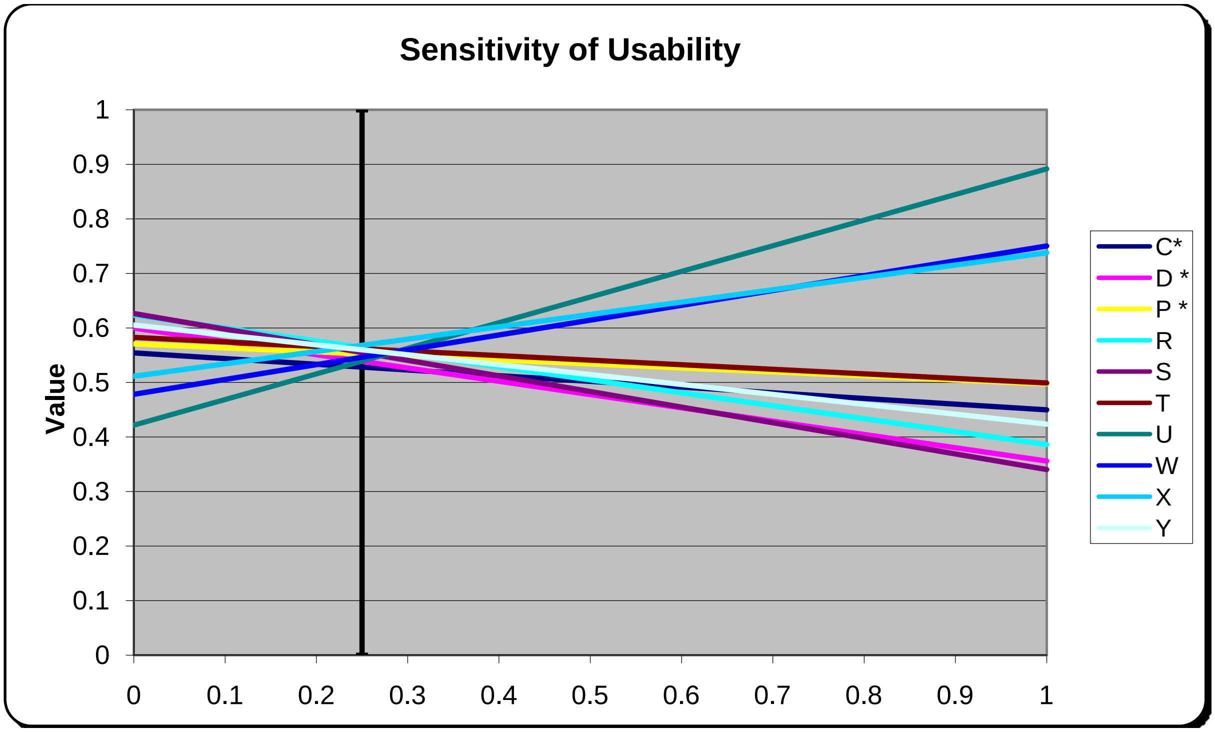
Alternative	# Tenets	Primary Gap	Classification	Months Useful	Performance	Suitability	Interop. Issues
A*	2	None	FOUO	60	2	4	Significant
B *	0	None	FOUO	60	1	5	None
C*	1	G1	FOUO	12	2	4	Minor
D *	1	G1	FOUO	50	2	3	Minor
E *	1	G6	FOUO	60	1	5	None
F *	1	G6	FOUO	60	1	5	None
G *	1	G6	FOUO	12	3	5	Significant
H*	1	None	FOUO	1	1	4	Significant
I *	1	None	FOUO	36	4	3	Significant
J *	1	None	SEC/REL	60	1	5	None
K *	1	None	FOUO	24	2	3	Minor
L *	0	G8 and Below	FOUO	24	3	5	Minor
M *	1	None	FOUO	60	2	3	Significant
N *	0	None	FOUO	12	4	1	None
O *	3	G3	FOUO	3	2	3	Significant
