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Value-Driven Enterprise Architecture Score: Evaluation Applied to Joint Force Protection Future State Design

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VALUE-DRIVEN ENTERPRISE ARCHITECTURE SCORE: EVALUATION APPLIED TO JOINT FORCE PROTECTION FUTURE STATE DESIGN

THESIS

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THESIS

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Degree of Master of Science in Systems Engineering

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March 2009

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Abstract

This research presents a methodology to evaluate the quality of a system's architecture using principles drawn from Value-Focused Thinking (VFT) and resulting in a Value-Driven Enterprise Architecture Score (VDEA-Score). This is an overall numerical architecture quality score useful to a system's management team to identify the advantages and disadvantages of a system design and associated architecture documentation or to track its quality across discrete evaluation epochs. This effort determined which aspects of the architecture are most valuable to the stakeholder in the areas of (1) the system effectiveness values (quality of the instantiated system being represented and its ability to perform its stated mission) and (2) the architecture quality values (intrinsic quality of the products themselves in terms of documentation standards and desired attributes). The results are reported across three theses. In this thesis, the architecture documentation quality aspects are specifically addressed by examining various "ilities" (e.g., usability, modifiability, accessibility, etc.) regarded as essential to any architecture. The evaluation methodology was tested against architectures from two enterprises including the sponsor's enterprise of joint force protection. An overall architecture documentation quality score is reported for both enterprises useful for identifying areas for potential improvement.

Acknowledgments

We would like to acknowledge the help of many people during this research. First, we would like to thank the members of our thesis project. We thank our engineering management comrades Captains Craig Mills and Justin Osgood for their force protection expertise and teamwork throughout the whole development effort. We also thank our thesis advisors--Dr Thal and Maj Havlicek from the Air Force Center for Systems Engineering--and reader Lt Col Long. Their direction, support, and patience during our research with numerous suggestions were invaluable in guiding us in the best direction to follow. Thanks as well to Lynn Curtis for all her administrative help.

Thanks are further due to the sponsor of our research. Under the March 2008, Air Force Institute of Technology Research Proposal "Net-centric Joint Force Protection Values" (Havlicek, 2008), the Physical Security Equipment Action Group represented by the Security Equipment Integration Working Group chaired by Electronic Systems Center's 642d Electronic Systems Squadron provided the funds and numerous force protection subject matter experts to make this research possible.

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VALUE-DRIVEN ENTERPRISE ARCHITECTURE SCORE: EVALUATION APPLIED TO JOINT FORCE PROTECTION FUTURE STATE DESIGN

I. Introduction

According to the Defense Science Board and other major studies, good architectures are a key to good interoperability (DoD, 2007a:1-1). As the DoD continues its transformation to interoperable, net-centric systems with increasing reliance on the underlying architecture descriptions for development, the authors recognized a need for a tool to assist the system’s management team in evaluating the quality of their system's architecture. The authors developed the Value-Driven Enterprise Architecture Score (VDEA-Score) to identify both the strengths and areas for improvement for enhancing the usefulness of the system's architecture. This may also serve as a baseline measure to compare future iterations of the system's architecture through assessment of the Architecture Quality and System Effectiveness values.

1.1. General Background

The U.S. Clinger-Cohen Act of 1996 was established, in part, to ensure that Department of Defense (DoD) information technology (IT) and national security systems were interoperable. This act also emphasized a great need for joint architectures and required that all federal government chief information officers "develop, maintain, and facilitate the implementation of a sound and integrated information technology architecture" (U.S. Congress, 1996). As the DoD began its transformation to net-centric warfare (NCW), the importance of joint architectures to ensure interoperability was highlighted. The requirement for architecture development was further expounded by the Chairman of the Joint Chiefs of Staff (CJCS, 2007).

The DoD Architecture Framework v1.5 (DoDAF) is the means to interoperable architecture. Consisting of 29 products (or views) representing different perspectives (operational view or OV, system view or SV, technical view or TV, and all-view or AV), it aids in the system design and serves to document and communicate important decisions and problems. Architectures are further beneficial to “facilitate decision making by conveying the necessary information to the decision maker for the decision at hand as well as enabling the reuse of architecture information for additional needs” (DoD, 2007a:3-1).

Additionally, the Net-Centric Enterprise Solutions for Interoperability (NESI) provides voluntary guidance and an evaluation checklist for NCW programs. This cross-service effort between the Air Force, Navy, and Defense Information Systems Agency (DISA) guides the design, implementation, maintenance, evolution, and use of the Information Technology (IT) portion of net-centric solutions for defense application (NESI, 2008)

1.2. Specific Background

As NCW transforms the force protection domain, interoperability is crucial for ensuring smooth operations. DoD studies have shown inadequacies in providing comprehensive, integrated, and sustainable joint force protection capability (Defense Science Board Task Force, 2006). Seeking to integrate tactical systems, sensors, and security personnel to protect forces while promoting interoperability across the four services, the DoD created the Security Equipment Integration Working Group (SEIWG) with representatives from the U.S. Air Force (USAF), U.S. Army (USA), U.S. Navy (USN), and the U.S. Marine Corps (USMC).

The SEIWG domain spans the DoD and shares the goal of interoperability with the Integrated Unit, Base and Installation Protection (IUBIP) team as well as the more site-specific Joint Force Protection Advanced Security System Joint Capability Technology Demonstration (JFPASS JCTD). The JFPASS JCTD demonstrates an integrated system-of-systems to protect military installations, incorporates comprehensive situational awareness for force protection providers, reduces manning due to systems integration and robotics, and reduces logistics cost. Functional areas for installation protection addressed include: perimeter security, chemical-biological-radiological defense, access control, non-intrusive inspection, and waterside security.

Within the SEIWG mission to "coordinate and influence system architecture, technical design, and systems integration" (Havlicek, 2008), the working group is working to improve interoperability by developing the "to-be" architecture for joint net-centric force protection within the DoDAF and NESI guidelines. These architecture views are intended to cover the Detect, Assess, Warn, Defend, and Recover (DAWDR) activities; be suitable for inclusion in a Joint Protection Capability Development Document (CDD); and provide guidance to all services ensuring interoperability of force protection systems.

1.3. Research Problem

The Air Force's 642d Electronic Systems Squadron (ELSS), as the current chair of the SEIWG, solicited AFIT's help in researching joint force protection values with measures and a framework to evaluate the quality of their proposed "to-be" architecture. Satisfying this need will provide better insight into the important factors impacting the overall joint force protection process.

1.4. Research Objective

To complete this research problem, the objective was two-fold. The first aspect was developing a reliable and repeatable model to evaluate the quality of any DoDAF architecture. The second was to apply this model using common joint force protection values to evaluate a "To-Be" architecture for net-centric force protection resulting in an overall value score. The following investigative questions were addressed during this research.

1. What are the "best" methods to evaluate and measure the overall quality of an architecture?

2. What are the major categories and sub-categories that should be considered when evaluating an architecture?

3. What are the major categories and sub-categories that should be considered when evaluating force protection processes?

4. How do these categories and sub-categories rank in terms of importance?

5. How well does current JFPASS architecture meet the weighted values of the force protection community?

1.5. Methodology

Developed in 1992 by Keeney (1994) and refined in 1996 by Kirkwood (1997), Value-Focused Thinking (VFT) is a decision analysis tool that organizations have successfully used to make decisions and is a natural fit to the force protection value problem. The antithesis to usual alternative-based approaches to decision making, VFT provides an opportunity for proactive decision making that focuses on objectives, as opposed to reactive decision making that focuses on means. VFT has been employed in a wide range of areas such as climate change research, nuclear waste transportation, and public health in the mining industry (Kirkwood, 1997).

More specifically, the AFIT-developed 10-Step VFT Process as reported by several authors such as Shoviak (2001), Jurk (2002), and Braziel (2004) was used to guide the VDEA-Score development. This effort determined which aspects of the architecture are most valuable to the stakeholder in the areas of (1) the system effectiveness values (quality of the instantiated system being represented and its ability to perform its stated mission) and (2) the architecture quality values (intrinsic quality of the products in terms of documentation standards and desired attributes). These values formed the model used to evaluate the “To-Be” force protection architecture.

1.6. Research Scope

The overall research effort was divided between this thesis (specifically focused on the architecture product quality values) and the work of Osgood (2009) and Mills (2009) on the force protection focused system values. This thesis examined various “ilities” (e.g., usability, modifiability, accessibility, etc.) regarded as vital to any architecture. This effort began by taking a generic perspective to thus enable the reuse of the value categories, definitions, and measures to other projects. It was then tailored to joint force protection by applying weighting factors according to how the sponsor valued each category. An overall architecture quality score was then derived as a reference point. But more specifically, the score was used to identify areas of improvement. Finally, as a reference point to validate the value categories (definitions and measures), a subsequent evaluation of another program’s architecture views was conducted.

1.7. Chapter Overview

Chapter 2 presents a literature review that provides insight into force protection, architectures, and other architecture evaluation methods. The decision analysis methodology and VFT process, as well as their relevance to this research, will also be discussed in Chapter 2. Chapter 3 discusses the methodology used to determine the architecture value hierarchy, definition of the values used, how these values are measured using VFT, and how these values were weighted to enable evaluation. The analysis of the value model is provided in Chapter 4 by evaluating a “To-Be” architecture for force protection to judge its quality and effectiveness, identify any deficiencies in the value model, and create a composite value-focused joint force protection score. Chapter 5 summarizes the research results and proposes conclusions and recommendations for future research.

II. Background

This chapter provides background information on joint force protection and quality system architecting. The chapter then continues with an examination of decision analysis methodology, culminating in the value-focused thinking (VFT) approach for determining a degree of quality leading to the concept of a VDEA-Score for architecture quality. It addresses published information on system architecting and more specifically quality attributes referred to as the "ilities." Finally, a review of information available regarding approaches to quantifying these attributes is included.

2.1. Joint Force Protection

Force protection is specifically identified in the National Military Strategy (NMS). The NMS specifies, "The Armed Forces must have the ability to operate across the air, land, sea, space and cyberspace domains of the battlespace. Armed Forces must employ military capabilities to ensure access to these domains to *protect the Nation, forces in the field and US global interests*" (emphasis added, CJCS, 2004).

Although very general and focused on implementation by 2015, the Protection Joint Functional Concept (PJFC) provides the next level of guidance. By way of definition, the PJCF states that:

> protection is a process, set of activities, or utilization of capabilities by which the joint force protects personnel (combatant/non-combatant), physical assets, and information of the United States, allies and friends, required to ensure fighting potential can be applied at the decisive time and place against the full spectrum of threats. (J8, 2004:7)

The PJCF recognizes that "current protection efforts are characterized by channelized and sometimes conflicting efforts...[which] ...could create wasteful and potentially harmful technical and operational gaps" (J8, 2004: 9). To combat these technical and operational gaps, the PJFC specifies that "execution of protection operations in 2015 must be integrated with the overarching Joint Force operations construct" (J8, 2004:8) as depicted in Figure 1.

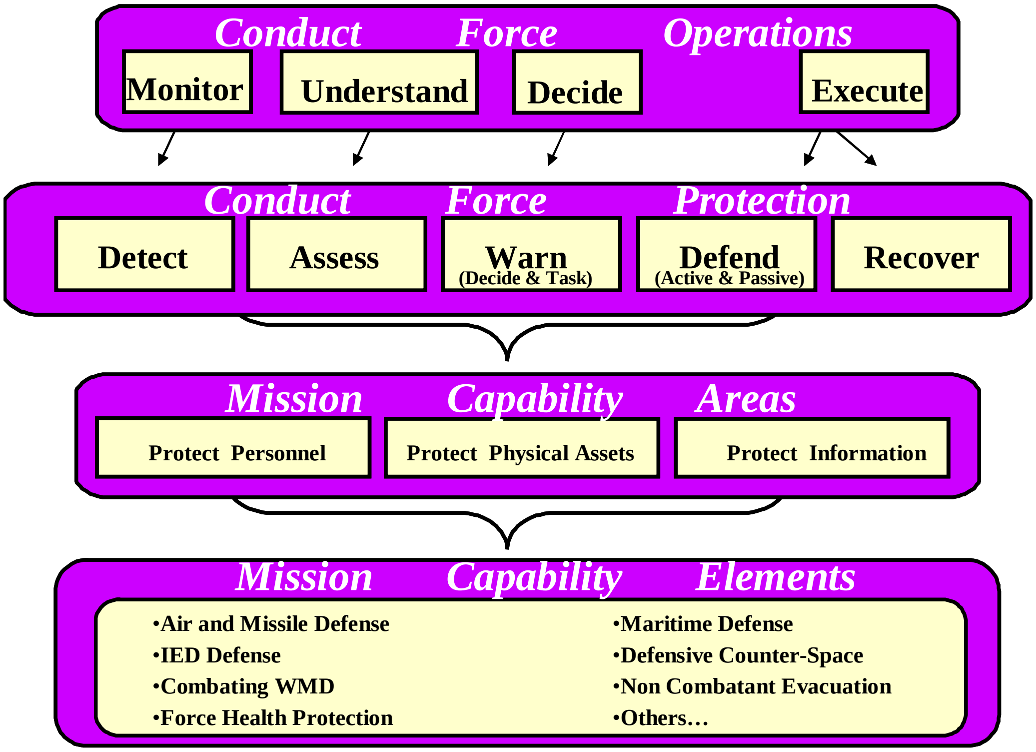

Figure 1. The Protection Construct (J8, 2004: 8)

Therefore, for integrated joint forces, interoperability is the key doctrinal idea to enable operations in a joint environment. The Universal Joint Task List (UJTL) is the next level of guidance giving each service its specific missions and areas of responsibility. The UJTL defines interoperability as "the ability of systems, units, or forces to provide service to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together" (CJCS, 2002: A-5). While the UJTL addresses interoperability and specifies which portions of the mission each service will do, how to actually implement this is not specified. Thus, each service is allowed to implement it differently. As more instances of joint basing occur, especially in deployed locations in which Air Force security personnel are augmenting other service's forces, interoperability is crucial for ensuring smooth operations.

With the SEIWG's mission to "coordinate and influence system architecture, technical design, and systems integration" (Havlicek, 2008: 2), it is working to improve interoperability by developing the "to-be" architecture for joint net-centric force protection. As the current chair of the SEIWG, the 642d ELSS solicited AFIT's help in researching joint force protection values with measures and a framework to evaluate the quality of their proposed "to-be" architecture (Havlicek, 2008:2).

2.2. Decision Analysis

The SEIWG faces hard decisions accomplishing its mission across DoD force protection stakeholders. Clemen (2001:2-3) identifies four sources of difficulty in making a decision. First is complexity. Many issues, possible courses of action, possible outcomes, etc., may be almost impossible to keep straight at one time and require organization and analysis. Secondly, the uncertainty inherent in the situation may prove difficult. Thirdly, multiple objectives (especially if an advance toward one causes problems with another) may drive tradeoffs in benefit and cost between objectives. Finally, differing perspectives or inputs can drive differing conclusions or choices. This is especially poignant in the joint force protection arena when consulting stakeholders across the DoD whose approaches may be significantly different from each other.

The concepts of decision analysis exist to provide “structure and guidance for thinking systematically about hard decisions” (Clemen, 2001:2). Two main approaches in thinking are found in literature—alternative-focused thinking (AFT) and value-focused thinking (VFT).

2.3. Alternative vs. Value-Focused Thinking

The differences between Alternative-Focused Thinking and Value-Focused Thinking are straightforward. From an AFT perspective, the decision maker identifies the problem and then compares the alternatives available for solving it. VFT, on the other hand, focuses more on what is important or valued by the decision maker, who then explores ways to achieve the best value. Keeney (1993:3) pointedly describes the difference between the two as: “[values] are fundamentally important in any decision situation. Alternatives are relevant only because they are the means to achieve your values.”

Instead of primarily looking at available alternatives, the goal of VFT is to create a mutually-exclusive and collectively-exhaustive set of values which contain all the important points to the decision maker (Kirkwood, 2007:17). This, in turn, leaves the door open to potential undiscovered alternatives which may prove more beneficial in reaching the desired objectives. Shoviak (2001:46) provided a good table summary of the advantages of VFT as shown in Table 1 followed by Jurk’s (2002:27) synopsis of key VFT terminology in Table 2.

Table 1. Advantages of VFT (Shoviak, 2001:46)

Advantage	Description
Uncovering hidden objectives	Value-focused thinking includes a number of techniques that can be used to stimulate creativity in identifying possible objectives not yet realized.
Creating alternatives	Focusing on the values that should be guiding the decision makes the search for new alternatives a creative and productive exercise (Keeney, 1994: 39). Creating new alternatives may be more important than evaluating available alternatives.
Identifying decision opportunities	Decision situations should be viewed as opportunities to take advantage of and not as problems to solve. Systematically evaluating whether and how to better achieve your values may create decision opportunities.
Guiding strategic thinking	Value-focused thinking compels the decision-maker to formulate strategic objectives.
Inter-connecting decisions	"Strategic objectives provide common guidance for all decisions in an organization and form the basis for more detailed fundamental objectives appropriate for specific decisions" (Keeney, 1994: 34).
Guiding information collection	When what is important to the decision situation is known, then one can be sure to collect information about the important objectives and not waste valuable resources collecting information about objectives that are not important.
Facilitating improvement in multiple-stakeholder decisions	Many decisions involve multiple stakeholders who have their own interests in the decision. Value-focused thinking helps to facilitate communications among the stakeholders regarding the important objectives for decision. "In situations with controversy, a common understanding about what are important [objectives] may provide a better basis for compromise and/or consensus with regard to selecting alternatives" (Kirkwood, 1997: 23).
Improving communication	Value-focused thinking uses a common vocabulary regarding the achievement of objectives in a particular decision context. This basis should help facilitate communication and understanding.
Evaluating alternatives	Value-focused thinking provides a framework for quantifying values, which allows one to construct a quantitative value model to evaluate various alternatives and rank them by total value. Sensitivity analysis of an alternative's desirability to a specific value may be conducted to provide the decision-maker powerful insight.

Table 2. Key VFT Terminology (Jurk, 2002:27)

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

In determining the values, Burk (1997), Parnell (2007), Knighton (2007), and Dawley et al., (2008) describe three standards of sources: platinum, gold, and silver. In order of preference, platinum comes first by using interviews with senior stakeholders and the actual decision maker to determine the values. Gold is next using published policy or strategic planning documents approved by the decision maker. Least desirable is silver, which relies on interviews with subject matter experts (SMEs) and stakeholder representatives. These standards may also be combined. “For example, we could combine a review of several gold-standard documents with findings from interviews with decision makers and stakeholders” (Parnell, 2007).

For this effort, the SEIWG is not comparing competing architectures but rather comparing against today’s performance. The SEIWG is developing a future “to-be” architecture that reflects the important aspects of force protection. Therefore, the VFT approach is the most appropriate for this effort.

2.4. Ten-Step VFT Process

A number of research efforts have benefited from this VFT approach by applying the following 10-step process developed at AFIT and reported by several authors such as Shoviak (2001), Jurk (2002), and Braziel (2004). This process, shown graphically in Figure 2, was derived from the methodology described by Keeney (1992) and Kirkwood (1997). The authors used this 10-Step VFT process to guide the VDEA-Score methodology development.

2.4.1. Step 1: Problem Identification

This VFT process begins with the most-important aspect of understanding the context of the decision by clearly identifying the problem. Identifying the wrong problem leads to wasted effort and what Clemen refers to as an “error of the third kind” (2001:5). Braziel (2004:27) suggests that the decision maker should ask two questions: "What is important to me in terms of this decision? What is it that I value in a solution?" Answering these may help properly identify the problem and lead to the beginning construction of a value hierarchy.

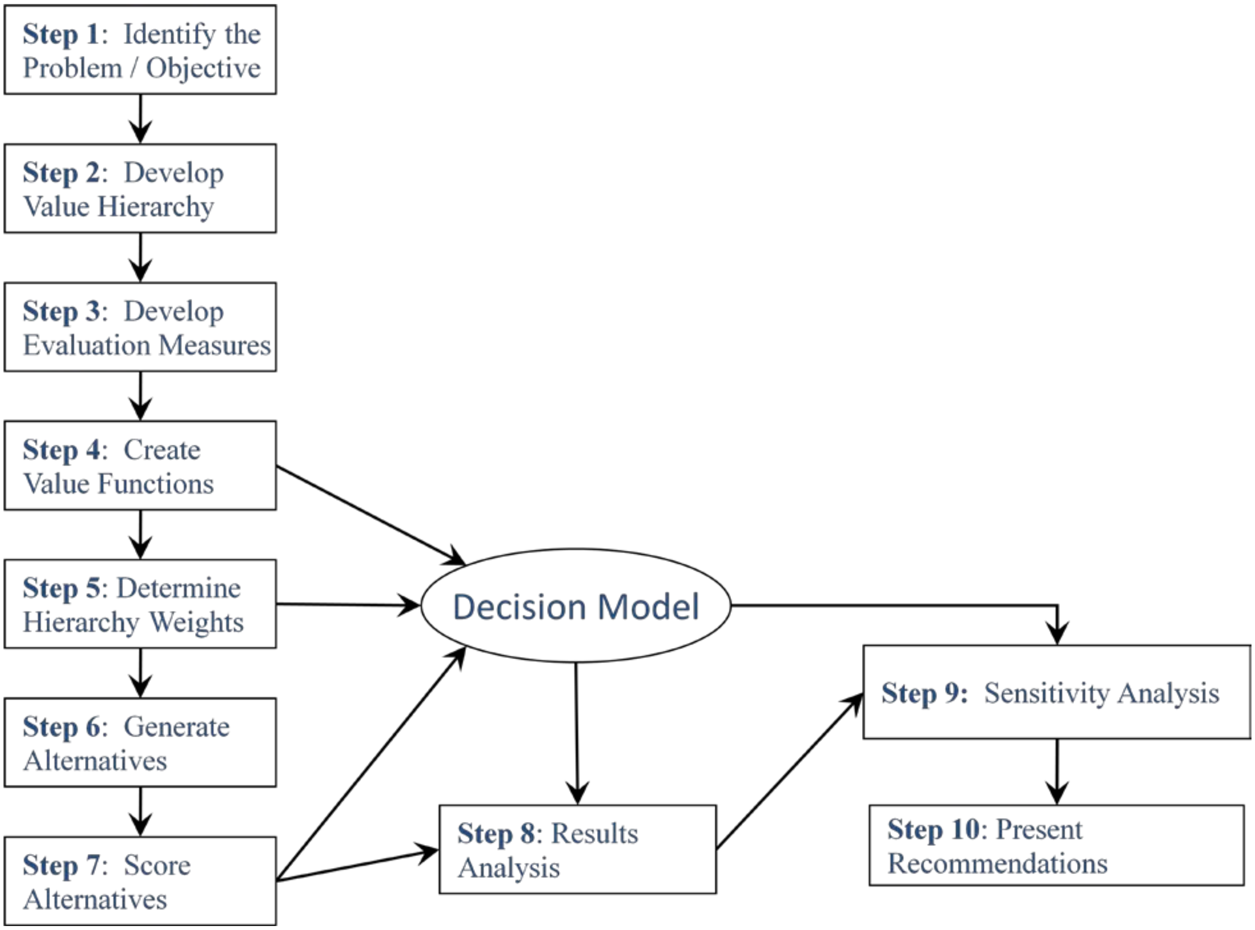

Figure 2. VFT Ten-Step Process (Shoviak, 2001:63)

2.4.2. Step 2: Create Value Hierarchy

With the problem identified, the value hierarchy can be constructed as a graphical representation of the important values. This allows the decision maker or stakeholders to better visualize the values and help identify any missing values or "holes" which need to be filled (Keeney, 1992:69). When creating the value hierarchy, five desirable properties exist that should be kept in mind: completeness, nonredundancy, decomposability, operability, and small size (Kirkwood: 1997:16-18). Table 3 describes these properties.

Table 3. Value Hierarchy Desired Properties (Kirkwood: 1997:16-18)

Desired Property	Description
Completeness (or "collectively-exhaustive")	The values, when taken together as a group at each tier, appropriately addresses all the values for evaluating the overall objective of the decision.
Nonredundancy (or "mutually exclusive")	No values in the same tier overlap.
Decomposability (or "independence")	The score from one value's measure does not depend on the score of another.
Operability	The hierarchy is understandable for those who may use it
Small Size	The hierarchy easier to communicate to stakeholders and uses few resources.

2.4.2.1. Generating Values

To generate the objectives or values which are important to the decision problem, Shoviak (2001:48) provides the following list of questions based on techniques Keeney developed (1994:35).

1. Develop a wish list. What do you want? What do you value? What should you want?

2. Identify alternatives. What is a perfect alternative, a terrible alternative, some reasonable alternative?

3. Consider problems and shortcomings. What needs fixing?

4. Predict consequences. What has occurred that was good or bad? What might occur that you care about?

5. Identify goals, constraints, and guidelines. What are your aspirations? What limitations are placed on you?

6. Consider different perspectives. What would your competitor or constituency be concerned about? At sometime in the future, what would concern you?

7. Determine strategic objectives. What are your ultimate objectives? What are your values that are absolutely fundamental?

8. Determine generic objectives. What objectives do you have for your customers, your employees, your shareholders, and yourself? What environmental, social, economic, or health and safety objectives are important?

2.4.2.2. Structuring Values

The value hierarchy or tree is constructed to show how the values relate to each other. At the top of the tree is the most-general but highest-level objective. This tree can be further divided down to lower levels or tiers where the lower-level values more specifically describe the higher-level objectives or values. This iterative decomposition of general (higher-level) values into more specific (lower-level) values continues until “the values are subdivided to a level at which measurement and evaluation is possible” (Braziel 2004:32). Jurk (2002:36) provided the example in Figure 3 to help illustrate this concept using “Buy the Best Truck” as the highest level objective with performance, practicality, and safety as the first-tier values.

2.4.3. Step 3: Develop Evaluation Measures

After the value hierarchy is built such that the lowest tier has the most specific values, one or more measures are developed for each bottom-tier value. These measures are the means of determining the extent to which value is earned. Referring again to the Jurk (2001:38) example in Figure 3, an example measure for the "Power" value could be "Horsepower."

Measures can be classified as either natural or constructed and direct or proxy. As the name implies, a natural measure is widely used and understood, such as "horsepower" from the example. A constructed measure, on the other hand, is created to address a particular issue when a natural measure is unavailable or inappropriate. In terms of direct or proxy, a "direct scale directly measures the degree of attainment of an objective, while a proxy scale reflects the degree of attainment of its associated objective, but does not directly measure this" (Kirkwood 1997:24). Therefore, a natural and direct measure is the goal while trying to minimize the use of constructed and proxy measures.

Keeney (1992:112-116) further points out three properties desirable for an evaluation measure: measurability, operationality, and understandability. Measurability means the specific measure "must clearly and appropriately quantify what the decision-maker is interested in and nothing more" (Braziel 2004:38). The operationality property "express(es) relative preferences for different levels of achievement of an objective as indicated by attribute levels" (Keeney, 1992:114). Finally, understandability strives to eliminate ambiguities so "no loss of information [occurs] when one person assigns [a measure] level to describe a consequence and another person interprets that level" (Keeney, 1992:116).

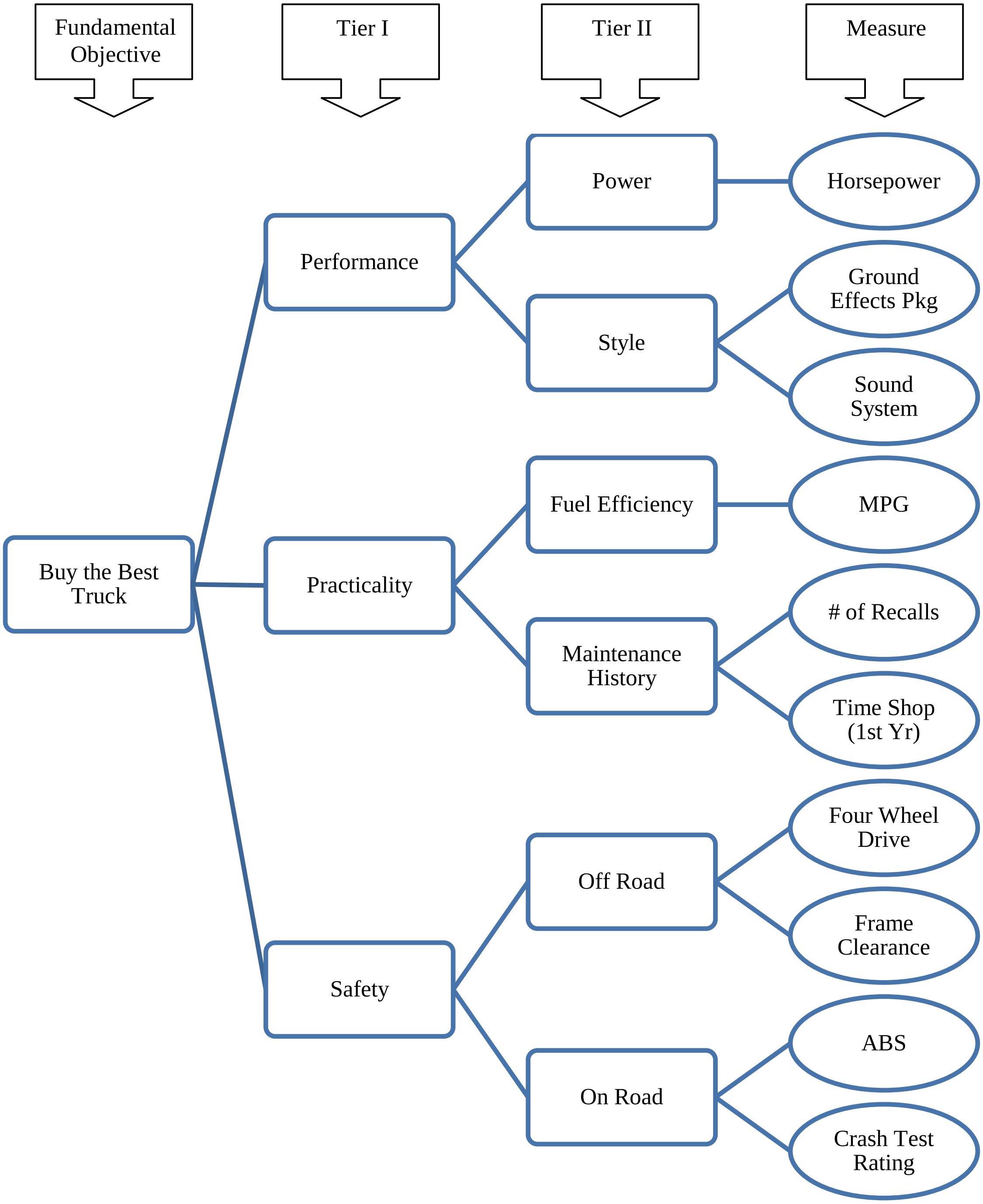

Figure 3. "Buy the Best Truck" Hierarchy (Jurk, 2002:36)

2.4.4. Step 4: Create Value Functions

With the evaluation measures determined, a value function for each measure must be created. Because each measure may have a completely different unit or scale, simply summing all the evaluated measures does not result in a useful overall score. Hence, the Single Dimension Value Function (SDVF) converts each measure into a common "value unit" between zero and one where "the least preferred score being considered for a particular evaluation measure will have a single dimensional value of zero, and the most preferred score will have a single dimensional value of one" (Kirkwood, 1997:61).

The SDVF is best viewed as a graph created by an x and y-axis. The range of points encompassing the specific evaluation measure forms the x-axis. The value score (0 to 1) is placed on the y-axis. Therefore, the decision maker determines the corresponding value of each measure based on the function created.

Three primary types of SDVFs are discrete, piecewise linear, and exponential. The piecewise linear function "is made up of segments of straight lines that are joined together" whereas the exponential "uses a specific mathematical form" (Kirkwood 1997:61). These SDVFs may also be either monotonically increasing (increased y-axis value for an increased x-axis score) or decreasing (decreased y-axis value for an increased x-axis score). Examples of these are shown in Figures 4-6. Figure 4 shows a discrete SDVF where each successive evaluation category earns more value. In Figure 5, SDVF 1 shows a decreasing rate of value earned for increased evaluation score. SDVF 2 shows a constant increase in value with increased evaluation score. SDVF 3 shows an increasing value rate for increased evaluation score. In Figure 6, SDVF 1 shows a slower decreasing rate of value lost with increased evaluation score.

SDVF 2 shows a constant decrease in value with increased evaluation score. SDVF 3 shows an increasing rate of value lost with increased evaluation score.

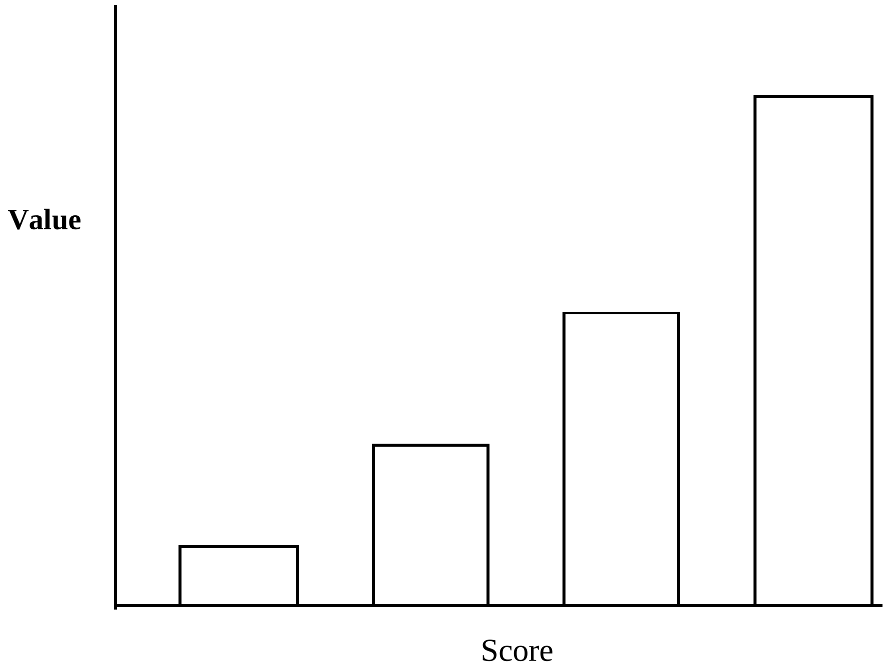

Figure 4. Discrete or Categorical Functions (Jurk, 2002:43)

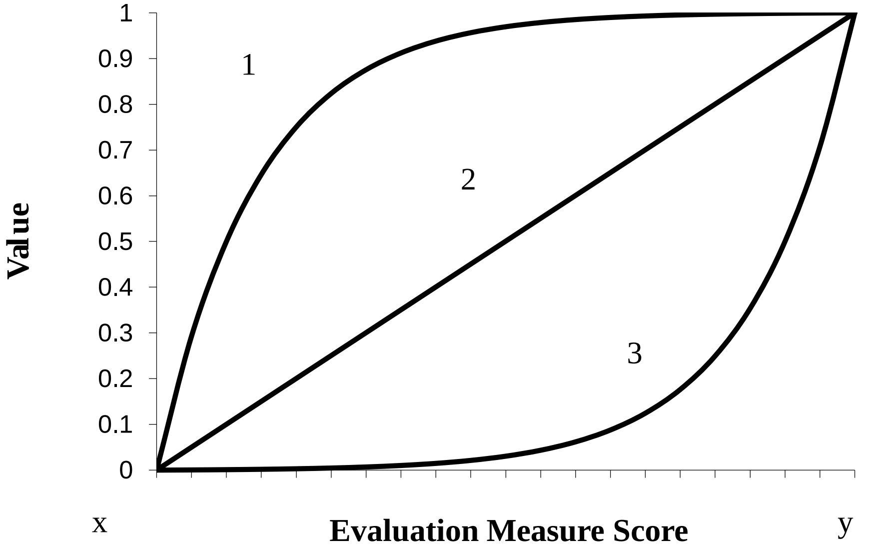

Figure 5. Example Monotonically Increasing Functions (Kirkwood, 1997)

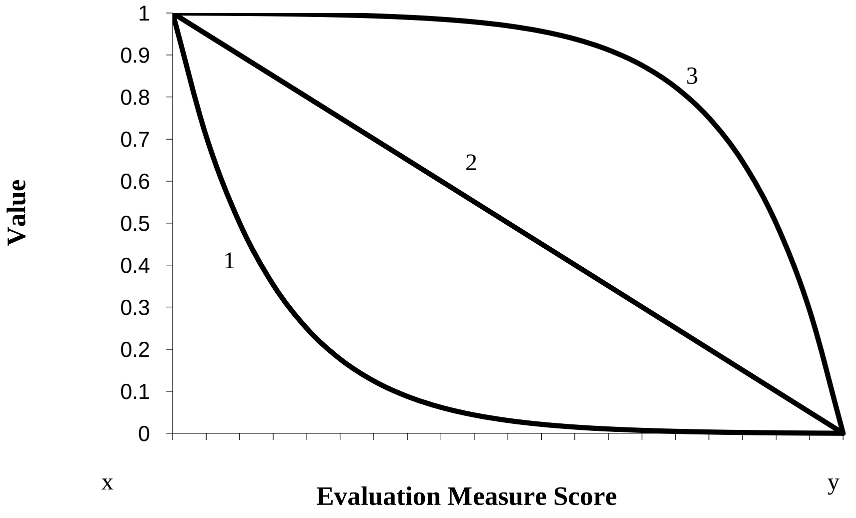

Figure 6. Example Monotonically Decreasing Functions (Kirkwood, 1997)

2.4.5. Step 5: Weight Value Hierarchy

Because all value categories are not equal in the eye of the decision maker, each one should be considered against each other in terms of its importance after creating the value functions. The decision maker assigns a weight to each value as a portion of the total weight of the hierarchy which when summed equals one. Continuing with Jurk's (2002:45) truck example as shown in Figure 7, the top of the hierarchy ("Buy the Best Truck") has a total weight of one. For the three values on the second tier, the weight of these values is determined by considering their importance against one another within the same branch and tier (called the local weight) which likewise sums to one. This is repeated for each branch and tier until each value has a local weight.

Now that each value has a local weight, a global weight is determined which shows each value's relative importance in the overall hierarchy. Katzer (2002:4) explains this is accomplished by "multiplying the local weights for each successive tier above it." Figure 8 illustrates the overall global weights applied to the "Buy the Best Truck" example.

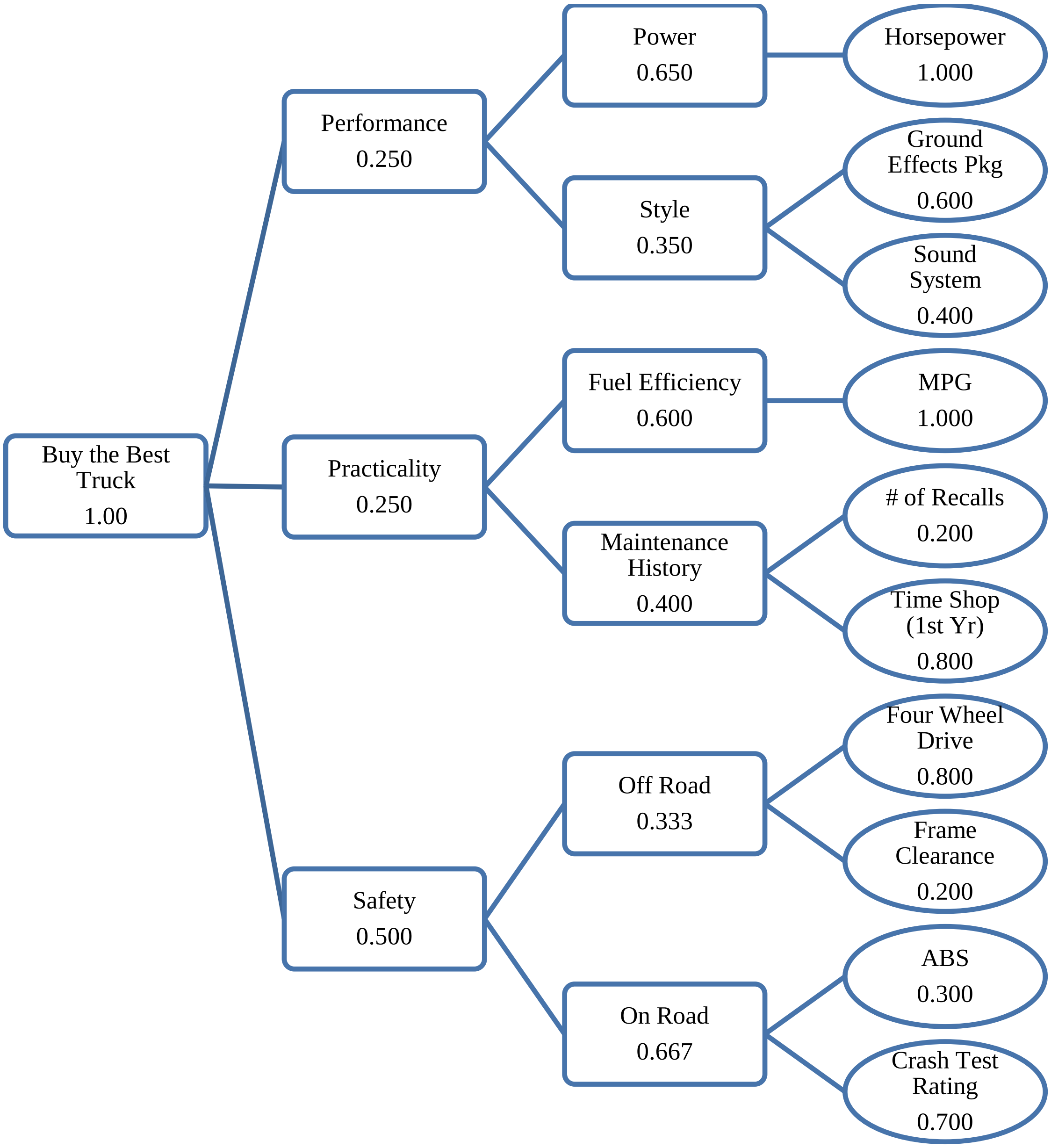

Figure 7. "Buy the Best Truck" Example with Local Weights (Jurk, 2002:45)