P *	2	G8 and Below	FOUO	60	2	4	Minor
Q *	2	G2	FOUO	36	2	4	Significant
R	1	G1	FOUO	36	3	3	Minor
S	1	G1	FOUO	50	2	3	Minor
T	1	G1	FOUO	50	2	3	Minor
U	1	None	FOUO	24	3	5	Minor
V	1	None	FOUO	36	3	5	Minor
W	1	None	FOUO	60	3	4	Minor
X	2	G7	SEC/REL	12	2	5	None
Y	1	G1	FOUO	36	3	4	Minor
Z	1	G8 and Below	FOUO	60	2	4	Minor
AA	3	G3	FOUO	60	2	3	Minor
BB	2	G8 and Below	FOUO	60	3	5	None
CC	2	G3	FOUO	60	2	4	Minor
DD	1	G1	FOUO	60	1	5	None

Alternative	TRL	Months to Fielding	% Max Capacity	Interaction Min/Hr	Training Hours	Training Level
A*	2	24	20	2-5	40	3
B *	4	14	0	0-1	0	3
C*	5	8	5	>30	4	3
D *	3	8	5	>30	16	3
E *	1	24	0	0-1	0	3
F *	5	24	0	0-1	0	3
G *	4	18	20	0-1	0	3
H*	1	6	100	16-30	40	3
I *	7	4	1	2-5	1	3
J *	1	9	0	0-1	0	3
K *	2	18	20	0-1	4	3
L *	6	18	1	2-5	4	3
M *	1	24	5	16-30	8	3
N *	3	2	80	0-1	4	3
O *	2	14	1	16-30	8	3
P *	6	6	10	2-5	40	3
Q *	4	20	2	6-15	80	3
R	6	9	2	16-30	24	3
S	6	12	5	>30	20	3
T	4	18	1	16-30	6	3
U	6	4	5	0-1	1	3
V	5	18	20	16-30	4	3
W	4	18	3	2-5	2	3
X	6	6	2	2-5	4	3
Y	5	12	5	16-30	8	3
Z	3	4	2	0-1	4	3
AA	7	7	2	>30	20	3
BB	6	12	2	0-1	4	3
CC	6	12	3	6-15	1	3
DD	6	9	0	0-1	0	3

Appendix C: Sensitivity Graphs



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0.2
0.3
0.4
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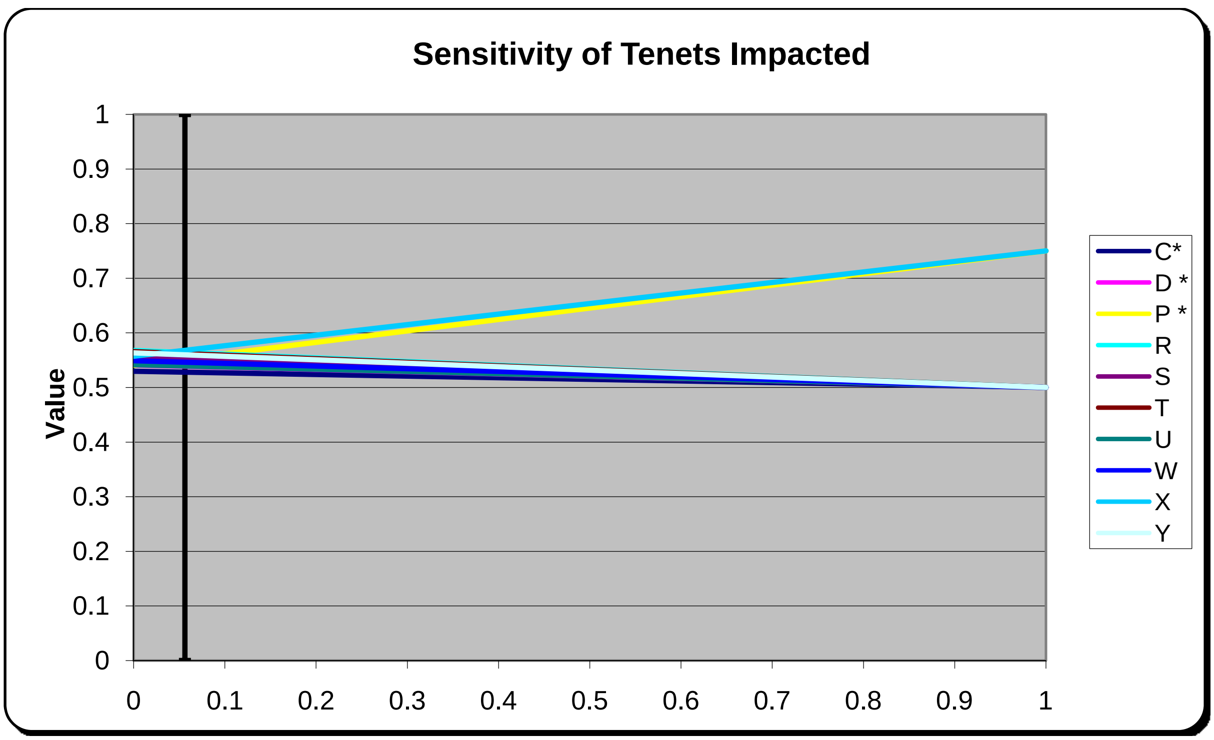