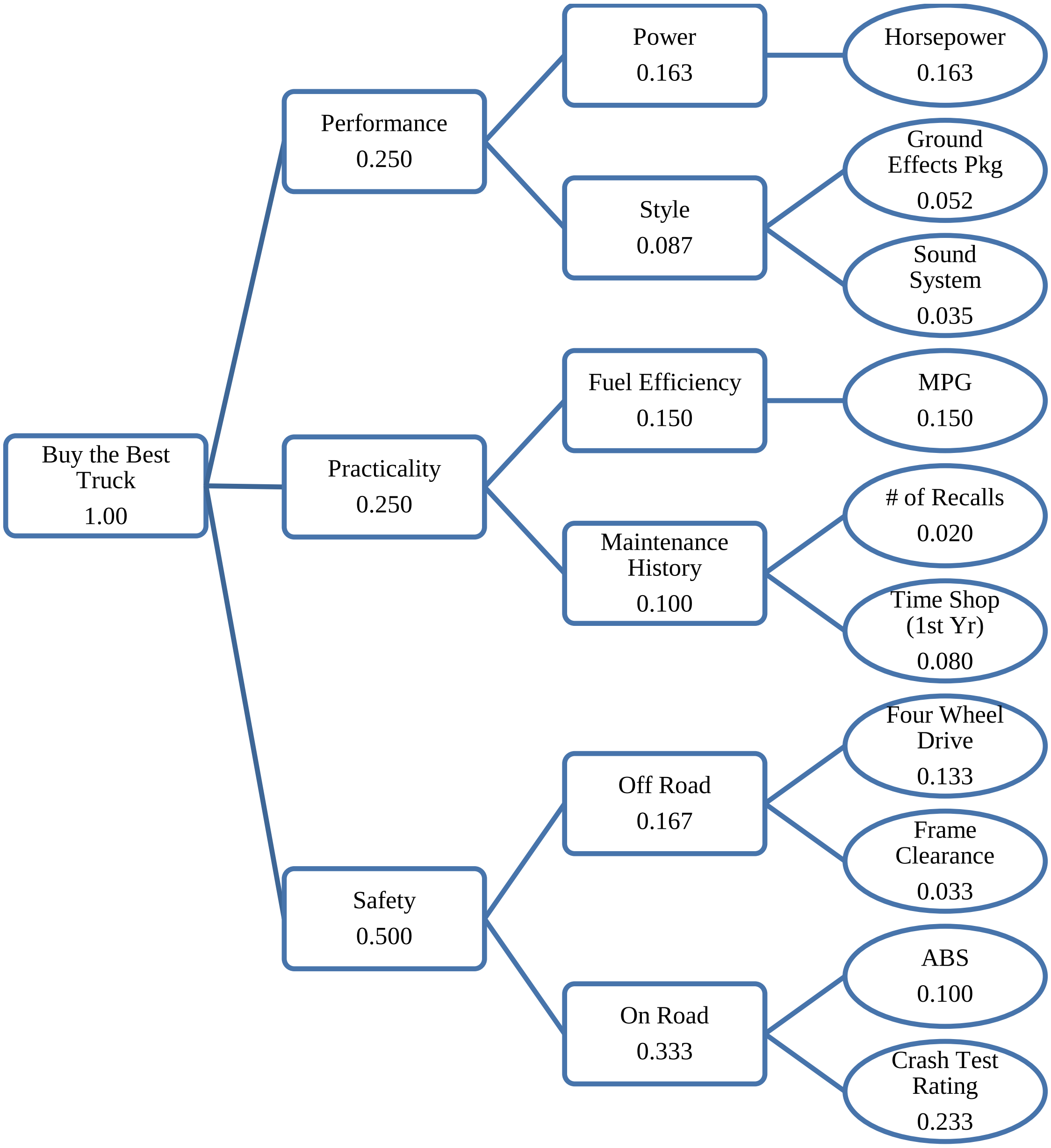

Figure 8. "Buy the Best Truck" Example with Global Weights (Jurk, 2002:49)

2.4.6. Step 6: Alternative Generation

With the value hierarchy appropriately weighted, potential alternatives may be generated which meet the decision need. Regarding these alternatives, Keeney (1992:198) points out that "alternatives should be created that best achieve the values specified for the decision situation...[and these] alternatives themselves can trigger thought processes that generate new alternatives." Braziel (2004:39) points out that the value functions of the hierarchy act as a "screening criterion." If too many alternatives are presented, those scoring zero against the values may easily be removed. On the other hand, if not enough alternatives present themselves, then the "hierarchy can identify value gaps...[which are] instrumental in modifying the hierarchy in order for alternatives to score better in critical areas" (Braziel 2004:39).

2.4.7. Step 7: Alternative Scoring

After the alternatives to be evaluated are presented, each one is evaluated according to the measures for each value. The result from each measure is then applied to the SDVF for a value score. Depending on the number of measures and the number of alternatives, this may be a lengthy step.

2.4.8. Step 8: Deterministic Analysis

With the score for each value determined, the associated weights are next applied resulting in the weighted sum score providing the means to rank order the alternatives. The additive value function is the frequently used decision analysis mathematical equation for this rank ordering (Braziel 2004:40). Assuming the prerequisites were in place from the previous steps (SDVF with values between zero and one and weighted such that the combined weights for an alternative sums to one), the general additive value function is (Kirkwood, 1997:230):

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

$$\text{and} \sum_{i=1}^{n} \lambda_i = 1$$

Where,

$v(x) \equiv$ overall score

$v_i(x_i) \equiv$ score value of the i^{th}measure,

$\lambda_i \equiv$ weight of the i^{th}measure,

$$n = \sum_{\forall i \in \{measures\}} 1$$

Shoviak (2001:60) further points out that this function does not take into account any interaction with any other alternatives. This preferential independence condition therefore implies "that the decision-maker's preferences associated with any one objective are independent of the evaluation measure scores associated with all other objectives" (Shoviak 2001:60).

2.4.9. Step 9: Sensitivity Analysis

As additional insight for the decision maker, analyzing the sensitivity of the previous rank ordering can be accomplished by changing the assigned weightings. Because there is little-to-no change in the SDVFs, the weight of each value is varied systematically while maintaining the other value weightings proportionally the same. The resulting effect on the overall score and rankings can be tracked to provide the decision maker insight to the impact the weightings may have on the choice of alternative.

2.4.10. Step 10: Conclusions & Recommendations

Finally, all these results are presented to the decision maker. This objective ranking serves as a supporting tool to solving the decision problem. The decision maker may make a better informed decision with the aid of these results.

2.5. Architectures

2.5.1. Definitions of Architecting, Benefits, Growth, and Guidance

Over the past decade, the field of systems engineering with its holistic approach to dealing with increasingly complex systems has grown tremendously. An important tool in the system engineer’s toolbox is the system architecture. While there are many different definitions for system architecture, the DoD Architecture Framework (DoDAF) definition is: “The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time" (DoD, 2007a:ES-1). Hence the fundamental purpose behind the architecture is to deconstruct the complex system into an easier-to-understand representation of the system.

Architectures are used for a variety of purposes which include supporting strategic planning, identifying capability needs, relating needs to systems development and integration, and facilitating interoperability and supportability (DoD, 2007a:3-1). They are further valuable in aiding the decision maker by providing pertinent information associated with each of those purposes. They can also be used at different portfolio levels as described in DoDAF v1.5 (DoD, 2007a: 3-1):

- Enterprise – Architectures, particularly federated architectures, are used at the enterprise level to make better decisions that improve (1) human resource utilization, (2) deployment of assets, (3) warfighter investments, and (4) identification of the enterprise boundary (interfaces) and assignment of functional responsibility.

- Mission Area – Architectures are used at the mission area level to better manage capabilities within and across mission areas and improve investment decisions. Architectures at this level are federated to support the development of enterprise architectures. They also provide roadmaps and descriptions of future or desired end states.

- Component and Program – Architectures are used at the component and program level to identify capability requirements and operational resource needs that meet business or warfighting objectives. Component and program architectures may then be integrated to support decision making at the mission level.

Besides these practical system architecture uses, architectures within the DoD are created to comply with law and policy. Tables 4 and 5 describe the various federal policies (DoD, 2007a: 3-2) and DoD directives (DoD, 2007a: 3-3) specifying architecture use.

In response to all these directives and to aid the DoD in developing architectures, DoDAF, volume I (DoD, 2007a:1-1) quotes USD(A&T), ASD(C3I) and J6 as stating that “The Defense Science Board and other major studies have concluded that one of the key means for ensuring interoperable and cost-effective military systems is to establish comprehensive architectural guidance for all of DoD." Therefore, it is essential to remember that good architectures lead to good interoperability. This guidance is embodied in the DoD Architecture Framework (DoDAF) which currently is in version 1.5.

Table 4. Federal Policy for Architectures (DoD, 2007a: 3-2)

Policy/Guidance	Description
Clinger-Cohen Act of 1996	Recognizes the need for Federal Agencies to improve the way they select and manage IT resources and states information technology architecture, with respect to an executive agency, means an integrated framework for evolving or maintaining existing IT and acquiring new IT to achieve the agency's strategic goals and information resources management goals". Chief Information Officers are assigned the responsibility for "developing, maintaining, and facilitating the implementation of a sound and integrated IT architecture for the executive agency."
Office of Management and Budget Circular A-130	"Establishes policy for the management of Federal information resources" and calls for the use of Enterprise Architectures to support capital planning and investment control processes. Includes implementation principles and guidelines for creating and maintaining Enterprise Architectures.
E-Government Act of 2002	Calls for the development of Enterprise Architecture to aid in enhancing the management and promotion of electronic government services and processes.
OMB Federal Enterprise Architecture Reference Models (FEA RM)	Facilitates cross-agency analysis and the identification of duplicative investments, gaps, and opportunities for collaboration within and across Federal Agencies. Alignment with the reference models ensures that important elements of the FEA are described in a common and consistent way. The DoD Enterprise Architecture Reference Models are aligned with the FEA RM.
OMB Enterprise Architecture Assessment Framework (EAAF)	Serves as the basis for enterprise architecture maturity assessments. Compliance with the EAAF ensures that enterprise architectures are advanced and appropriately developed to improve the performance of information resource management and IT investment decision making.
General Accounting Office Enterprise Architecture Management Maturity Framework (EAMMF)	"Outlines the steps toward achieving a stable and mature process for managing the development, maintenance, and implementation of enterprise architecture." Using the EAMMF allows managers to determine what steps are needed for improving architecture management.

Table 5. DoD Decision Support Process (DoD, 2007a:3-3)

Process	Description
Joint Capabilities Integration and Development System	"Requires a collaborative process that utilizes joint concepts and integrated architectures to identify prioritized capability gaps and integrated joint DOTMLPF and policy approaches (materiel and non-materiel) to resolve those gaps." Incorporates the requirement for the net-ready key performance parameter (NRKPP) in accordance with DoD Directive 4630.5, DoD Instruction 4630.8, and Chairman Joint Chiefs of Staff (CJCS) Instruction (CJCSI) 6212.01D.
Planning, Programming, Budgeting, and Execution	DoD policy has not formalized the use of architectures in the PPBE process but DoD Services, such as the Navy and Air Force, have noted that architectures provide a context for developing program priorities, formulating programmatic modifications, and making IT investment decisions.
Defense Acquisition System	Includes the requirement for an integrated architecture in developing integrated plans or roadmaps to conduct capability assessments, guide systems development, and define the associated investment plans as the basis for aligning resources.
Portfolio Management	Calls for "the management of selected groupings of IT investments using strategic planning, architectures, and outcome-based performance measures to achieve a mission capability".

The actual act of architecting itself is defined by Maier and Rechtin (2002:1) as "the art and science of designing and building systems." This is an important recognition that architecting has both a scientific approach and a practiced approach as "a process of insights, vision, intuitions, judgment calls, and even taste" (Maier and Rechtin 2002:2). As such, many different approaches may be taken to developing architecture with differing emphasis on what is important.

2.5.2. Importance of the "ilities"

As part of the art of architecting, a key aspect in determining the value of a system or its architecture lies in an examination of the "ilities." These are defined as "the operational and support requirements a program must address (e.g., availability, maintainability, vulnerability, reliability, supportability, etc.)" (Haskins, 2006:Appendix p6). As Dahlgren and de Neufville (2007:2) pointed out, "Systems engineers need to understand why successful systems perform well in the "ilities" (flexibility, adaptability, upgradeability, reliability, scalability, and robustness) and others don't so that they can incorporate that successful thought process into the design, development, and spiral development of new systems." In the March 2003 Software Engineering Institute's (SEI) Workshop on the DoDAF and software architecture, the discussions point out that "some parts of the community believe that architecture is shaped more by its quality attributes or "ilities" (performance, availability, modifiability, security, usability, etc.) than by its functionality" (Wood, 2003:10). Voas (2004:14) likens the "itities" to a secret sauce.

> The -ilities (or software attributes) are a collection of closely related behaviors that by themselves have little or no value to the end users, but they can greatly increase a software application or system's value when added. To use an analogy, an -ility in an application or system is like a condiment on an entrée: not valuable as a stand-alone item but capable of significantly enhancing the flavor when added properly.

Only a few of the "ilities" mentioned here are specifically identified in literature and captured in more detail in the matrix found in Appendix A. No standard list of applicable "ilities" exists as almost any attribute imaginable may be implemented as an "ility" by just adding "ility" to the end of it as evidenced by the large collection listed on wikipedia (Wikipedia, 2008).

2.5.3. Architecture Evaluation

In the course of actually examining these "ilities" in any attempt to determine their quality, this process indeed falls into the category of more art than direct science. Continuing his analogy, Voas (2004:14) points out the importance of degrees of goodness such as putting just enough or too much salt on a steak makes it either taste great or be difficult to eat. As such, directly measuring certain quality attributes may not be possible and require nonnumeric scoring techniques. Others such as Lu Han (2006:1), however, argue (albeit referring specifically to computing-related systems involving human-factors considerations) that “measuring ilities in a general way is hopeless.”

Several means of evaluating architectures or specific attributes exist. However, in the course of the authors’ literature review, very little was found in terms of attempting to provide a quality score related specifically to DoDAF architectures. This gap in the literature reconfirms the Software Engineering Institute's (2003:10) finding that specific "analysis methods for the DoDAF have not been reported publicly." Most of the existing methods such as the Enterprise Architecture Assessment Framework (EAAF) (OMB, 2008), Enterprise Architecture Management Maturity Framework (EAMMF) (GAO, 2003), Interoperability Score (i-Score) (Ford, 2008), Multi-Attribute Tradespace Exploration (MATE) (Ross and Hastings, 2006), Architecture Level Modifiability Analysis (ALMA) (Bengtsson, 2004), System Engineering Process Activities (SEPA) (Barber, 2003), International Standards Organization/International Electrotechnical Commision (ISO/IEC) 9126 (Botella, 2004), Software Architecture Analysis Method (SAAM) (Kazman, 1994), and Architecture Tradeoff Analysis Method^{SM} (ATAM) (Kazman, 2000), apply more to software coding or were deemed inappropriate for the scope of this effort in evaluating the architecture products. However, building on some of these methods’ concepts, the Architecture Evaluation Framework (AEF) (Lehto, 2005; Mazhelis, 2006) and the Enterprise Architecture Score Card^{TM} (Schekkerman, 2004; Jamison, 2005) did provide relevant insight into methodologies more closely scoped to this effort. The range in these models' scope compared to the target scope for this effort is depicted in Figure 9.

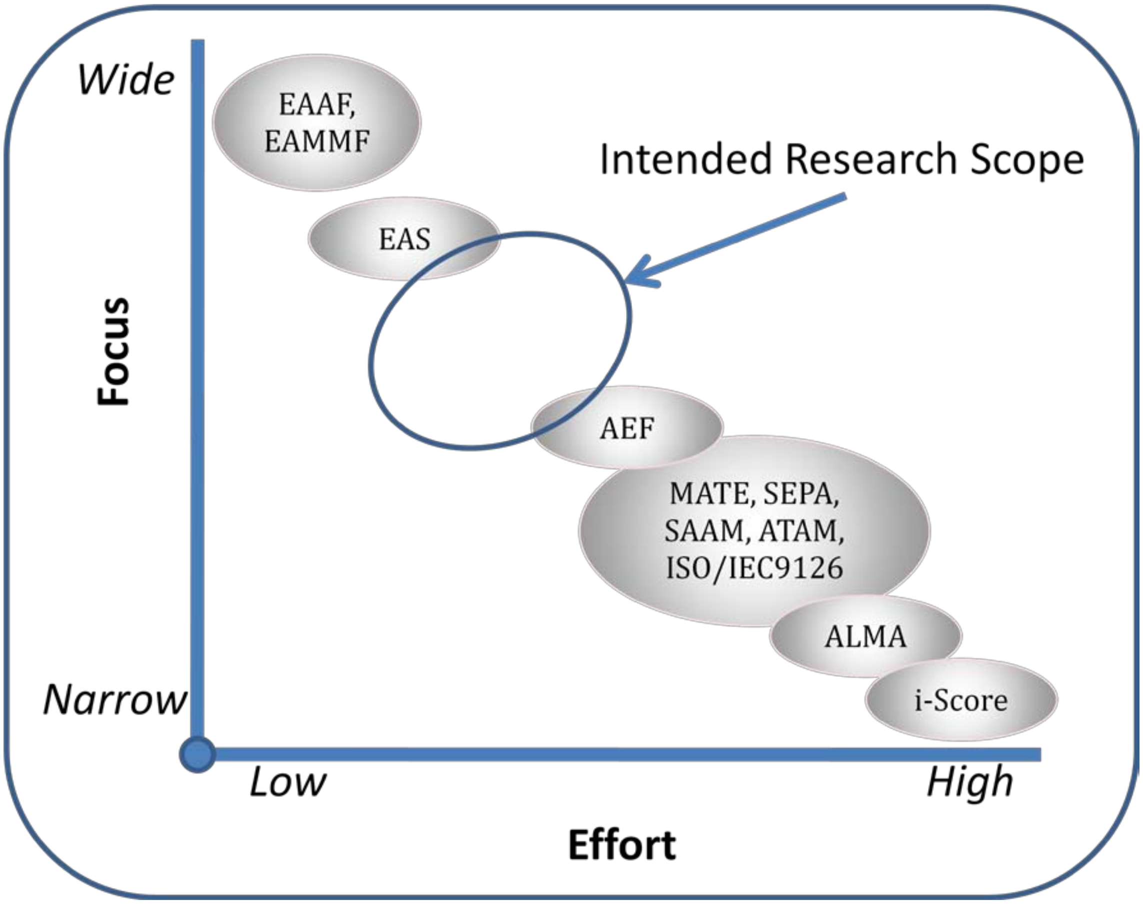

Figure 9. Architecture Evaluation by Focus and Effort

2.5.3.1. Enterprise Architecture Assessment Framework (EAAF)

The EAAF is used by the Office of Management and Budget (OMB) to evaluate the maturity and effectiveness of federal agency enterprise architecture programs. Specifically, the EAAF checks compliance with architecture mandates such as the Clinger-Cohen Act and OMB A-130. This framework comprises 14 assessment criteria where each criterion consists of five maturity levels (OMB, 2008). This framework was considered out of scope for use in this research effort because of the focus on higher, agency-level compliance issues rather than system-related.

2.5.3.2. Enterprise Architecture Management Maturity Framework (EAMMF)

Similar to the EAAF, the EAMMF is used by the General Accounting Office (GAO) to evaluate maturity and the steps needed to improve architecture management. Comprised of 31 core elements, 5 stages, and 4 attributes, the EAMMF is also a means for checking agency compliance with federal policy (GAO, 2003). This framework was considered out of scope at the same level as the EAAF.

2.5.3.3. Interoperability Score (i-Score)

While i-Score only addresses a single aspect of the overall system and architecture, it was important to review Ford's (2008) work for an understanding of the possible depth and quantifiability one could go into in determining each specific area of interest's measure of quality. With the drive toward network-centric operations, an increased focus of research has tried to improve the interoperability of systems. Ford's (2008:2) research presents the i-Score as "a generalized measure of the interoperability of systems of all types, supporting an operational thread."

The i-Score methodology examines “existing architecture data (specifically, DoDAF OV-5, OV-2, and SV-3) and applies graph, optimization and interoperability theory to provide a generalized measurement of interoperability” (Ford, 2008:2). The methodology walks through the six steps of (Ford, 2008:3-5):

1) diagram the operation thread and define the set of supporting systems;
2) create an interoperability matrix;
3) calculate the i-Score;
4) determine the optimum i-Score;
5) calculate the interoperability gap; and
6) perform interoperability analysis.

This method results in a single number measure between zero and one of how well the system interoperates along the examined operational thread (Ford, 2008:4). While this groundbreaking research provides a quantifiable interoperability number, this thesis's authors determined the depth of analysis to reach this number was significantly deeper than any other measures and the intent of the VDEA scorecard. i-Score may prove useful, however, if future research in other value measures enables a similar depth of analysis. VDEA could be the framework that binds such measures together.

2.5.3.4. Multi-Attribute Tradespace Exploration (MATE)

While not necessarily focused on evaluating the quality of system architecture, MATE provides additional insight to the importance of architectures and means of making tradeoff decisions based on the architecture. MATE began as a process to incorporate decision theory into model and simulation-based design primarily applied to the space domain (Ross, 2003:3).

Through numerous research efforts at the Massachusetts Institute of Technology's Systems Engineering Advancement Research Initiative (MIT SEARi); MATE continues to evolve and find new areas of application such as additions for systems of systems design (Chattopadhyay, 2008), value robustness (Ross, 2008), providing a framework for incorporating "ilities" into tradespace studies (McManus, 2006), and quantifying important system "ilities" such as flexibility, survivability, and changeability (Ross, 2006). While finding numerous applications to address such attributes as changeability, survivability, flexibility, robustness, and other ilities, the more detailed level of MATE analysis and its application more to system characteristics than the architecture themselves is beyond the scope of this effort.

2.5.3.5. Architecture Level Modifiability Analysis (ALMA)

This method focuses more narrowly on the analysis of how modifiable the architecture is and specifically focused on software architectures. As reported by Bengtsson (2004), ALMA was the combination of independent work by Bengtssom and Bosch (1999)for predicting maintenance efforts based on the system's software architecture as well as the work of Lassing et al. (1999) for identifying inflexibility at the software architecture level. ALMA uses a "unified architecture-level modifiability analysis method that; distinguishes multiple analysis goals, has visible assumptions and provides repeatable techniques for performing the steps" (Bengtsson, 2004:129-130).

The five main steps of ALMA are selecting the goal, describing the software architecture, developing the scenario, and evaluating and interpreting the scenario. Different specific techniques are used in some of these main steps depending on the goal. In general, the goal is typically one of the following three: "prediction of future maintenance cost, identification of system inflexibility and comparison of two or more alternative architectures" (Bengtsson, 2004:130). This method's modifiability analysis method was determined too narrow for the thesis problem.

2.5.3.6. System Engineering Process Activities (SEPA)

Another method reviewed for evaluating architectures is SEPA. While not dealing with quality attributes directly, SEPA focuses on requirements and architecture in the software realm. SEPA's objective is "to enable comprehensive support for architecture derivation and evaluation through formal processes and complementary tools emphasizing architecture analysis as well as requirements management" (Barber, 2003:1). SEPA emphasizes early evaluation of the architecture in the development process. The intent of this evaluation is to provide an early opportunity to fix requirements errors as well as ensure the software architecture's accuracy for use in building the system. This method utilizes a number of tools, models, and simulations inappropriate for this thesis problem.

2.5.3.7. ISO/IEC 9124 (Botella, 2004)

As one of the most widespread quality models, the International Standards Organization's ISO/IEC 9124 serves as a guide for the evaluation of software quality which defines a general quality model framework applicable to different kinds of software. Most importantly, ISO/IEC 9124 defines six higher-level product quality characteristics which are divided into other sub-characteristics as shown in Table 6 and are then decomposed into attributes producing a multilevel hierarchy. The attributes at the bottom of the hierarchy should be measureable software attributes which can have a quality value determined by applying some metric. While generic in nature and specifically geared towards software, ISO/IEC 9124 still provides more guidelines for the consideration of quality values which may apply to a more generic system architecture value hierarchy.

Table 6. ISO Values (Botella, 2004)

Characteristics	Sub-characteristics
Functionality	Suitability
	Accuracy
	Interoperability
	Security
	Functionality Compliance
Reliability	Maturity
	Fault Tolerance
	Recoverability
	Reliability Compliance
Usability	Understandability
	Learnability
	Operability
	Attractiveness
	Usability Compliance
Efficiency	Time Behavior
	Resource Utilization
	Efficiency Compliance
Maintainability	Analysability
	Changeability
	Stability
	Testability
	Maintainability Compliance
Portability	Adaptability
	Installability
	Co-existence
	Replaceability
	Portability Compliance

2.5.3.8. Software Architecture Analysis Method (SAAM)

As its name implies, SAAM is likewise focused on software systems and the stakeholder. In regards to this effort, the focus on software architecture is too narrow to directly apply to this thesis effort. SAAM specifies functionality, structure, and allocation as three important "perspectives for understanding and describing architectures" (Kazman, 1994). SAAM has also been extended to assess software architectures with respect to different quality factors by obtaining scenarios from the stakeholders and then exploring their effects on the architecture. In particular, much work has focused on architectural analysis of the individual attributes of modifiability, performance analysis, availability analysis, and security analysis. The SAAM process consists of the four major steps of developing scenarios, describing the architectures, evaluating the scenarios and performing an overall evaluation (Kazman, 1994).

2.5.3.9. Architecture Trade-off Analysis Method (ATAM^{SM})

Growing on the work from SAAM, the ATAM is developed for the architecture of complex software intensive systems as "a method for evaluating architecture-level designs that considers multiple quality attributes" (Kazman, 1998:1). The goal is to gain early insight into whether or not the complete architecture meets requirements. While also more narrow and detailed to apply directly, ATAM provides some useful concepts to consider.

Where other methods focus on individual attributes, ATAM attempts to capture the impact of interactions between attributes. This method intends to find trade-off points between attributes, improve communication between stakeholders with regard to each attribute, clarify and refine the requirements, and provide the necessary framework for ongoing, simultaneous system design and analysis processes. The four main areas of effort comprise the ATAM are:

"scenario and requirements gathering, architectural views and scenario realization, model building and analysis, and tradeoffs" (Kazman, 1998:2).

2.5.3.10. Architecture Evaluation Framework (AEF)

Building on the ATAM concepts, the AEF was developed to define the necessary tools and procedures to evaluate system architecture within the telecommunications domain. The first step is creating a hierarchy with more generic top-level factors based on their identified relevant business drivers down to more specific leaf-level factors. Next, their relative importance is determined by applying weights according the Analytic Hierarchy Process (AHP) technique. Here, a pair-wise comparison of each branch and each level is conducted in relation to a specific business driver. For each of the lower leaf-level factors, measures are created in the form of specific questions. The evaluation team then answers each question to evaluate the effect that answer has on the specific business driver being considered. This effect is then scored as a number on a scale of zero (has a negative effect) to one (has a positive effect). These values, when combined with their relative weighting, "are used to evaluate the overall appropriateness score of the architecture" (Mazhelis, 2006:3). Alternative architectures can subsequently be compared as well. Likewise, a sensitivity analysis can be made to evaluate changes in the score due to changes in the weights (Lehto, 2005; Mazhelis, 2006).

While the AEF was tailored to the company and their specific needs, this method's approach provides a close comparison at a high level to the VFT approach. However, the use of the AHP technique is a notable exception. Considered overly complex for this thesis effort, AHP often requires "extensive pair-wise comparisons... and extensive mathematical calculations...[which] seem to obscure, rather than illuminate, the tradeoffs" (Kirkwood, 1997:260). Additionally, adding a new value to the mix would require a potentially lengthy recalculation of the pair-wise comparisons.

2.5.3.11. Enterprise Architecture Score Card™

One of the methods discovered closer in scope to provide a high-level measure of architecture quality and completeness is the Enterprise Architecture Score Card™ developed by Schekkerman (2004). EAS is geared more to industry's approach to architecture versus the DoD with its greater emphasis on business drivers. While considered too qualitative for this research effort, EAS helps distinguish an upper bound for the level of detail focus for the direction of this research effort.

EAS's goal is "to help understand the relations and elements that influence the decision-making about the adoption of enterprise architecture concepts in several ways" (Schekkerman, 2004:3). It further serves to communicate "the essential elements and functioning of the enterprise" (Schekkerman, 2004:3) by providing a three point score (0-unclear, 1-partially clear, 2-clear) highlighting areas that are good or need further development. The Extended Enterprise Architecture Framework (E2AF)™ forms the basis of the scorecard in a matrix of four aspect areas and six abstract levels of concern.

The four aspect areas are Business, Information, Information Systems, and Technology Infrastructure. The Business aspect is the starting point involving the organizational and management processes in the architecture. The Information aspect is extracted from the business aspect to express the information needs; flows and relationships help to identify which functions can be automated. Information Systems then covers that automated support, while Technology Infrastructure covers the supporting technology environment for the information systems.

The six abstract levels of concern are Contextual, Environmental, Conceptual, Logical, Physical, and Transformational. The Contextual level (“Why?”) describes the mission, vision, and scope of the organization and architecture. The Environmental level (“With Who?”) examines the extended business relationships and information flows. The Conceptual level (“What?”) focuses on the goals, objectives, and requirements of the entities involved. The Logical level (“How?”) explores the ideal logical solutions. The Physical level (“With What?”) addresses the physical solutions and supporting products. Finally, the Transformational level (“When?”) describes the proposed solutions’ impacts.

The Enterprise Architecture Score Card methodology then builds on the E2AF by asking questions at each aspect area and abstraction level. The zero to one range of answers to each question helps identify where the architecture fulfills its purpose and what areas need improvement. The EAS further assesses a zero to one range for integration to address the consistency of the architecture. Finally, it is important to not misinterpret the numerical results from the EAS. These numbers merely show areas of strength and areas in need of improvement. There is no score that specifically represents “good” or “fail.”

III. Methodology

As discussed previously, joint force protection faces numerous challenges in its net-centric transformation especially in interoperability. A key enabler to good interoperability is a good architecture. The Security Equipment Integration Working Group (SEIWG), within the aspect of their mission to coordinate and influence system architecture, desired a tool to evaluate the quality of their proposed "to-be" architecture. As described in the previous chapter, the architecture evaluation tools fell short of the desired capability. Therefore, the principles of Value-Focused Thinking (VFT) also described in the previous chapter guided the development of a new tool--the Value-Driven Enterprise Architecture Score (VDEA-Score).

This chapter describes the methodology used to identify the problem and develop the weighted hierarchy with measures and value functions of the values deemed most important to the stakeholder. This forms the VDEA-Score model for evaluation. For the purpose of this thesis, the emphasis is on the architecture quality values meaning the intrinsic quality of the products themselves in terms of documentation standards and desired attributes. The alternative generation and scoring process will also be discussed. Finally, discussion of the applicability of the VDEA-Score model of architecture quality values to another system's architecture concludes this chapter.

3.1. Problem Identification

For this effort, the core question asked by the decision maker was to determine if common joint force protection values could be used as a basis for evaluating a “To-Be” architecture for net-centric force protection. The research team answered this question by creating a new VDEA-Score evaluation methodology used to develop a single joint force protection value model with measures of effectiveness and evaluate the candidate joint force protection architecture. This value model may aid in future evaluating, scoring, and ranking "To-Be" architectures based on values important to the decision maker. This VDEA-Score allows the decision maker to measure the effects of changes to Concept of Operations (CONOPS), resources, or level of net-centricity as proposed in revisions of the "To-Be" architectural product suite and determine the degree of change to the overall value expected to joint force protection.

A weighted, hierarchical tree of component values of the Joint Force Protection architecture was thus desired to identify components that are influenced by net-centricity and interoperability. In addition, the decision maker wanted a set of measures, with associated utility curves, to evaluate the degree to which each value component was achieved within a DoDAF architectural product suite. Lastly, the decision maker wanted a composite value-focused Joint Force Protection score for an overall CONOPS as depicted in a suite of architectural products. This would create a single measure for the value created by investing Joint Force Protection resources to match the "To-Be" architecture. Therefore, the problem was, "How should common Joint Force Protection values be used to evaluate a "To-Be" architecture for net-centric force protection?"

3.2. Develop and Verify Value Hierarchy

The initial value hierarchy was formed by two branches divided into an architecture-specific branch and a system-specific branch. This approach enhanced the hierarchy's decomposability by dividing it into an architecture-specific branch to address the quality of the architectural views or products and a system-specific branch to address the effectiveness quality of the system represented by the architectural views or products. The two-branch division also maintains exclusivity of component value between the architecture quality and system effectiveness values which allows for full separation of the two branches for separate reuse across diverse applications supporting Kirkwood's (1997) desirable property of nonredundancy. This division further supports Kirkwood's (1997) other desirable property of easier operability. Not only is the hierarchy easier to read, but the two-branch division also facilitates reuse especially of the architecture quality values to apply to another program's architecture.

To develop an initial set of "ility" values, a number of questions were considered by the authors based on personal experience and literature review such as: What are the overall objectives? What values are essential to ensuring effective joint force protection? What values are essential to architectures? As discussed in Chapter 2, no standard list of applicable "ilities" exists. The table in Appendix A represents the comprehensive list of possible values compiled by the authors through the literature review (e.g., Bottella (2004), Lehto (2005), Ross (2006), Dalgren (2007), and others) and brainstorming sessions. The Wikipedia (2008) listing under "ilities" was also included as considered by the authors as an internet brainstorming product.

Using the affinity diagram technique, the large list of "ilities" was converted to individual note cards. The research team physically arranged the cards without discussion into stacks of related terms resulting in 30 different groupings. After this initial grouping, discussion ensued amongst the team which further refined the groupings.

As part of this discussion, while keeping Kirkwood's (1997) principles of small size and completeness in mind, a number of subgroups and individual attributes were discarded as not applicable to this effort. The remaining 22 subgroups were examined for consolidation because some attributes could be considered synonyms or within the definitional scope of others.

Turning these subgroups into values for the hierarchy, the "ility" with the widest definitional scope was chosen and defined such that it could be decomposed by the other attributes in the subgroup. Likewise, the other "ilities" in the respective subgroups were defined to cover the important values in as few or decomposable attributes as possible. The resulting set of two complete, main groups emerged as the *Architecture Quality Values* and *System Effectiveness Values.* These two main groups formed the branches with subsequent tiers formed with their associated subgroups and attributes to establish the initial value hierarchy.

Using the initial value hierarchy as a starting point, the decision maker was interviewed to raise discussion and educe important values that the authors may have initially overlooked. The resulting value hierarchy established during this interview process is exhibited in Figure 10 with the additional tiers shown in Figure 11 for the *System Effectiveness Values* and Figure 12 for the *Architecture Quality Values*. The decision maker agreed that the proposed value hierarchy accurately mirrored values essential to this project. The second-tier objectives are general values essential to first-tier branches. The third-tier values are supporting values that provide greater detail about what is meant by the general second-tier value and so forth. The resulting hierarchy also satisfies Kirkwood's (1997) principles of completeness, non-redundancy, decomposability, operability, and (relatively) small size.

3.2.1. System Effectiveness Value

For this effort, System Effectiveness was defined as "the quality of the instantiated system being represented and its ability to perform its stated mission." While the authors believe these values of *Capability*, *Maintainability*, and *Interoperability* are applicable to most DoD systems at a high level, they were specifically defined to the force protection domain through their lower-tier values (Mills, 2009). The *System Effectiveness Value* branch of the hierarchy is provided in Figure 11 for reference because the focus of this paper is on the *Architecture Quality Values*.

3.2.2. Architecture Quality Values

This branch, shown in Figure 12, was defined as "the intrinsic quality of the products in terms of documentation standards and desired attributes." The authors contend that the values contained therein are applicable to any DoDAF architecture, independent of the described system. Table 7 expands the definition of each value in the Architecture Quality (AQ) sub-tier. Similar information can be found in Mills (2009) for the System Effectiveness (SE) sub-tier values. The asterisk notes a net-centric relation.

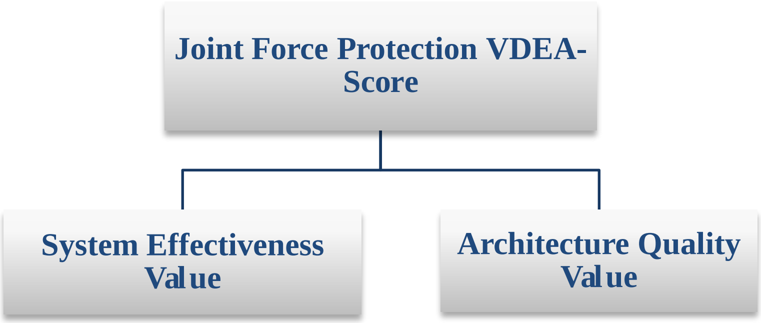

Figure 10. VDEA-Score Hierarchy with First-Tier Branch

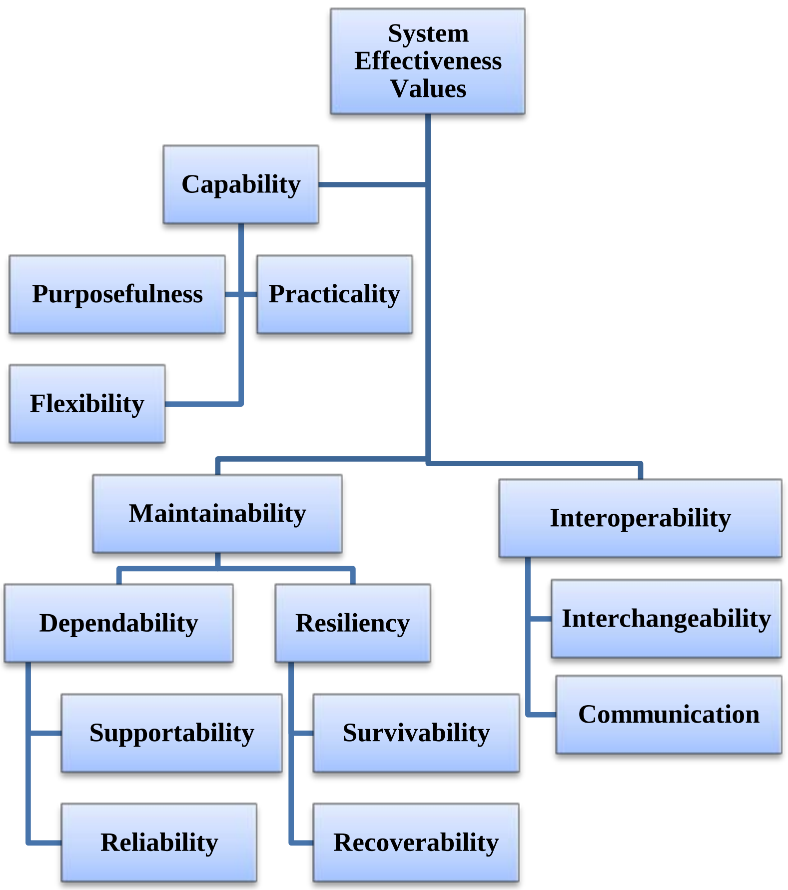

Figure 11. System Effectiveness Values Branch

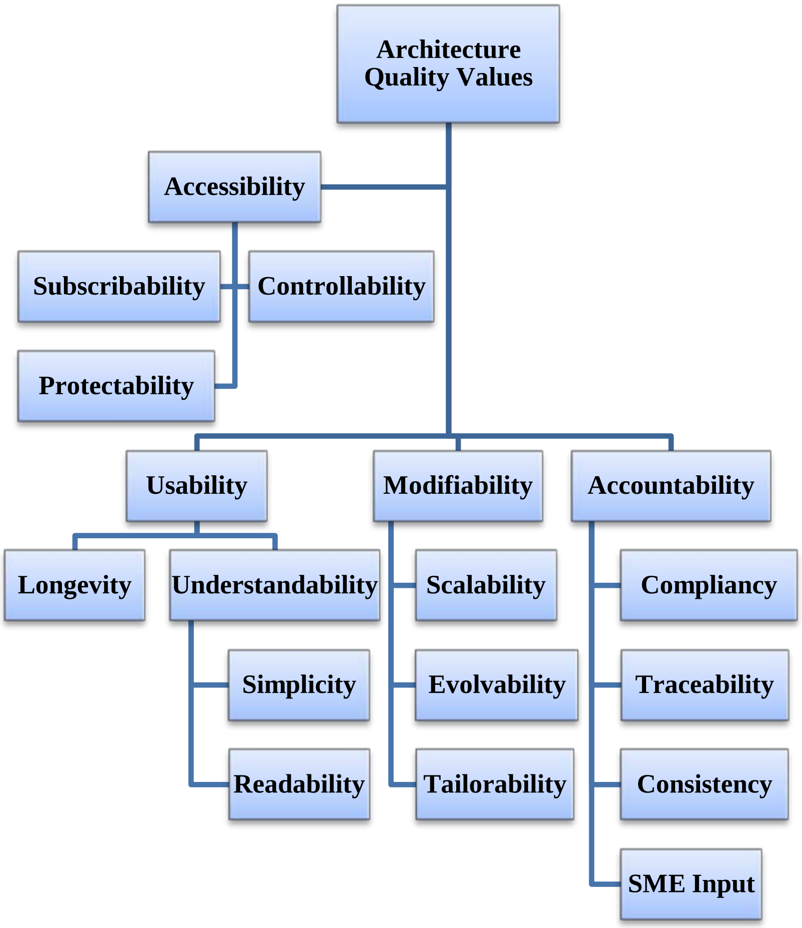

Figure 12. Architecture Quality Value Branch

Table 7. Architecture Quality Value Definitions

Accessibility	The assurance that information relating to architecture products can only be accessed or modified by those authorized to do so, preventing information use outside the architecture's intended context.
Subscribability*	How easily the information pertinent to a stakeholder can be accessed.
Controllability*	The assurance that only those authorized to modify architecture information can do so with appropriate revision control measures.
Protectability*	The assurance that only those authorized to access the information may do so.
Usability	The extent to which the architecture framework can be used by users to achieve goals effectively and efficiently.
Longevity	The degree to which the architecture product is available over time (i.e.: documentation).
Understandability	The level of difficulty needed to understand what the architecture is conveying.
Simplicity	How many diverse and autonomous, but interrelated and interdependent components or parts, are linked through many interconnections.
Readability	How easily the information is conveyed to the reader.
Modifiability	How easily the architecture framework can be updated, upgraded, or otherwise accepts changes.
Scalability*	The ability of the architecture to maintain its function and retain its desired properties when its scale is increased greatly without having a corresponding increase in complexity.
Tailorability	The ability of the architecture products' level of detail to be changed to meet the needs of different stakeholders.
Evolvability*	The ability of the architecture to change as needed to handle refinements.
Accountability	The ability of the architecture to be responsible for addressing the stakeholders requirements.
Compliancy*	How effective architecture products comply with DoDAF standards.
Traceability	The extent to which the information in the Operational Views match the information in the System Views.
Consistency	The agreement of parts or features of architecture products to one another or a whole.
SME Input	The extent of pertinent Subject Matter Expert involvement in architecture development

* Denotes net-centric relationship

3.4. Develop Evaluation Measures

With the value hierarchy established, evaluation measures for each of the values in the last tier in the hierarchy were developed for the evaluation. A brief description of each *Architecture Quality Value* evaluation measure follows. These measures were created in consultation with and validated by the decision maker. These measures are measurable, operational, and understandable, satisfying Keeney's (1992) three principles for evaluation measures. While suggested sources for the evaluator to review in answering each measure are provided, it is important to note that an answer may also be found through the review of other products. Appendix B serves as a summary evaluation sheet organized by value with each measure name, the respective evaluation question, and the possible result. Data collected for each evaluation measure is presented in Chapter 4.