D *
P *
R
S
T
U
W
X
Y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0.4
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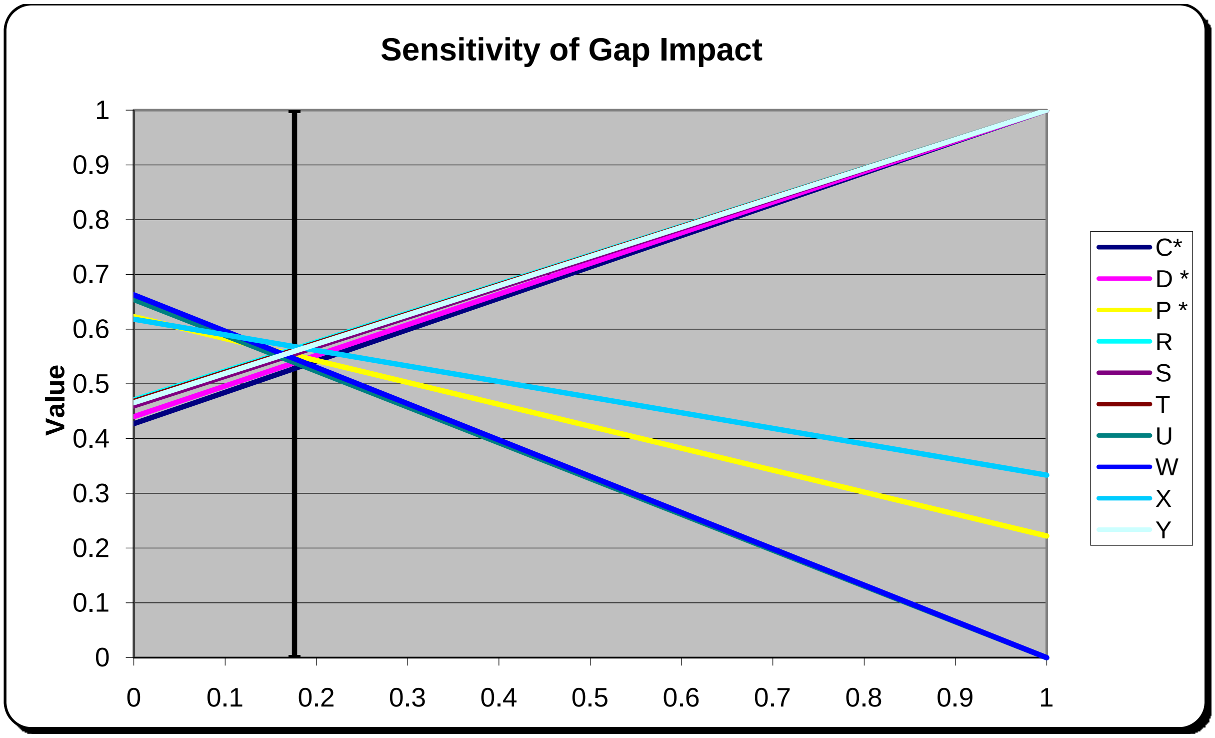
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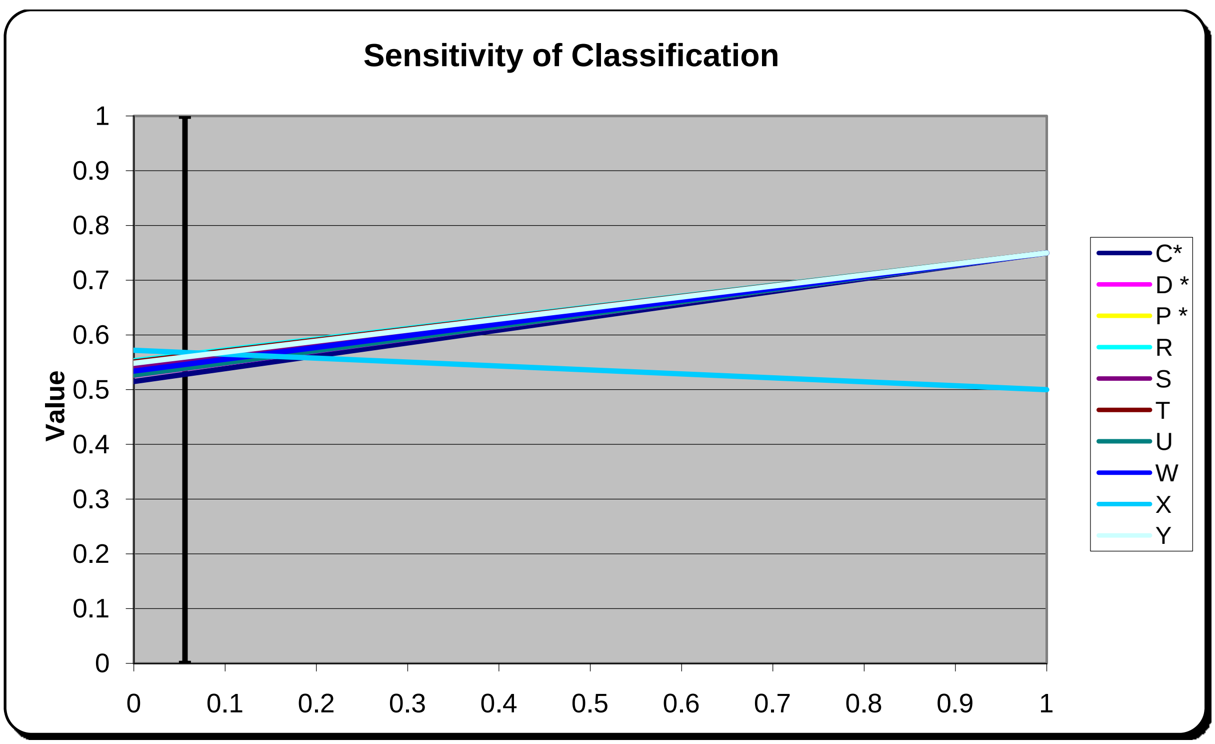
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P *
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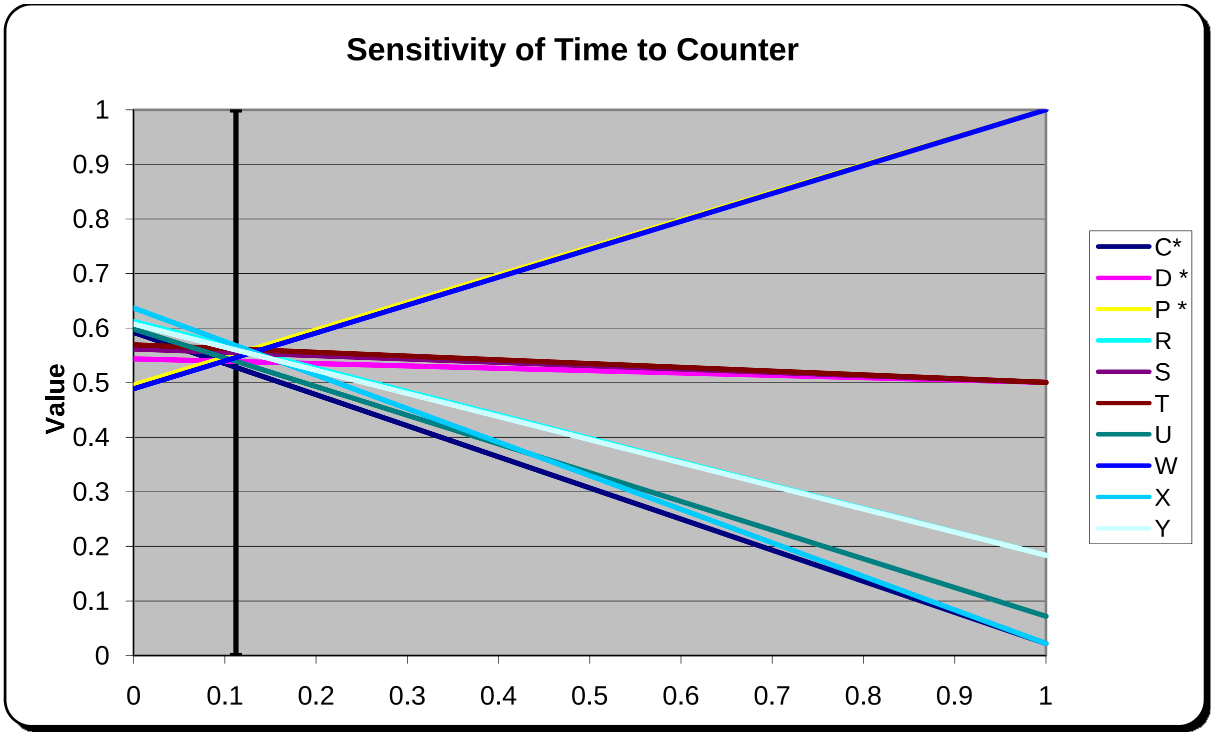
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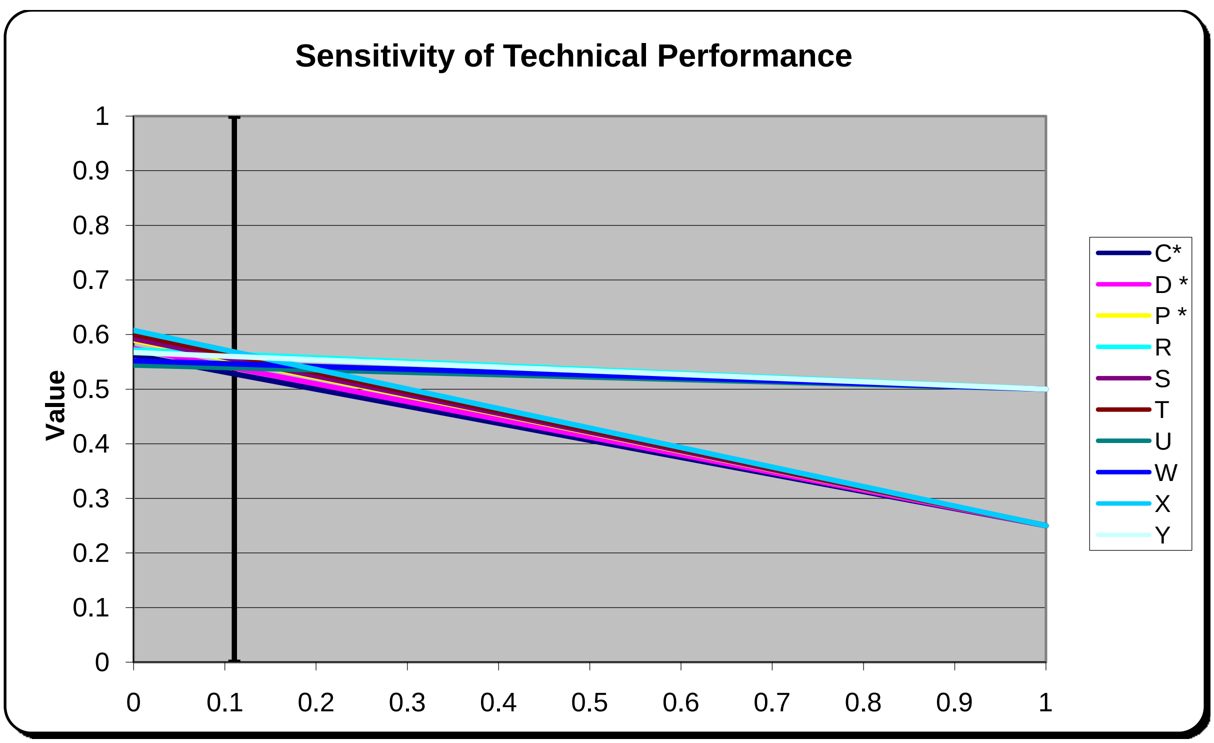
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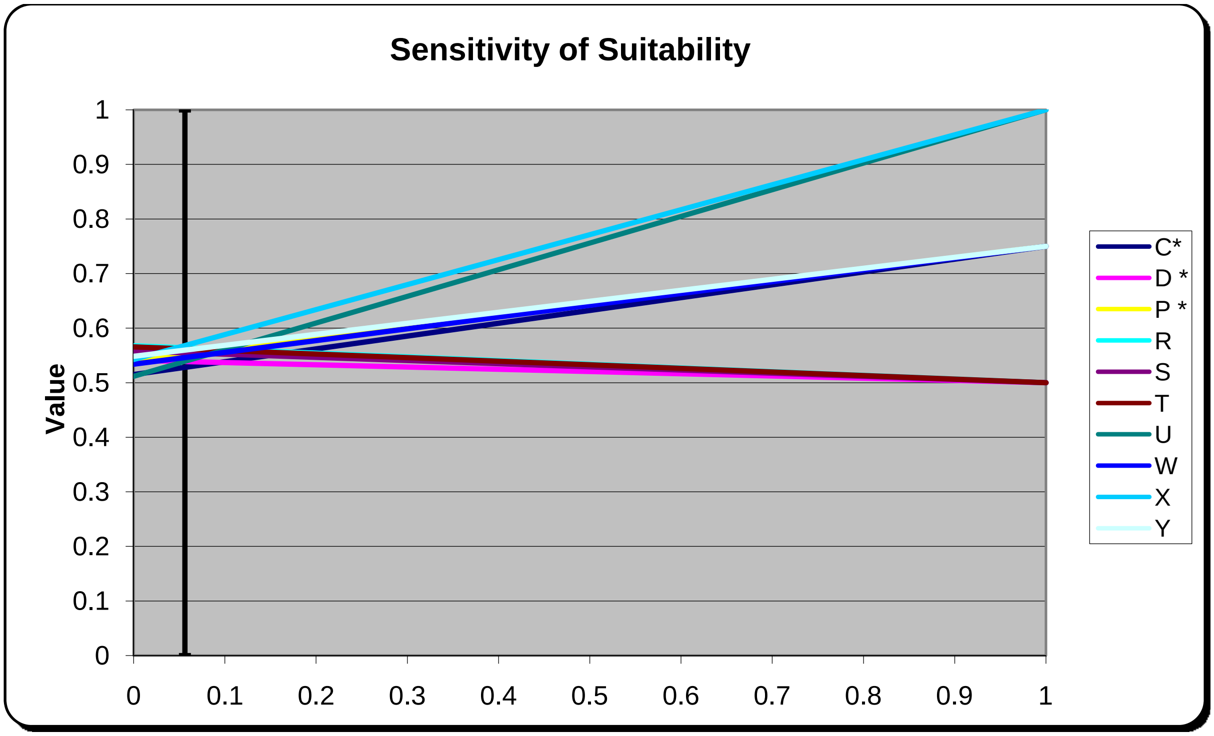