3.4.1. Evaluation Measures for Subscribability

Two measures are used to evaluate the *Subscribability* of the architecture products. DoD Directive 8320 (2007) states data is an essential enabler of net-centric warfare. Data shall be made visible, accessible, and understandable for interoperability purposes.

3.4.1.1. Access

The natural, direct ACCESS measurement determines the degree of difficulty the stakeholders have in obtaining electronic access to the products. The assumption was made that all stakeholders know they are indeed stakeholders and thus aware of the existence of the products and the starting point to obtain them. The AV-1 is the best source for describing the process to obtain the products. Most likely, the products are found in an on-line repository. It is possible the AV-2 may also be a source as the repository may include this information in its definition. If this information cannot be found in the architecture products, the evaluator's experience with the repository may be considered. For example, use of an official DoD or service-level repository such as the DoD Architecture Repository System (DARS) (DoD, 2009) or the Air Force Architecture Repository (Department of the Air Force, 2009) assumes existing access so the highest category (see below) is scored because this is not an evaluation of the official, central repository itself. If no share site or repository is used, thus requiring point-to-point transfer (e.g., a stakeholder has to request email distribution), the lowest category is scored. The possible score categories are:

- No means to gain access
- 1 week to gain access
- 3 days < access granted < 1 week
- 5 minutes < access granted < 3 days
- Access granted < 5 minutes

3.4.1.2. Product Locatability

The natural, direct PRODUCT LOCATABILITY measurement assesses the degree of difficulty the stakeholders have locating the desired architecture products after access has been obtained. The AV-1 or AV-2 may be sources for describing the process for locating the products. As in the previous measure, the evaluator's experience with the repository may be considered if the data structure is not documented in the products. Likewise, the use of an official repository (e.g., DARS) would score the highest category while emailing products to stakeholders would score the lowest category. The possible score categories are:

- Cannot locate products
- > 5 minutes to locate products
- < 5 minutes to locate products

3.4.2. Evaluation Measure for Protectability: Access Control

The ACCESS CONTROL measurement evaluates the degree of protection over the architecture products. This constructed, proxy measurement evaluates the information assurance issues of whether or not access control measures have been implemented appropriately to the level of protection required. Note that this assumes the architecture products' level of protection is accurately described. For example, the products posted to a community site have strong user identification and password requirements to access. The AV-1 or possibly TV-1 may be document sources to find information related to this measure. If not documented, the evaluator may consider the protection provided by the repository. For example, products located in DARS by default meet the highest category. A program-specific share site with no protections for official use only documents would fall in the lowest category. The possible score categories are:

- No plan or inadequate plan
- Plan exists but not implemented
- Appropriate protection implemented

3.4.3. Evaluation Measure for Controllability: Document Protection

The DOCUMENT PROTECTION measurement evaluates the controllability of the architecture products. This natural, direct measurement concerns configuration control by evaluating the degree of control over the architecture products to protect against unauthorized changes. This measure refers to the final published products which should be write-protected. Therefore, an unauthorized person should not be able to change and republish the products to the repository. The AV-1 may discuss this aspect either directly, refers to a configuration control plan, or by association through stating the use of an official repository as the location for the final published products. If not documented, again, the use of an official common repository meets the intent of the highest category. If a program-specific repository is used, the evaluator should examine the write protection of the documents. The possible score categories are:

- No plan for write protection
- Plan exists but not implemented
- All products controlled

3.4.4. Evaluation Measures for Longevity

This value consists of two measures to ascertain whether or not the architecture documentation may be available for reference or reuse over an extended period of time.

3.4.4.1. File Management

The constructed, direct FILE MANAGEMENT measure examines the status of an official file management system for holding the architecture products. If one exists, it is examined to determine its effectiveness by the extent to which documents are contained and maintained within it. The AV-1 may discuss this aspect either directly or by association through stating the use of an official repository as the location for the final published products. If not documented, the use of an official common repository meets the intent of the highest category. If a program-specific repository is used, the evaluator should examine its file structure and make a judgment call to determine if it meets the intent of a managed system. For example, if multiple and differing versions of a view are found in different folders without a naming convention to identify them as drafts versus final, then no credit for a system should be given. The possible score categories are:

- No official file management system

- File management system exists but does not contain all developed products or products not maintained
- File management system exists containing all developed products and maintained for currency

3.4.4.2. File Format

The constructed, proxy FILE FORMAT measurement evaluates the degree to which electronic copies of the products are available in an industry standard or interchangeable format allowing viewing over a period of time. The AV-1 is the likely source regarding the tools used which therefore drives the format available for the products. If this is not documented, the format of the products reviewed may be evaluated. The possible score categories are:

- No electronic products or no longer accessible
- Proprietary file format (i.e. only accessible with one type of proprietary software)
- General file format (i.e. available to common viewer such as Adobe Acrobat Reader, OpenOffice.org, common web browser, etc.)

3.4.5. Evaluation Measure for Simplicity

This value consists of three measures to ascertain the level of simplicity in the architecture documentation.

3.4.5.1. Connections

The constructed, proxy CONNECTIONS measurement examines how easy the links between entities are to understand. The evaluator examines the interfaces between steps, entities, activities, etc., of all available products. A subjective determination is then made if these items make sense or are laid out in an organized fashion within each available product. A percentage is then determined by the ratio of the total number of products in compliance to the total number of existing products.

3.4.5.2. Architecture Redundancy

The natural, proxy ARCHITECTURE REDUNDANCY measurement looks for any unnecessary duplication of information across all available products. For example, are there any extra entities, activities, links, etc., unnecessarily accomplishing the same goal? Note that this redundancy does not refer to intentionally designed redundant systems. The measurement categories are based on one redundancy discovered per number of entities reviewed. The possible score categories are:

- > 1 unnecessary duplication per 10 items
- 1 unnecessary duplication between 10 and 100 items
- 1 unnecessary duplication between 100 and 500 items
- 1 unnecessary duplication > 500

3.4.5.3. Architecture Economy

The constructed, proxy ARCHITECTURE ECONOMY measurement checks all available products for whether or not multiple steps are being used unnecessarily to represent the same activity (e.g., could three activities be represented sufficiently by consolidating into one?). However, because reasons may exist where consolidation might not be desired, it may be difficult to determine if such a condition is truly unnecessary without interviewing the architect. Therefore, a subjective, binary assessment is made by the evaluator with any specific items discovered referred to the program for their consideration.

3.4.6. Evaluation Measures for Readability: OV & SV Readability

The two constructed, proxy measures for *Readability* are OV READABILITY and SV READABILITY. These respectively measure whether or not Operational View and Systems View information are presented clearly and concisely. They are subjective evaluations by operational-level and systems engineer-level subject matter experts. Each available OV and SV product should be reviewed as a whole and subjectively rated readable/unreadable. The final assessment is a percentage of readable OV or SV views over their respective total available OV or SV views.

3.4.7. Evaluation Measure for Scalability: Scale

The constructed, proxy SCALE measure addresses the issue of whether or not the scale of architecture can be at least doubled while retaining its desired function and properties without significantly increasing complexity. SCALE is a subjective assessment of all available products to determine if none, some, most, or all views could handle double the nodes without undue complexity.

3.4.8. Evaluation Measure for Tailorability: Decomposition

The natural, direct DECOMPOSITION measure evaluates the degree to which the architecture can be tailored. The primary source for this measurement is the Operational Activity Model (OV-5). Many levels of decomposition are indicative of a high level of *Tailorability*. The possible score categories are:

- None
- 1 level
- 2 levels
- 3+ levels

3.4.9. Evaluation Measure for Evolvability: Tool Format

The TOOL FORMAT measure evaluates the degree to which the products can be easily edited to handle refinements based on the method of development. It is a constructed, proxy measure that assesses the effect of one input in relation to the ability to reflect the input through all views. For example, Telelogic's System Architect architecture-building software can carry a single input throughout multiple views. The AV-1 should be reviewed for the architecture development tools to be used. If not specified, the file format of the available views should be used. The possible score categories are:

- In general, the product has to be built again from the start
- In general, one input is reflected in single reference (e.g., no find and replace in Microsoft Powerpoint)
- In general, one input is reflected in instant view references but not other views (e.g., Microsoft Word's find and replace in all documents)
- In general, one input is reflected in all relevant views (e.g., a System Architect change applies to multiple views)

3.4.10. Evaluation Measure for Compliancy: DoDAF Compliancy

The natural, direct DODAF COMPLIANCY measure evaluates the percentage of architecture products which comply with DoDAF standards. Each available view should be compared to the appropriate DoDAF description to assess its compliancy (DoD, 2007b). The final determination is the ratio of the total number of products in compliance to the total number of available products.

3.4.11. Evaluation Measure for Traceability: Requirements Traceability

The natural, direct REQUIREMENTS TRACEABILITY measure evaluates the degree to which requirements are met by functions/activities. The Operational Activity to Systems Function Traceability Matrix (SV-5a) "depicts the mapping of operational activities to system functions and thus identifies the transformation of an operational need into a purposeful action performed by a system" (DoD, 2007b: 5-39). Therefore, the creation and validation of an SV-5 would accurately measure the value of *Traceability* by the percentage of operational activities mapped to system functions.

3.4.12. Evaluation Measures for Consistency: Internal & External Consistency

The INTERNAL CONSISTENCY measure determines if each available product is in agreement with itself. The EXTERNAL CONSISTENCY measure determines if each available product is in agreement with the other available products. Both of these natural, direct measures are determined by the ratio of the number of consistent products by the total number of products available.

3.4.13. Evaluation Measures for Subject Matter Expert (SME) Input

3.4.13.1. SME Effectiveness

The constructed, proxy SME EFFECTIVENESS measure evaluates the degree of effectiveness of the SME's involved with the architecture development. This is determined by examining the AV-1 for any plan for involving SMEs with the representation of effectiveness based on experience. Specifically for this effort, a SME with over five years of force protection experience was specified by the SEIWG as the most effective. The level of SME experience may be easily tailored to a specific program's need; however, the same five year specification may be left as the default for the general case. The possible score categories are:

- No Plan
- Plan/No SMEs identified
- SMEs identified but no reference to experience
- Identified SMEs average < 5 years experience
- Identified SMEs average > 5 years experience

3.4.13.2. SME Involvement

The natural, direct SME INVOLVEMENT measure evaluates the number of SMEs involved from different stakeholder organizations. Because this effort is a joint project, the SEIWG specified that involvement from multiple services would define the scoring categories (0, 1, 2, 3, 4, and Multiple SMEs from multiple services). By default, the same number of categories may be used with the number of services changed to number of organizations. For example, the number of major commands involved would be used instead of services for an Air Force-level program. The possible score categories are:

- No involvement
- One Stakeholder Organization SME
- Two Stakeholder Organization SME
- Three Stakeholder Organization SME
- Four Stakeholder Organization SME
- Many Stakeholder SMEs from many organizations

3.5. Create Single Dimension Value Functions

These measures consisted of different measurement units and different scales (although most here are categorical); therefore, Single Dimension Value Functions (SDVFs) were created to convert the units of each evaluation measure into a score ranging from zero to unity. This metric allowed for easy summation into an overall score. These value functions were drafted by the authors and refined and validated during meetings with the decision maker and SMEs. A summary table is provided in Appendix C for reference.

The worst and best case scenarios for each measure were discussed to establish the values of quality boundary (zero and one). Key intermediate points were then selected for each measure with values assigned by the decision maker. While these values represent the joint force protection domain, they may be used as the default or starting point to tailor according to the needs of another program's decision maker.

These graphs were developed using Hierarchy Builder Version 1.01 (Weir, 2008). This Microsoft Excel spreadsheet plug-in allows quick definition of the value functions by specifying the type of function (e.g., monotonically increasing exponential) and the pertinent inflection points.

3.5.1. Access Value Function

The ACCESS value function uses a discrete, categorical scale. Figure 13 specifies the value the decision maker placed on the measure's categories of time to grant access. The decision maker specified the worst case scenario (lower bound, assigned a value of zero) to be no available electronic access while the best case scenario (upper bound, assigned a value of one) is access within five minutes. The other categories ranged as shown in Figure 13 according to the decision maker's value.

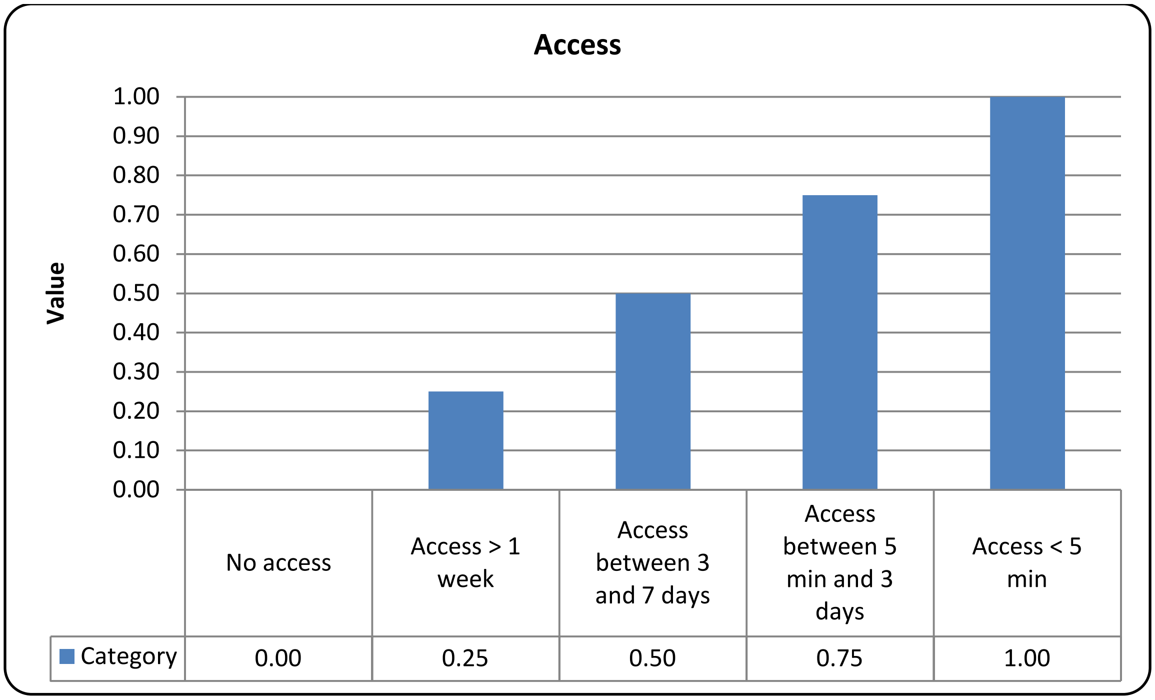

Figure 13. Access Value Function

3.5.2. Product Locatability Value Function

The PRODUCT LOCATABILITY value function uses a discrete, categorical scale. Figure 14 specifies the decision maker's value associated with how quickly the desired products can be located. The decision maker specified the worst case scenario to be the inability to locate the products while the best case scenario is locating the products within five minutes. The other categories ranged as shown in Figure 14 according to the decision maker's value.

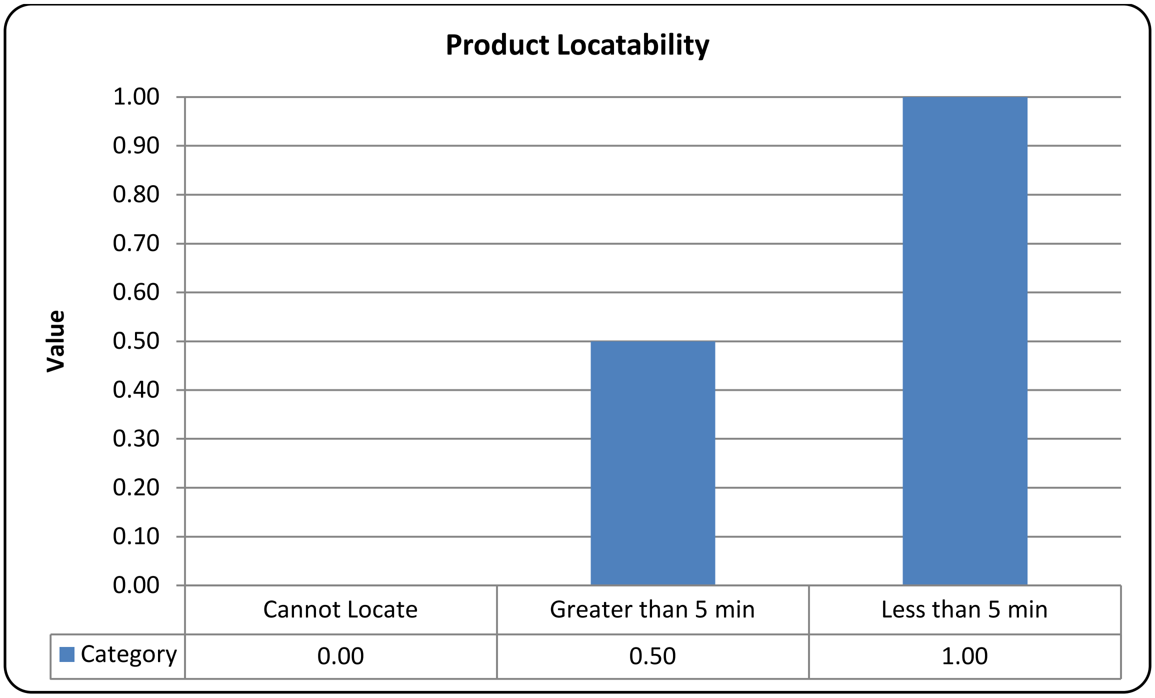

Figure 14. Product Locatability Value Function

3.5.3. Access Control Value Function

The ACCESS CONTROL value function uses a discrete, categorical scale. Figure 15 specifies the decision maker's value associated with the plan and implementation of the appropriate level of access protection over the architecture products. The decision maker specified the worst case scenario to be no plan or an inadequate plan while the best case scenario is implementation of appropriate protection. The other categories ranged as shown in Figure 15 according to the decision maker's value.

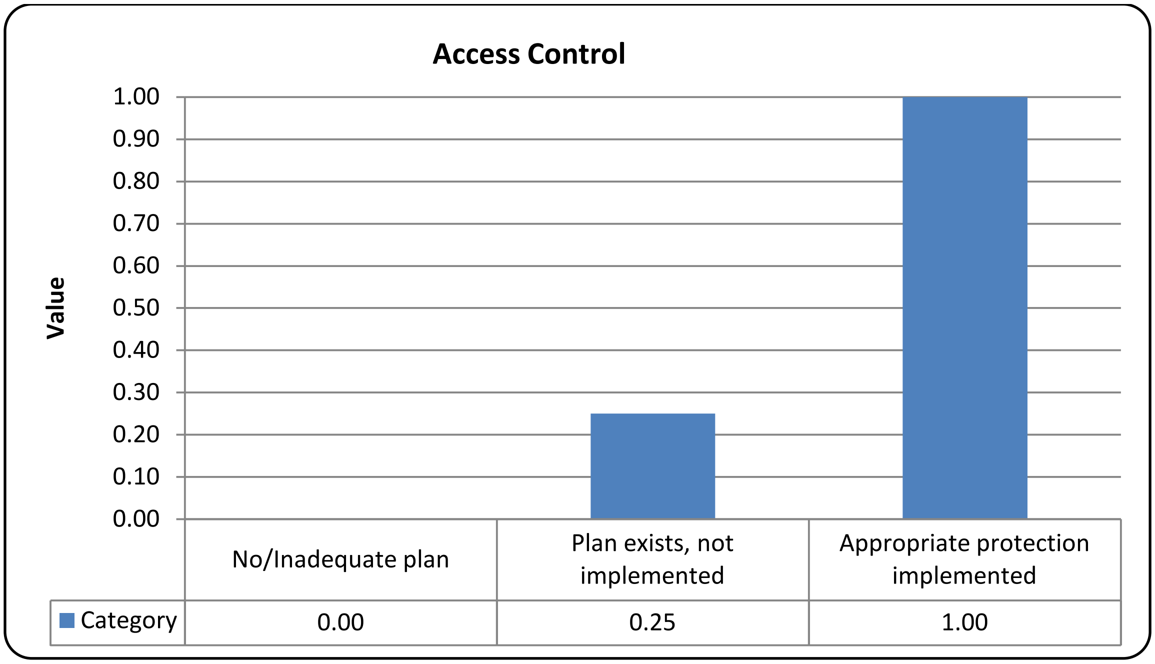

Figure 15. Access Control Value Function

3.5.4. Document Protection Value Function

The DOCUMENT PROTECTION value function uses a discrete, categorical scale. Figure 16 specifies the decision maker's value associated with the level of write-protection measures or configuration control in place. The decision maker specified the worst case scenario to be no write-protection plan or configuration control plan while the best case scenario is a plan exists and all products controlled. The other categories ranged as shown in Figure 16 according to the decision maker's value.