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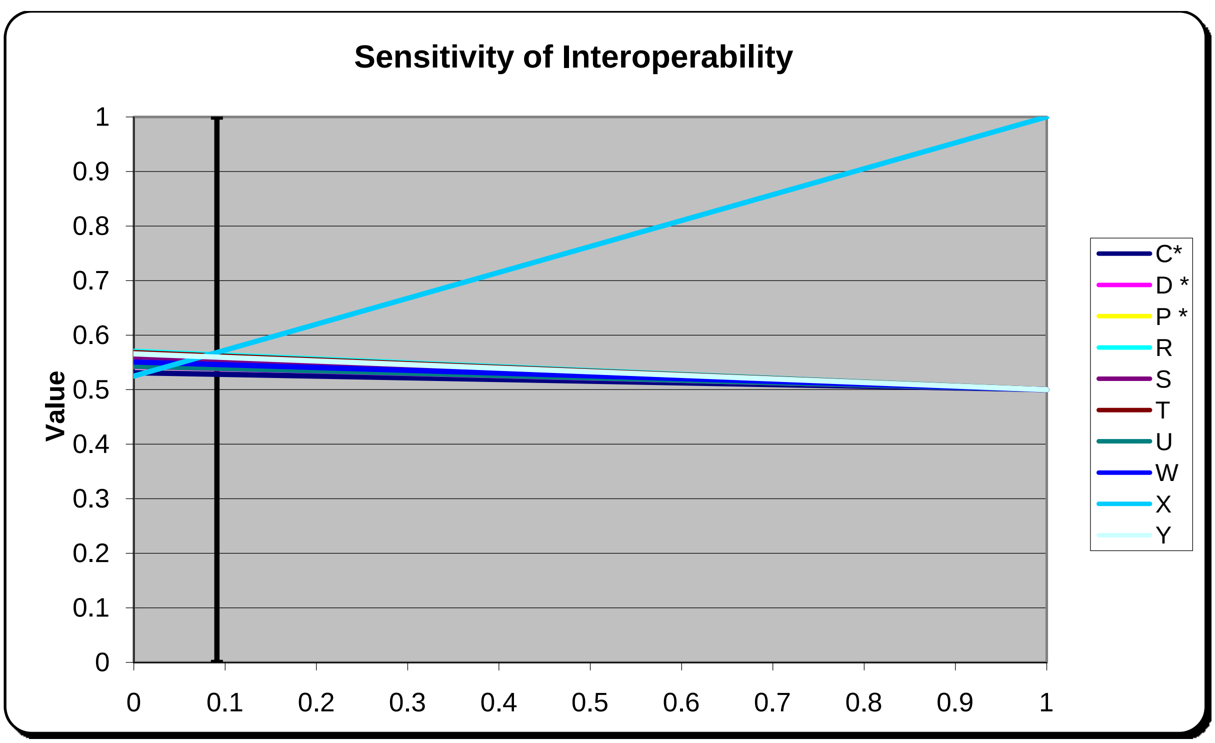
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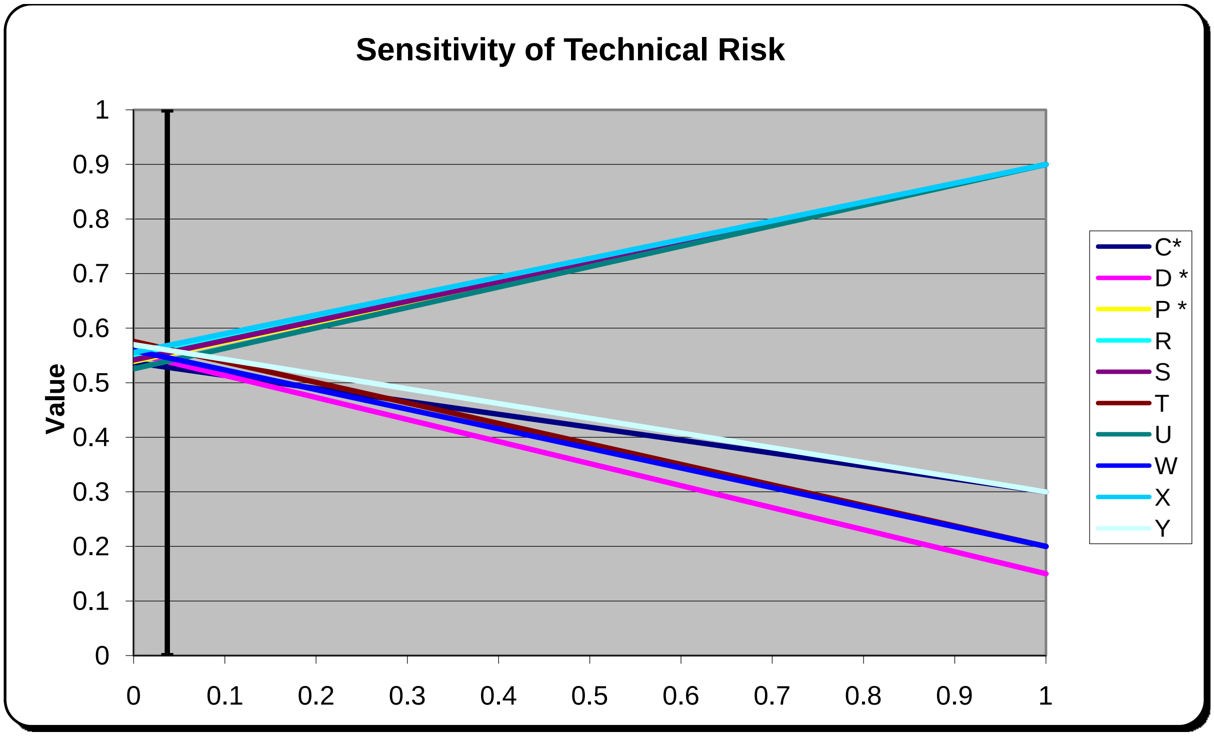
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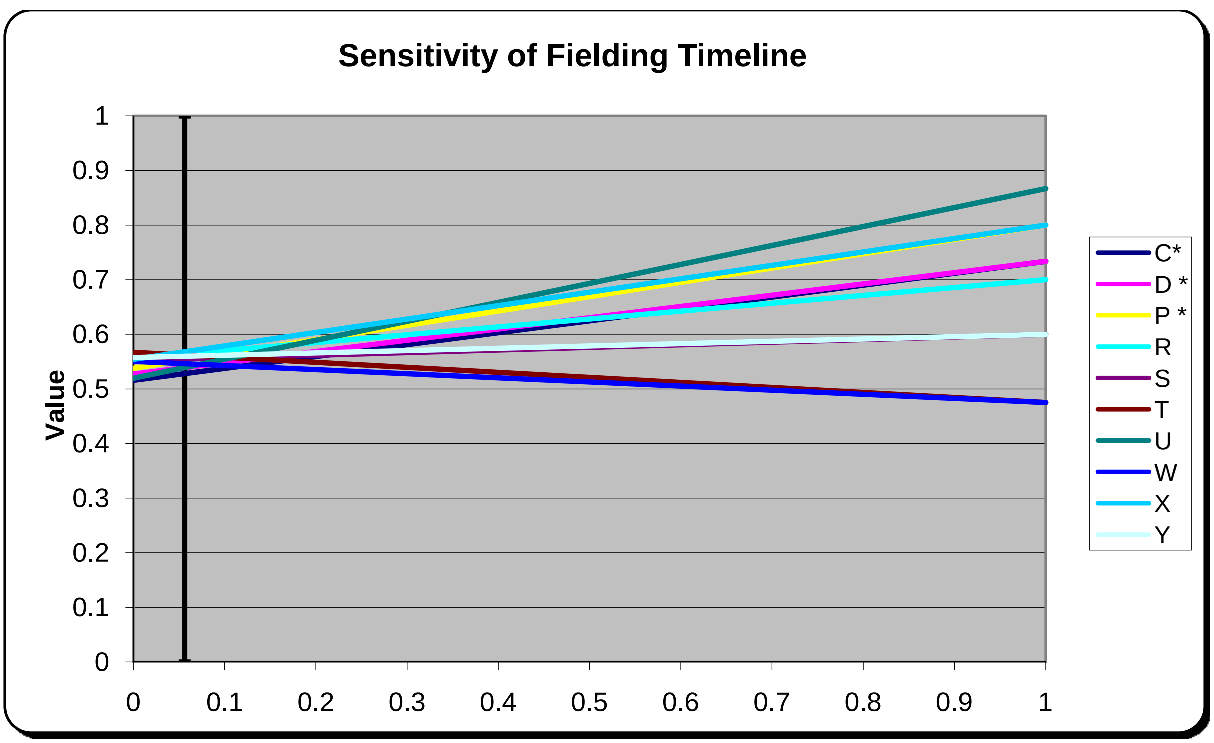
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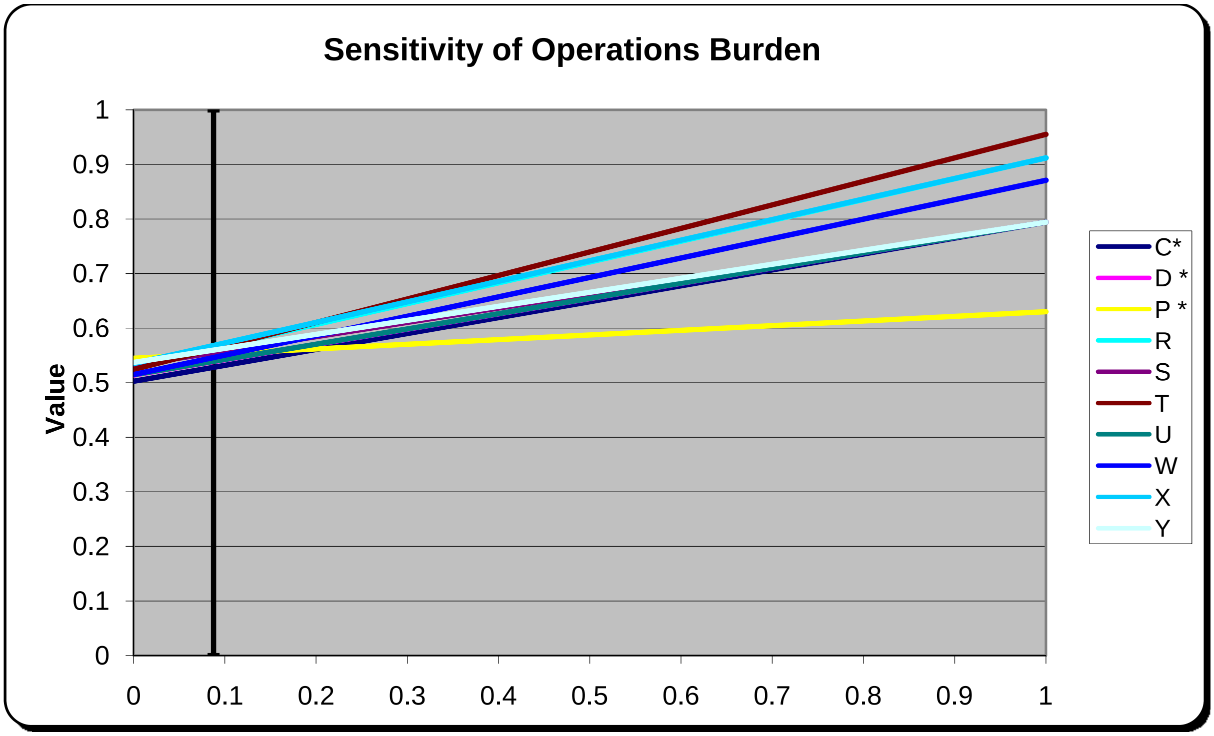
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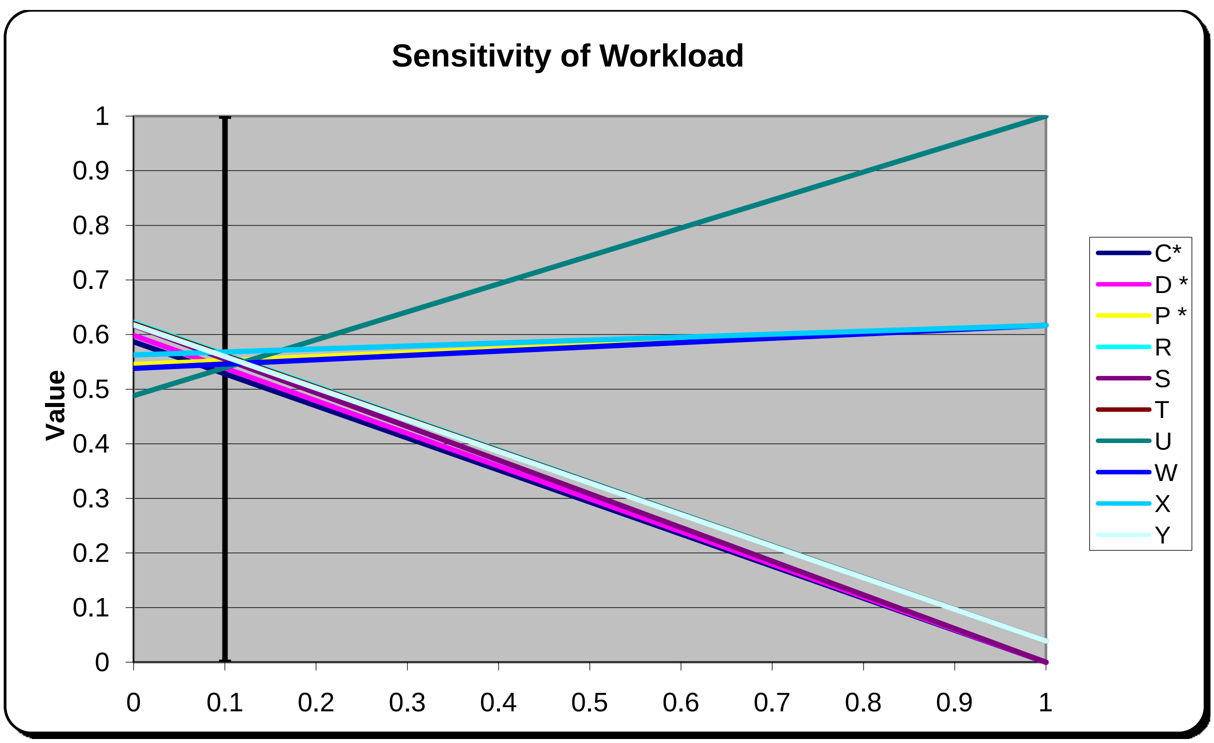
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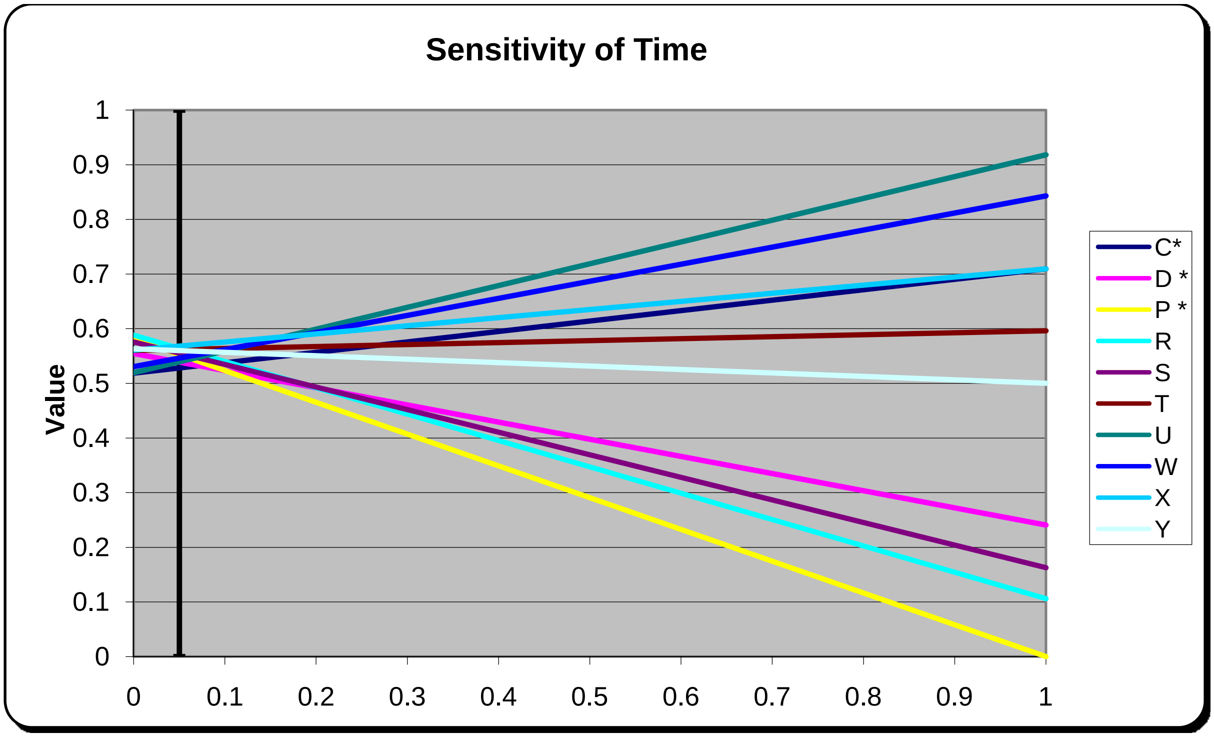
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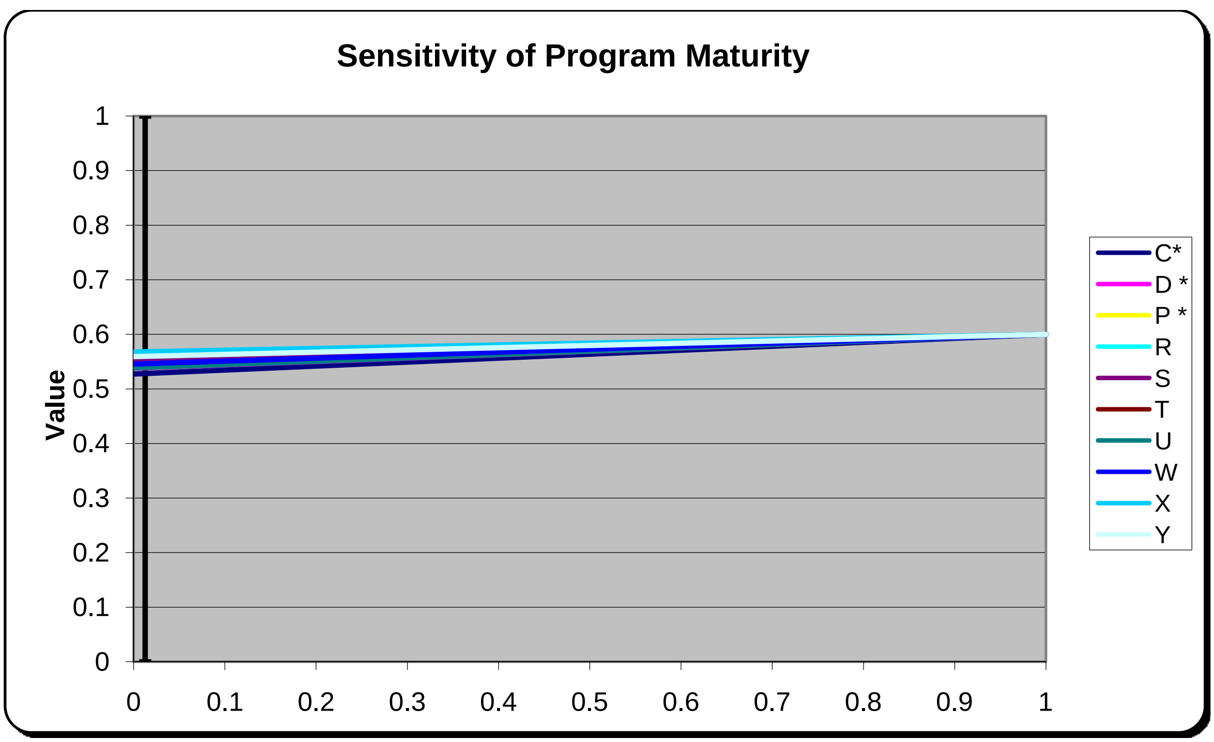