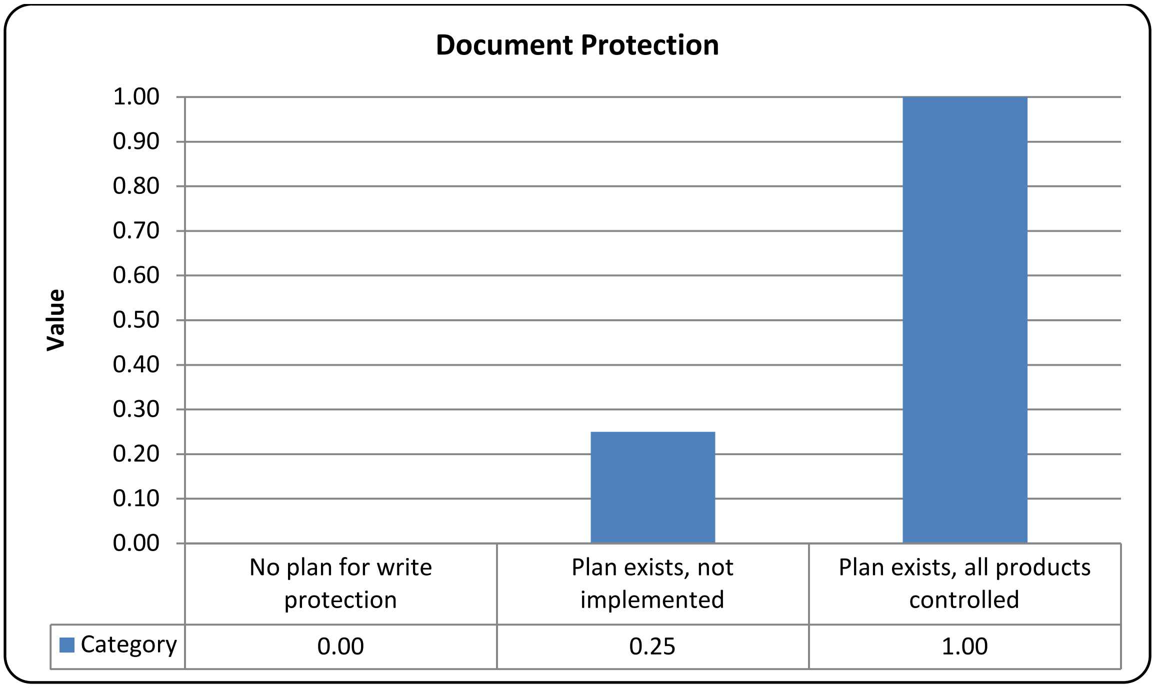

Figure 16. Document Protection Value Function

3.5.5. File Management Value Function

The FILE MANAGEMENT value function uses a discrete, categorical scale. Figure 17 specifies the decision maker's value associated with the file management scenarios. A notable difference in this value function is that the categories are not equally incremental. The research team initially proposed a higher 0.25 value for a file management system that was complete but not maintained. However, the decision maker determined that a system that exists, but is not complete provides the same value (0.5) as one that exists, but is not regularly maintained. The decision maker specified the worst case scenario to be no file management system while the best case scenario is implementation of a file management system with all products maintained. The other categories ranged as shown in Figure 17 according to the decision maker's value.

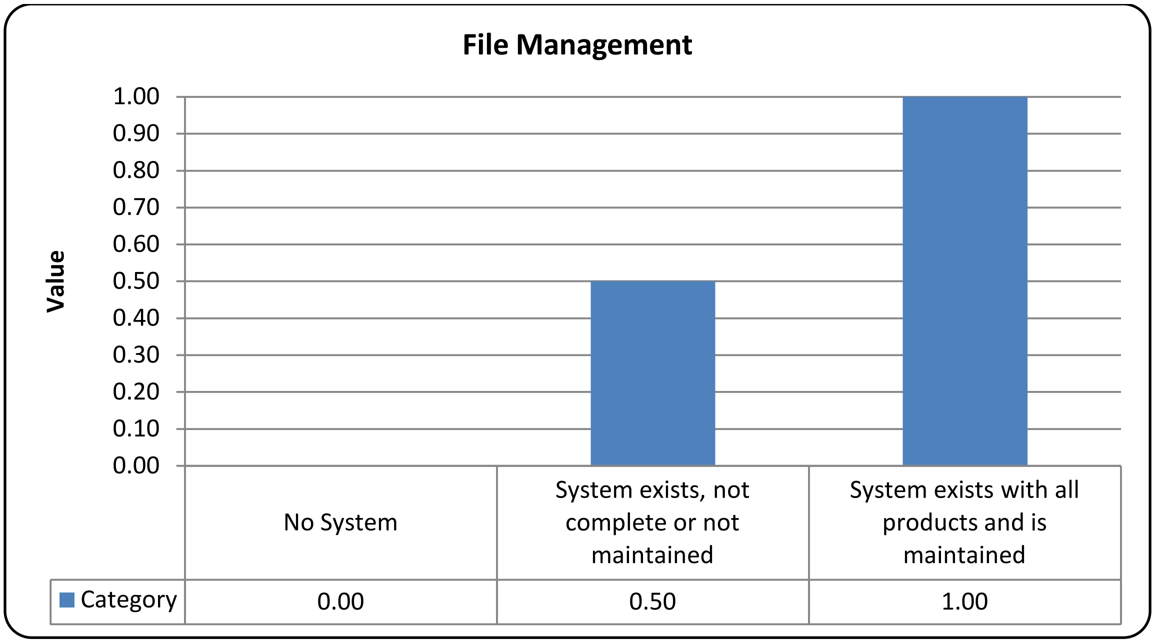

Figure 17. File Management Value Function

3.5.6. File Format Value Function

The FILE FORMAT value uses a discrete, categorical scale. Figure 18 specifies the decision maker’s value associated with the categories regarding the file formats for the architecture products. The decision maker specified the worst case scenario to be no electronic products or inaccessible products while the best case scenario is products in a general file format. The other categories ranged as shown in Figure 18 according to the decision maker’s value.

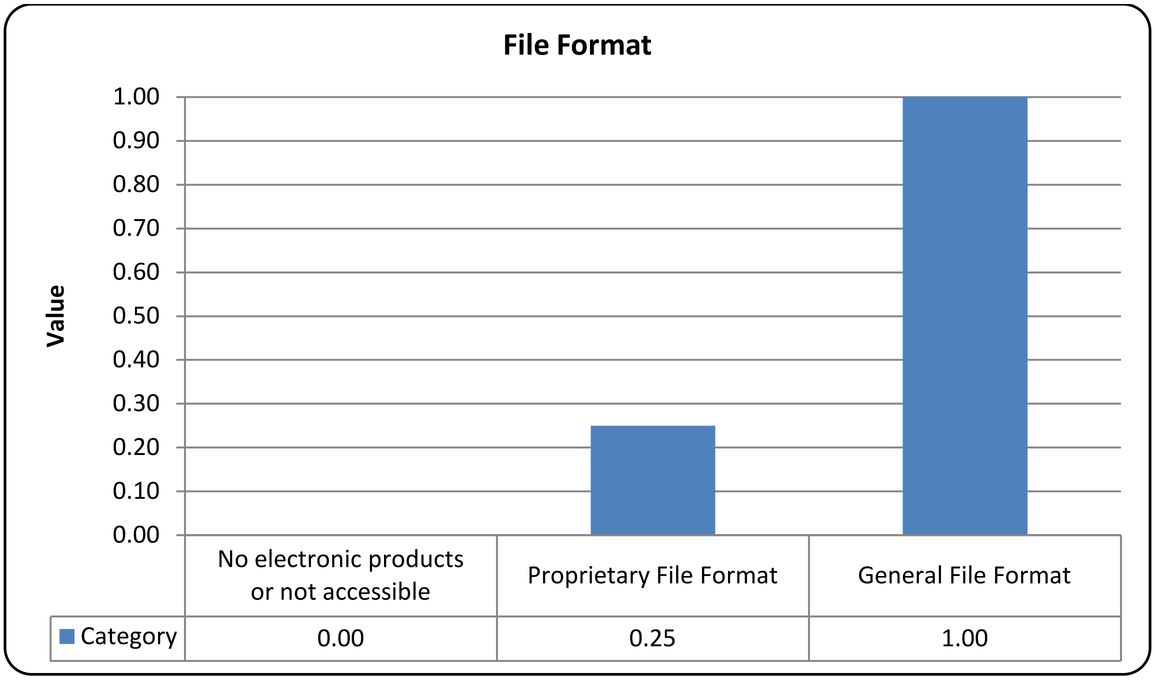

Figure 18. File Format Value Function

3.5.7. Connections Value Function

The CONNECTIONS value function uses a monotonically increasing, exponential scale. Figure 19 specifies the decision maker's value associated with the percent of products with easy to understand entities. The inflection point was specified as 0.3 on the value axis meaning 60 percent of the available products exist as such. The function begins to earn most of its value at the > 0.6 (or 60 percent) mark.

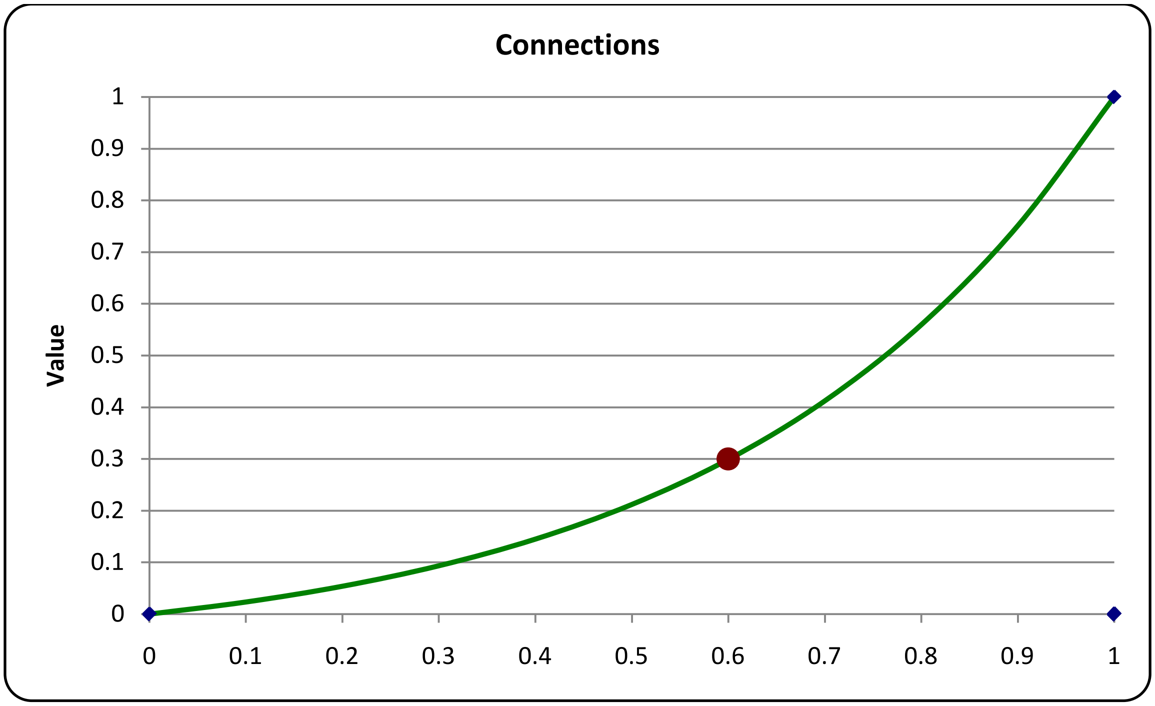

Figure 19. Connections Value Function

3.5.8. Architecture Redundancy Value Function

The ARCHITECTURE REDUNDANCY value function uses a discrete, categorical scale. Figure 20 specifies the decision maker's value associated with the number of entities found to be redundant. The decision maker specified the worst case scenario to be greater than one redundancy in 10 entities while the best case scenario is less than one redundancy in 500 entities. The other categories ranged as shown in Figure 20 according to the decision maker's value.

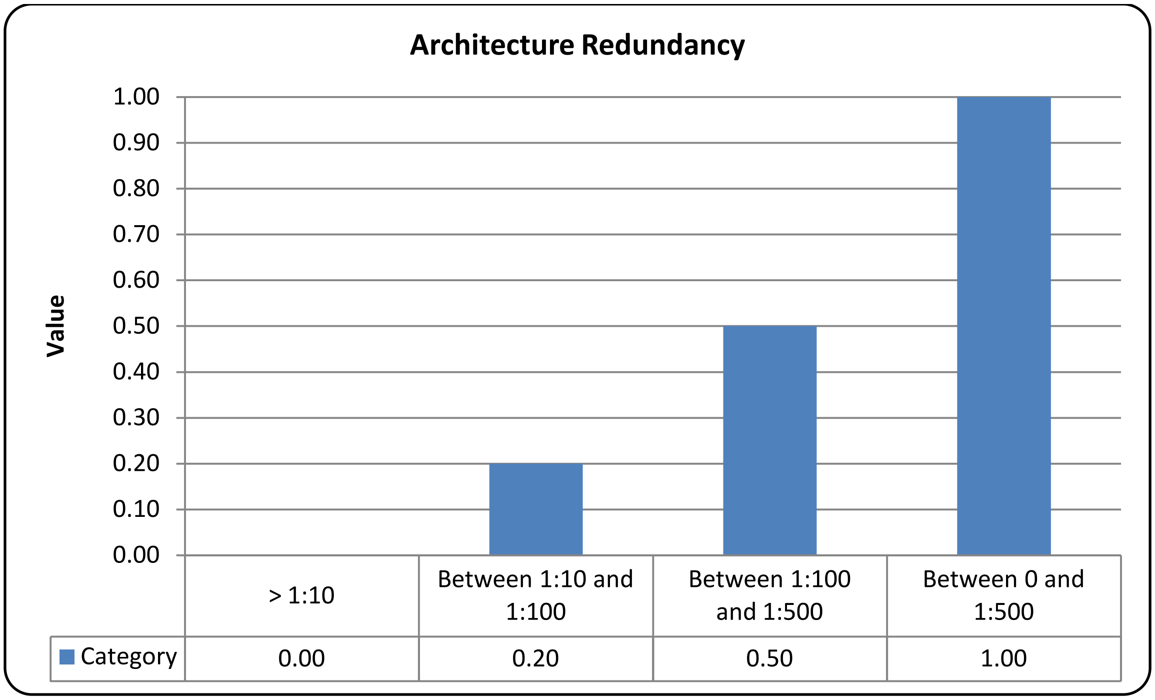

Figure 20. Architecture Redundancy Value Function

3.5.9. Architecture Economy Value Function

The ARCHITECTURE ECONOMY value function uses a discrete, binary scale. Because the measure is either a yes or a no, the value is by default the worst and best values of zero or one, respectively. This function is shown in Figure 21.

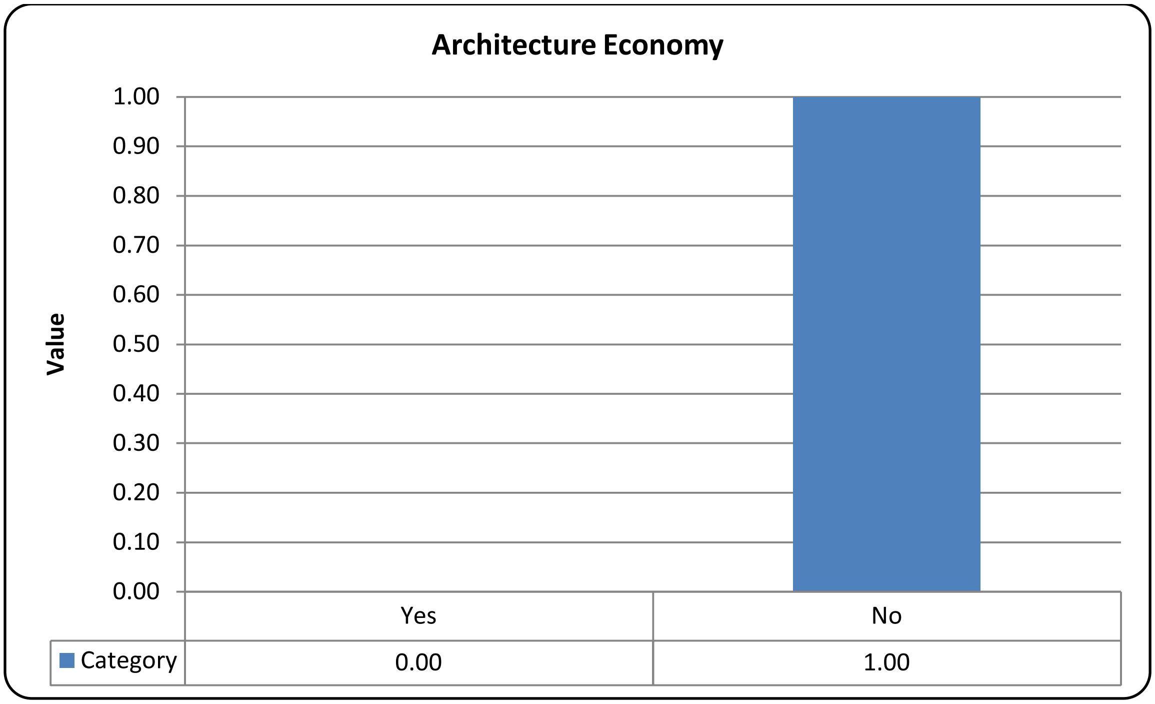

Figure 21. Architecture Economy Value Function

3.5.10. OV Readability Value Function

The OV READABILITY value function uses a monotonically increasing, S-curve scale. Figure 22 specifies the decision maker's value associated with the percentage of readable OVs. For the S-curve, greater value is earned with a higher percentage of readability (inflection point at 0.25) on the bottom end of the curve which then breaks at the 0.5 point where lesser value is earned as the percentage of readability increases (inflection points specified at 0.75).

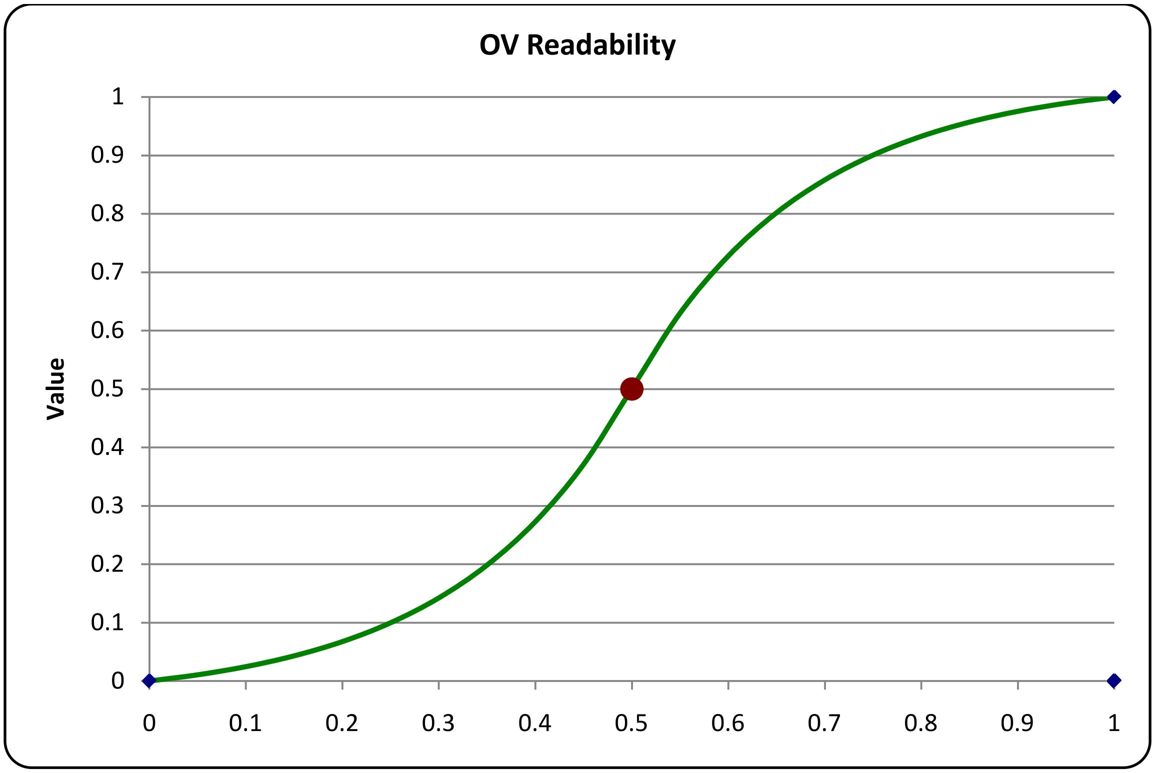

Figure 22. OV Readability Value Function

3.5.11. SV Readability Value Function

The SV READABILITY value function uses a monotonically increasing S-curve exactly the same as the OV READABILITY SDVF described previously. Figure 23 specifies the decision maker's value associated the percentage of readable SVs. For the S-curve, greater value is earned with a higher percentage of readability (inflection point at 0.25) on the bottom end of the curve which breaks at the 0.5 point where lesser value is earned as the percentage of readability increases (inflection points specified at 0.75).

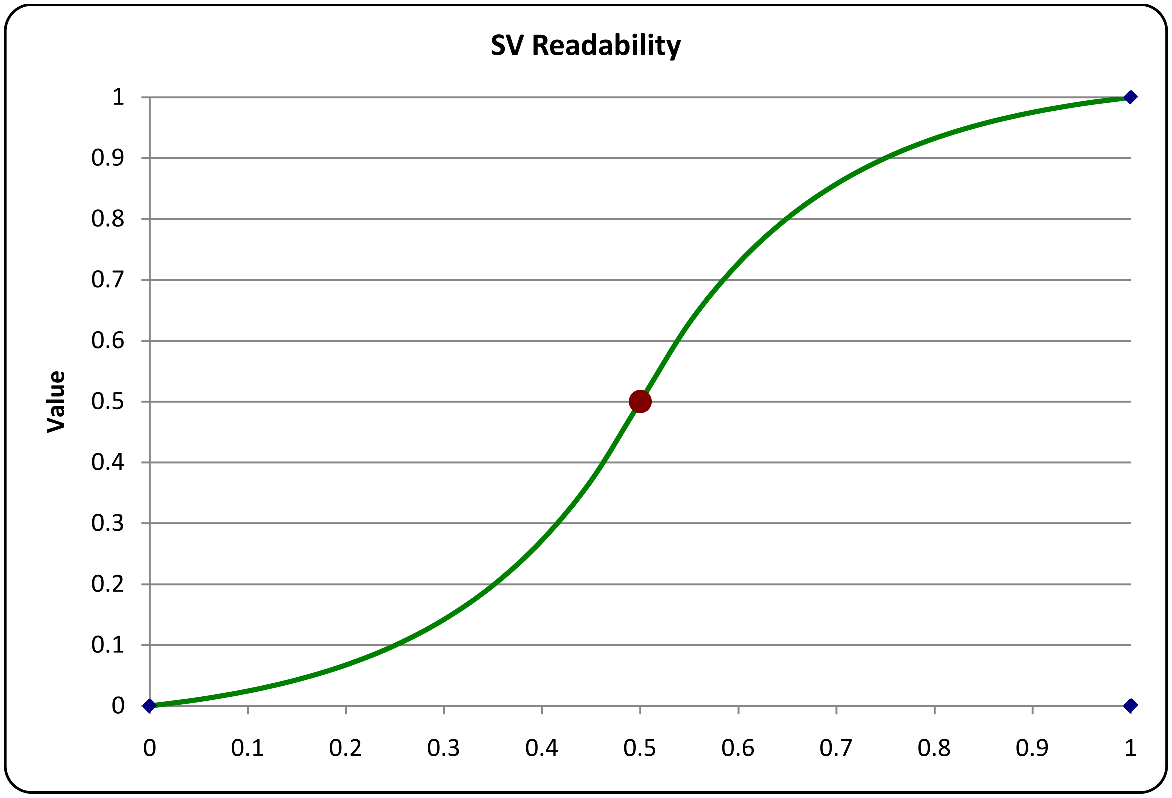

Figure 23. SV Readability Value Function

3.5.12. Scale Value Function

The SCALE value function uses a simple a discrete, categorical scale. Figure 24 specifies the decision maker's value associated with the ability of the architecture to double in scale without significantly increasing complexity. The decision maker specified the worst case scenario to be no views able to double in scale while the best case scenario is all views can double in scale without significantly increasing complexity. The other categories ranged as shown in Figure 24 according to the decision maker's value.

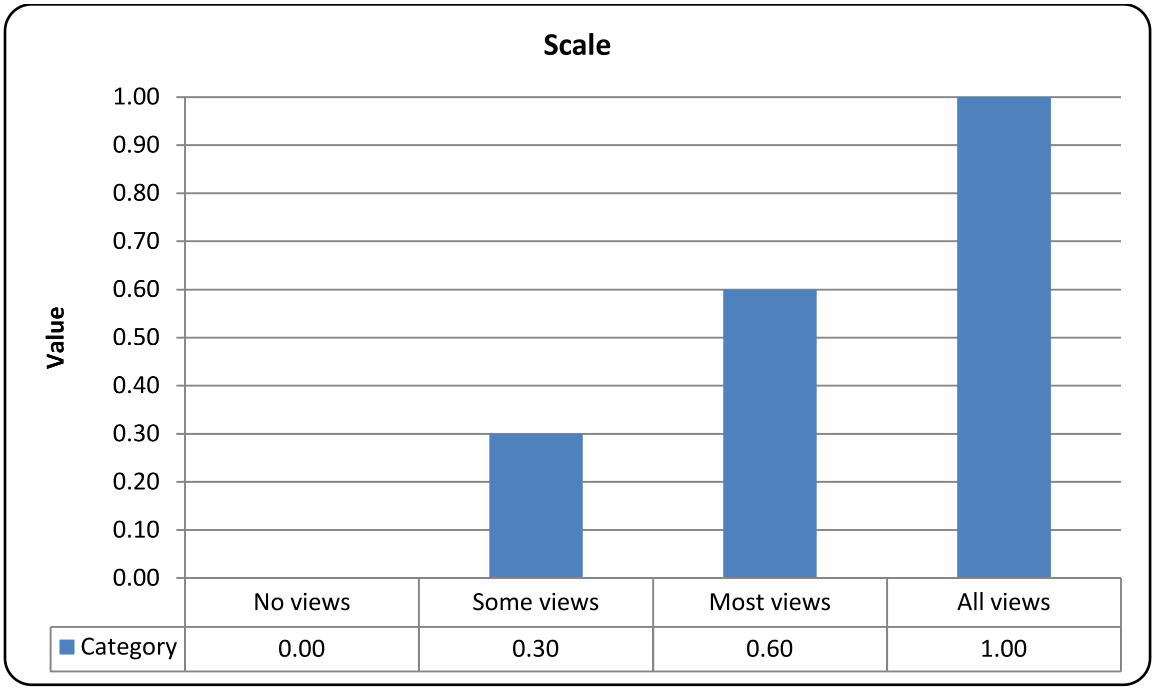

Figure 24. Scale Value Function

3.5.13. Decomposition Value Function

The DECOMPOSITION value function uses a discrete, categorical scale. Figure 25 specifies the decision maker's value associated with the levels of decomposition found in the OV-5. The decision maker specified the worst case scenario to be no decomposition while the best case scenario is decomposition to three or more levels. The other categories ranged as shown in Figure 25 according to the decision maker's value.

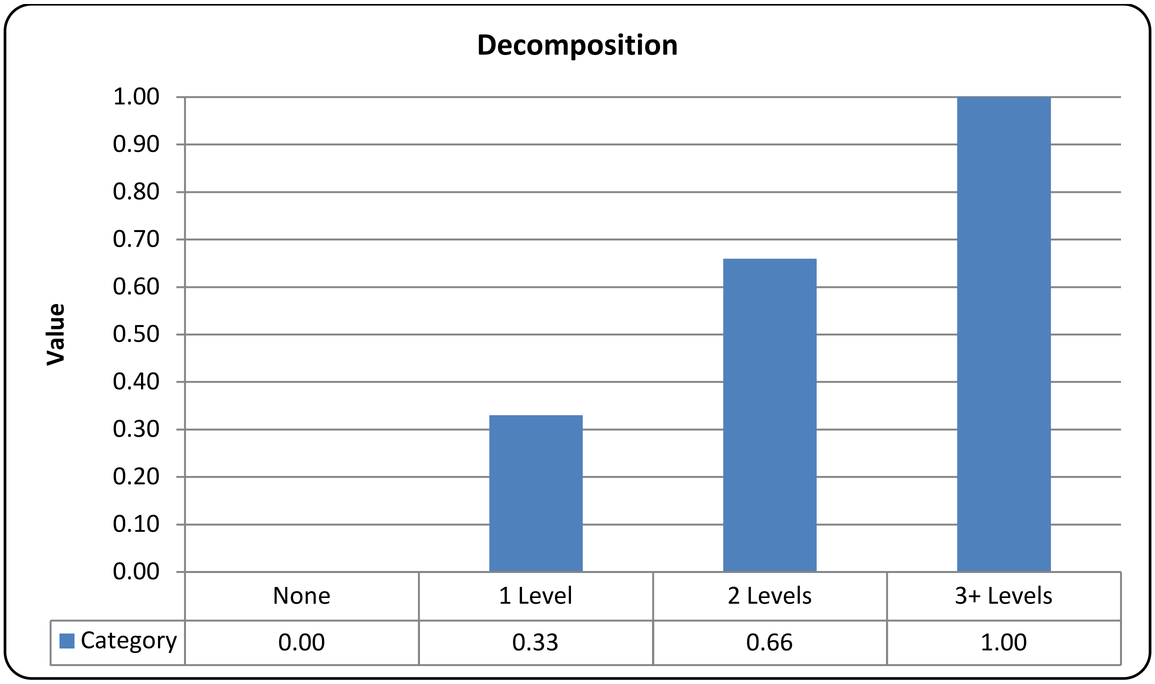

Figure 25. Decomposition Value Function

3.5.14. Tool Format Value Function

The TOOL FORMAT value function uses a discrete, categorical scale. Figure 26 specifies the decision maker's value associated with the ability of the tools used to incorporate changes. The decision maker specified the worst case scenario to be the inability of a tool to incorporate changes thus requiring views to be rebuilt while the best case scenario is one change carried through multiple views. The other categories ranged as shown in Figure 26 according to the decision maker's value.

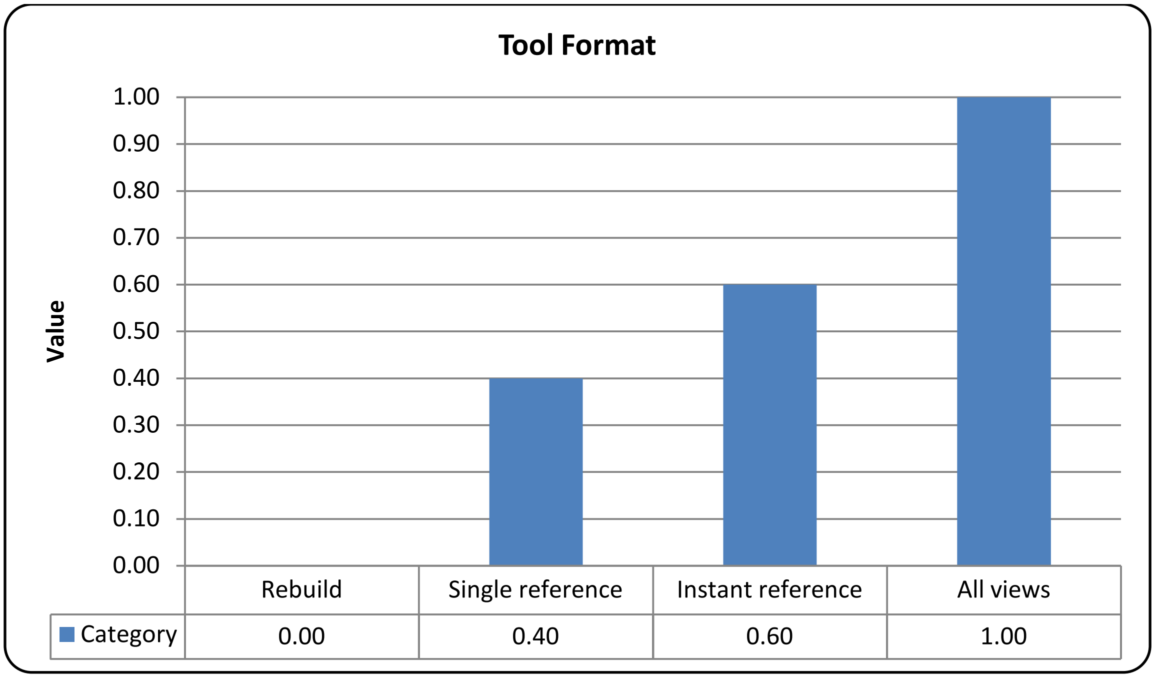

Figure 26. Tool Format Value Function

3.5.15. DoDAF Compliancy Value Function

The DODAF COMPLIANCY value function uses a monotonically increasing, linear scale. The decision maker's value of the percentage of products that comply with DoDAF standards increases linearly as the percentage of products in compliance increases. This is shown in Figure 27.

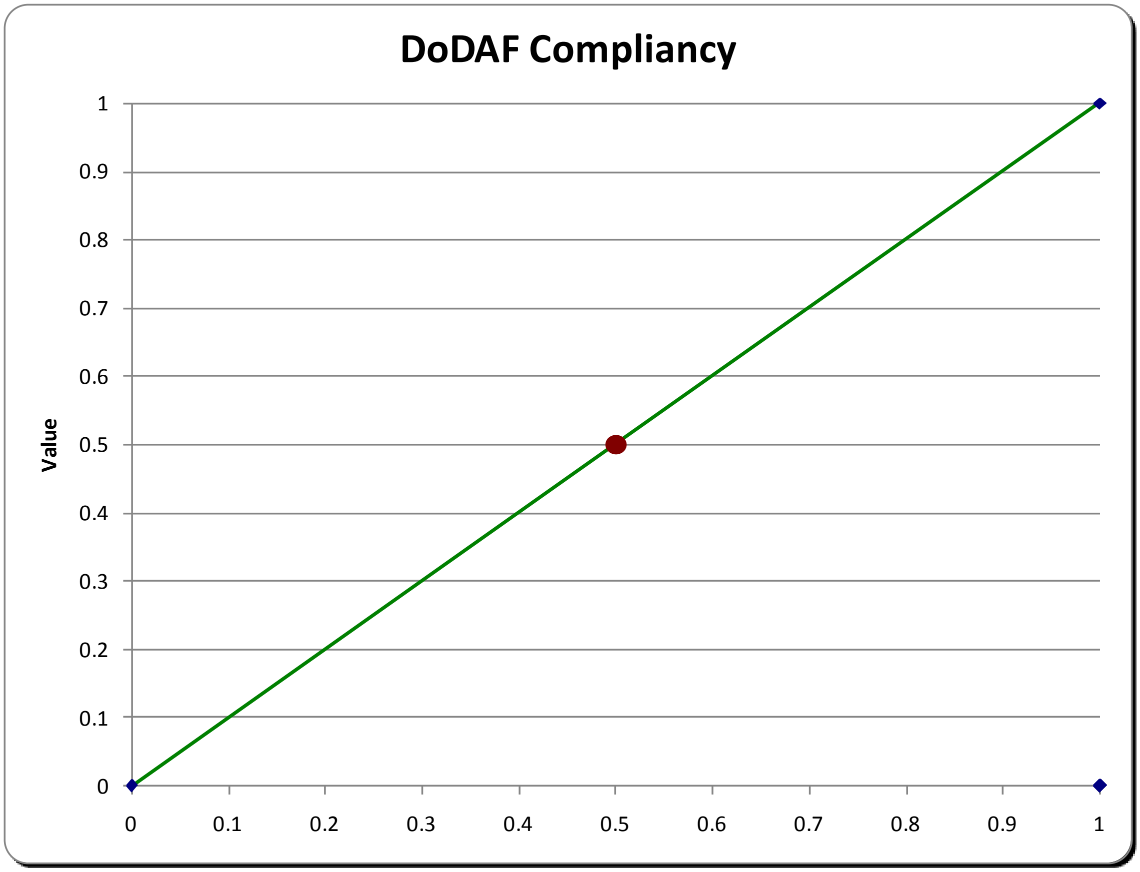

Figure 27. DoDAF Compliancy Value Function

3.5.16. Requirement Traceability Value Function

The REQUIREMENT TRACEABILITY value function uses a monotonically increasing, exponential scale. Figure 28 specifies the decision maker's value corresponding to the level of completeness of the SV-5. For this exponential, the inflection point was specified at the point 0.6, representing a 60 percent complete SV-5 and resulting in a value of 0.2. The function starts to earn value more quickly at the > 0.6 mark.

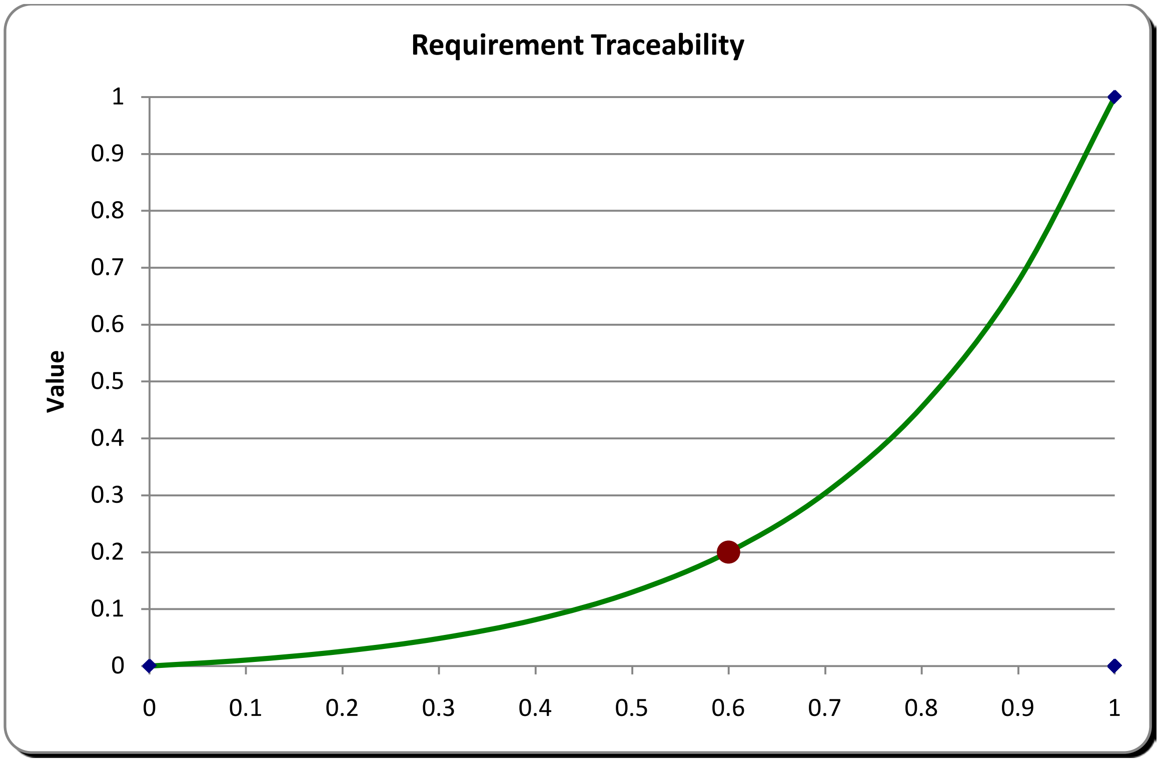

Figure 28. Requirements Traceability Value Function

3.5.17. Internal Consistency Value Function

The INTERNAL CONSISTENCY value function uses a monotonically increasing, S-curve scale. Figure 29 specifies the decision maker's value associated with the percentage of products that have no inconsistencies within themselves. For the S-curve, greater value is earned with a higher percentage of readability (inflection point at 0.25) on the bottom end of the curve which breaks at the 0.5 point where lesser value is earned as the percentage of readability increases (inflection points specified at 0.75).

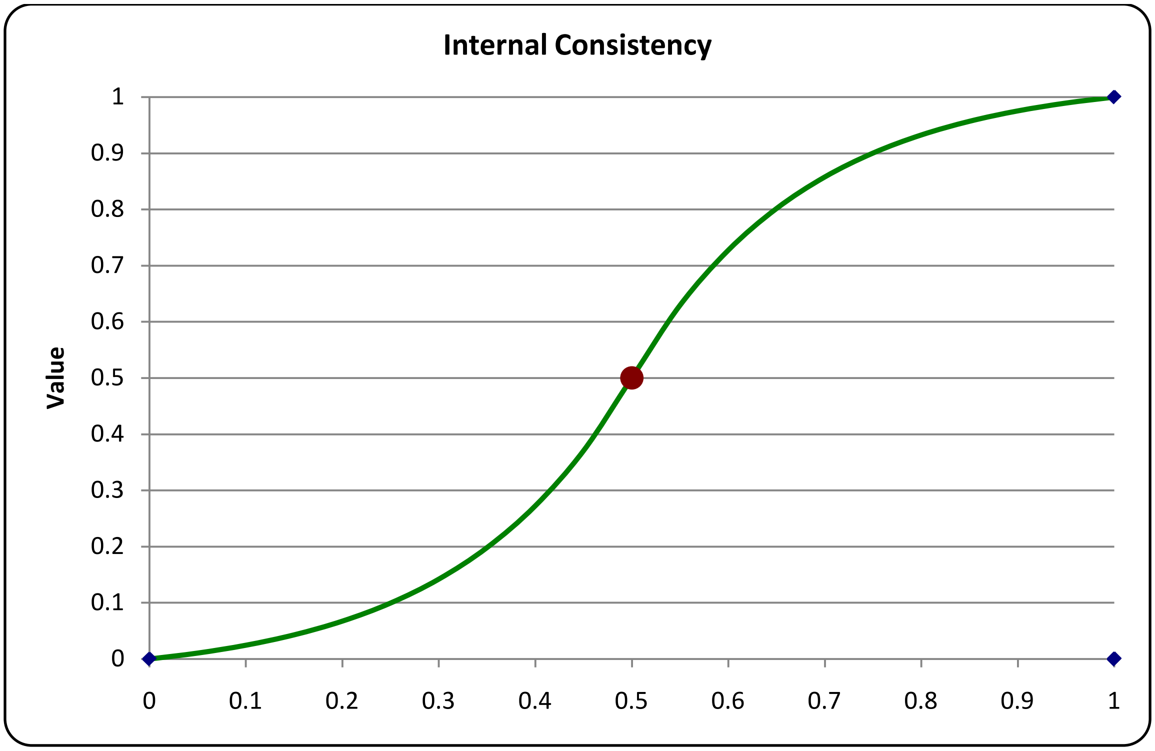

Figure 29. Internal Consistency Value Function

3.5.18. External Consistency Value Function

The EXTERNAL CONSISTENCY value function uses the same monotonically increasing, S-curve as the previous SDVF. Figure 30 specifies decision maker's value associated with the percentage of products with no inconsistencies to other products. For the S-curve, greater value is earned with a higher percentage of readability (inflection point at 0.25) on the bottom end of the curve which breaks at the 0.5 point where lesser value is earned as the percentage of readability increases (inflection points specified at 0.75).