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C*
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14. ABSTRACT

This research uses decision analysis to develop a structured, repeatable and most importantly defensible decision model for the evaluation of proposed IED defeat solutions submitted to the Joint IED Defeat Organization (JIEDDO). Additive value models using Value-Focused Thinking (VFT) and the Analytic Hierarchy Process (AHP) are examined as possible methodologies. VFT is determined to be the "best fit"for JIEDDO's decision situation in which proposals are submitted continuously and must be scored independently of previous proposals. VFT is first used to determine desirable qualities in IED defeat options, and then to generate a hierarchal value model to evaluate these qualities in a selected group of alternatives. The most important criteria for IED defeat proposal evaluation are: Need for the Capability, Operational Effectiveness, and Usability. A group of 30 proposals, previously assessed by the current JIEDDO process, is evaluated suing the VFT decision model and the rank ordered results are compared with JIEDDO's previous selection decisions. The VFT decision model results support JIEDDO's past decisions to accept or reject IED defeat proposals, validating the model. Sensitivity analysis is then conducted to allow further insight to the robustness of the model. The resulting effort creates a decision model that, when consistently applied, provides a repeatable and defensible decision support model that reflects JIEDDO's priorities for proposal selection.

15. SUBJECT TERMS

IED, JIEDDO, proposal selection, decision analysis, value-focused thinking, decision making, value, improvised weapons, hierarchies, selection

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