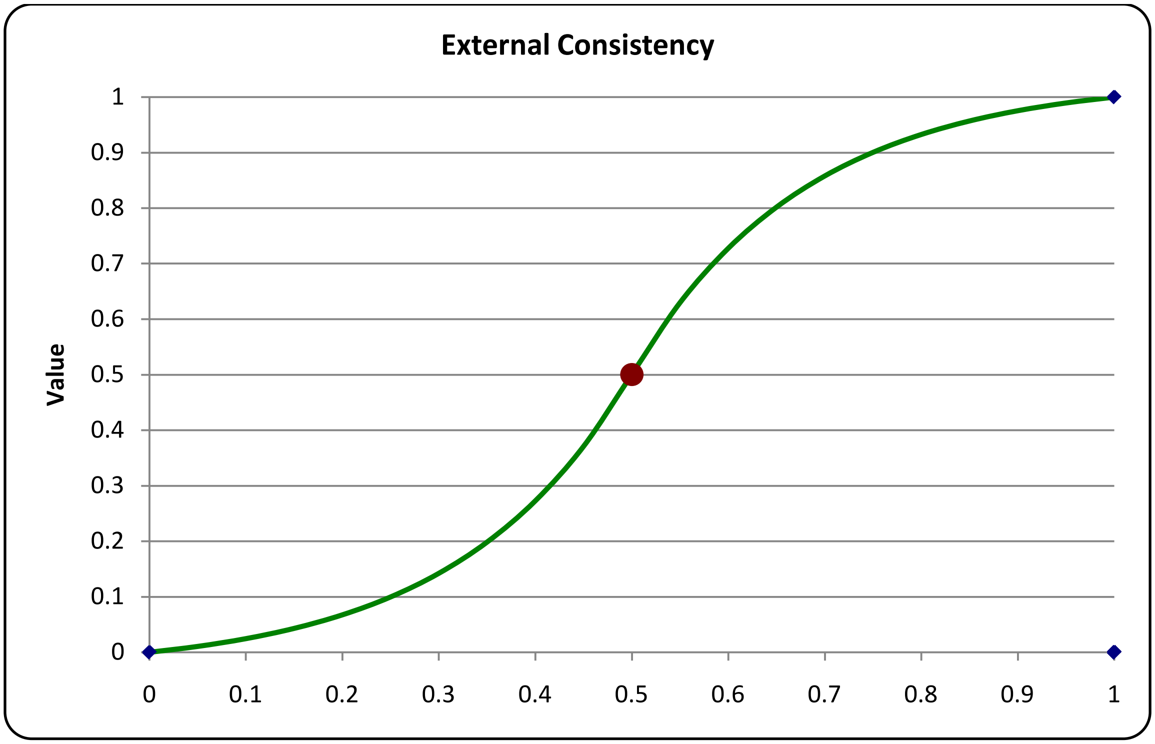

Figure 30. External Consistency Value Function

3.5.19. SME Effectiveness Value Function

The SME EFFECTIVENESS value function uses a discrete, categorical scale. Figure 31 specifies the decision maker's value associated with whether the SMEs have been identified and how much experience each SME has to contribute to the project. The decision maker specified the worst case scenario to be no plan for SMEs while the best case scenario is identifying SMEs with an average of over five years experience. The other categories ranged as shown in Figure 31 according to the decision maker’s value.

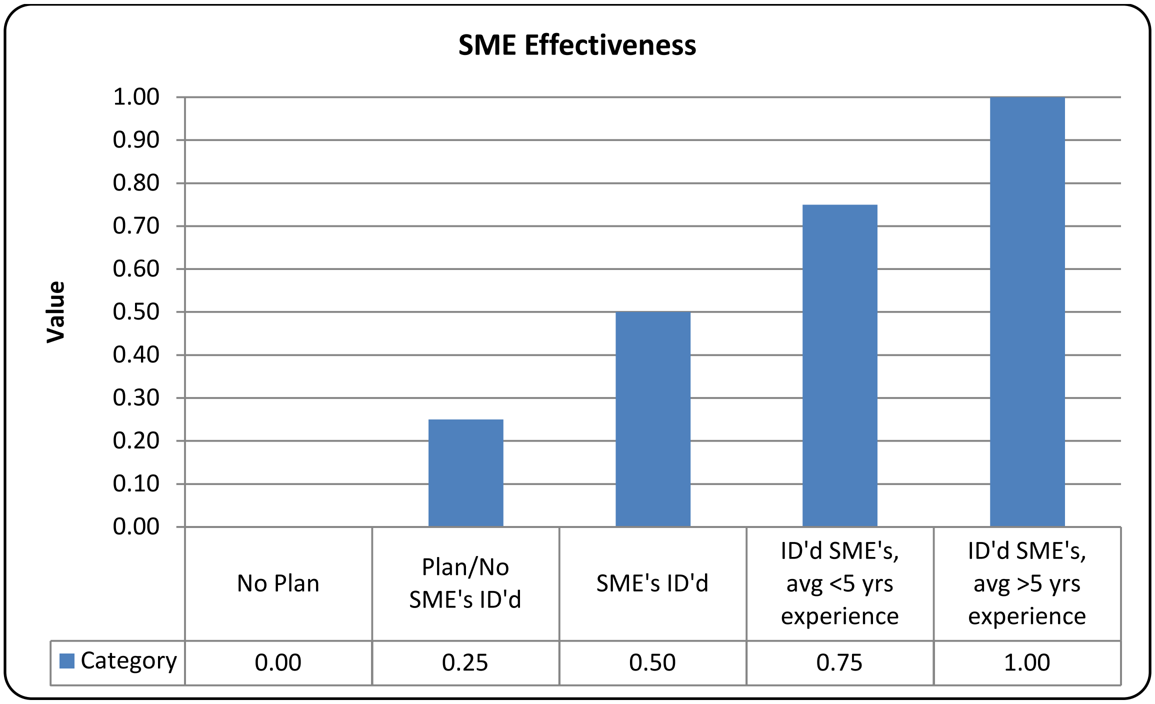

Figure 31. SME Effectiveness Value Function

3.5.20. SME Involvement Value Function

The SME INVOLVEMENT value function uses a discrete, categorical scale. Figure 32 specifies the decision maker's value associated with the number of actual SMEs and their organizations involved. The decision maker specified the worst case scenario to be no SME involvement while the best case scenario is involvement by multiple SMEs from multiple organizations. The other categories ranged as shown in Figure 32 according to the decision maker’s value.

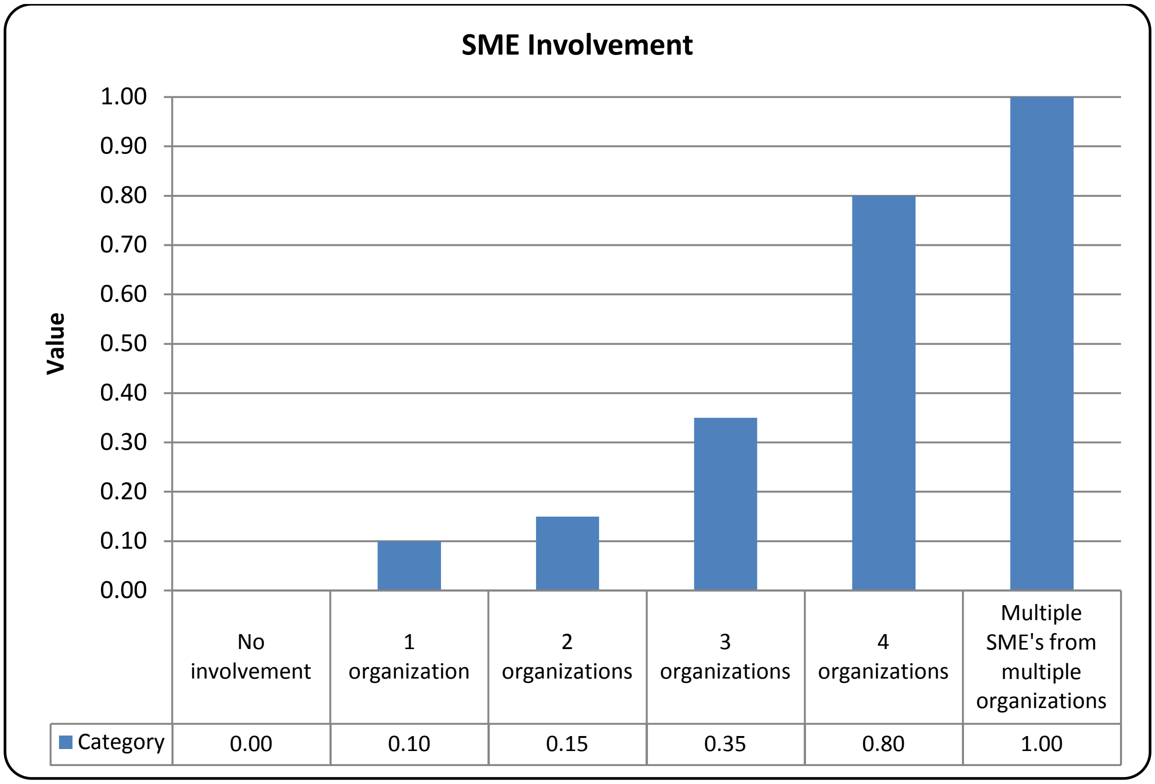

Figure 32. SME Involvement Value Function

3.6. Weight Architecture Quality Values Hierarchy

As previously discussed, the joint force protection VDEA-Score hierarchy consisted of multiple categories that the decision maker validated as valuable to architecture quality. These values are not equally essential, however. To account for these differences in importance, a direct weighting technique was employed. A local weight described how much weight a sub-value contributed to the value above it, while a global weight described how much weight each of the last-tier values in each branch of the value hierarchy contributed to the overall value at the top of the hierarchy.

The first tier of the value hierarchy consists of the two overall branches, as previously stated. The *System Effectiveness Values* branch focused on force protection-specific objectives, while the *Architecture Quality Values* branch focused primarily on architecture-specific objectives. The decision maker placed 60 percent (0.6 out of 1.0) importance on the *System Effectiveness Values* and 40 percent (0.4 out of 1.0) importance on the *Architecture Quality Values* branch as shown in Figure 33. These weightings of importance may easily be tailored based on a different decision maker's. Again, only the *Architecture Quality Values* branch was described in this thesis. The weighted *System Effectiveness Values* branch hierarchy is provided as reference (Mills, 2009) in Appendix D. The *Architecture Quality Values* hierarchy and their associated local and global weights are shown in Figure 34 where “L” is for local and “G” is for global weights. Table 8 also provides a summary listing of the values and their weights.

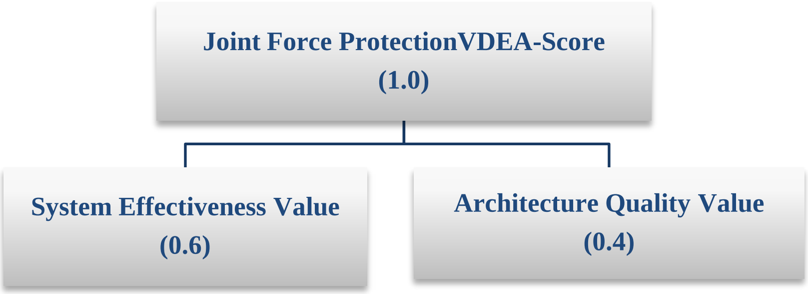

Figure 33. VDEA-Score Hierarchy First Tier Showing Local Weights

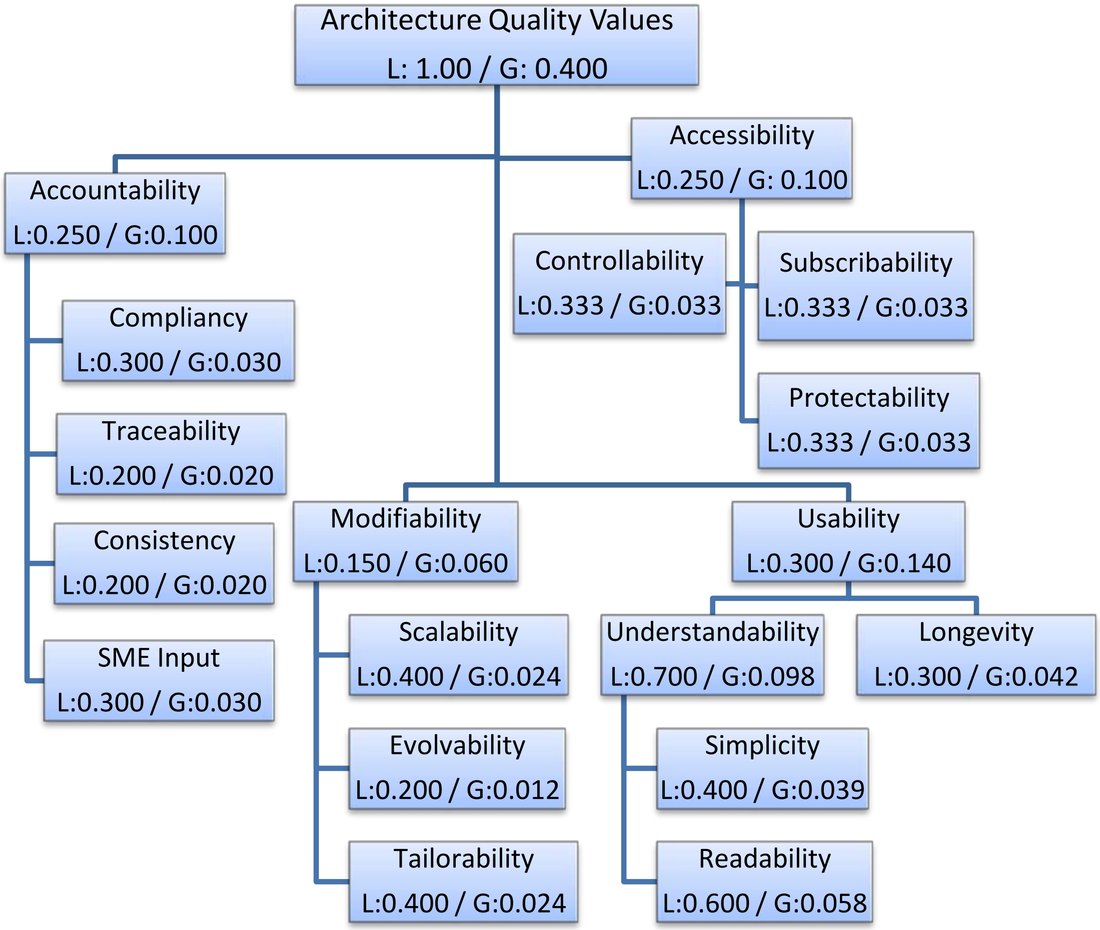

Figure 34. Architecture Quality Values Hierarchy with Weights

Table 8. Architecture Quality Value Weights

Value	Local Weight	Global Weight
Architecture Quality Values	1.000	0.400
Accessibility	0.250	0.100
Subscribability	0.333	0.033
Controllability	0.333	0.033
Protectability	0.333	0.033
Usability	0.350	0.140
Longevity	0.300	0.042
Understandability	0.700	0.098
Simplicity	0.400	0.039
Readability	0.600	0.058
Modifiability	0.150	0.600
Scalability	0.400	0.024
Tailorability	0.400	0.024
Evolvability	0.200	0.012
Accountability	0.250	0.100
Compliancy	0.300	0.030
Traceability	0.200	0.020
Consistency	0.200	0.020
SME Input	0.300	0.030

3.6.1. Local Weights for Second-Tier Values

The values comprising the second tier of the hierarchy under the *Architecture Quality Values* branch were the four values determined most-essential in regards to the quality of architecture. Thirty-five percent local importance (0.35 out of 1.0) was placed on *Usability*. Twenty-five percent importance (0.25 out of 1.0) was placed on both *Accessibility* and *Accountability*. The remaining fifteen percent (0.15 out of 1.0) was placed on *Modifiability.* The weights assigned to the values comprising the third-tier values are discussed in the following sections.

3.6.1.1. Local Weights for Accessibility Sub-Values

Calculating how much weight the third-tier values *Subscribability*, *Controllability*, and *Protectability* contribute to the second-tier objective *Accessibility* was a fairly simple process. All three values were assessed as equally important to *Accessibility*, thus they were all equally weighted at 0.333 out of 1.0. This distribution is displayed in Figure 35.

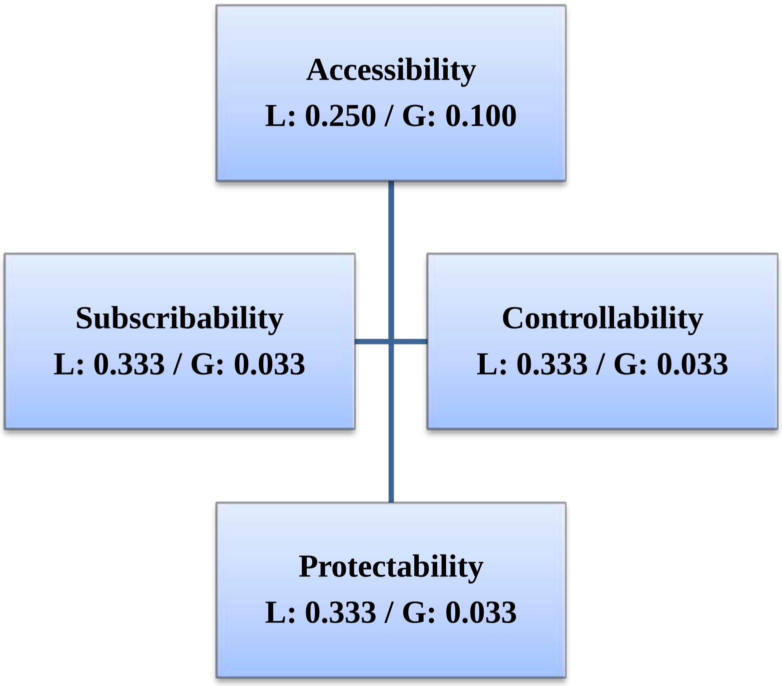

Figure 35. Local Weights for Accessibility Sub-Values

3.6.1.2. Local Weights for Usability Sub-Values

The decision maker concluded that for *Usability*, *Understandability* was more than twice as important as *Longevity*, and a 70 percent importance (0.7 out of 1.0) was placed on it. The remaining 30 percent (0.3 out of 1.0) went to *Longevity* as shown in Figure 36. Next, *Readability* was assessed as more important than *Simplicity*, which received 60 percent (0.6 out of 1.0) emphasis on it. The remaining 40 percent (0.4 out of 1.0) was placed on *Simplicity*.

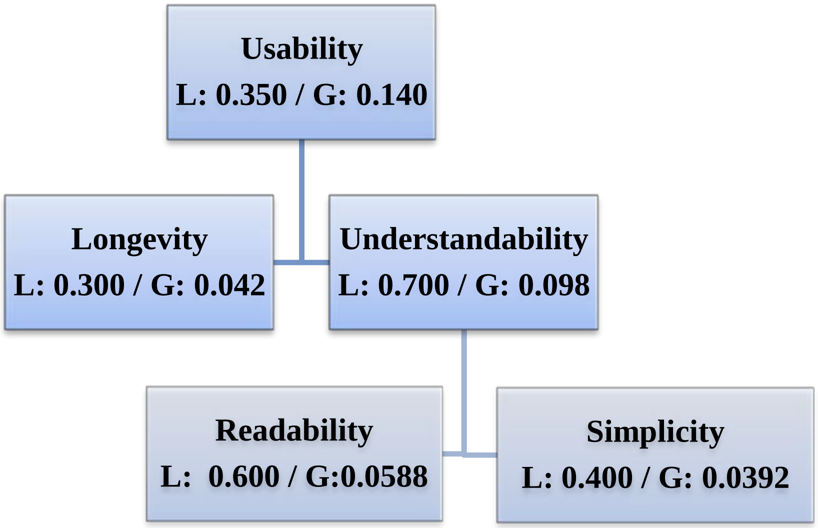

Figure 36. Local Weights for Usability Sub-Values

3.6.1.3. Local Weights for Modifiability Sub-Values

To determine how much weight *Scalability*, *Evolvability*, and *Tailorability* contribute to *Modifiability*, the decision maker first indicated that *Evolvability* was least valued because of the unlikely chance the products would be developed in a non-standard format. They determined that *Scalability* and *Tailorability* were equal in importance to *Modifiability*, but also that they were twice as important as *Evolvability*. This corresponds to a 40 percent importance (0.4 out of 1.0) granted to both *Scalability* and *Tailorability*, and the remaining 20 percent (0.2 out of 1.0) placed on *Evolvability* as shown in Figure 37.

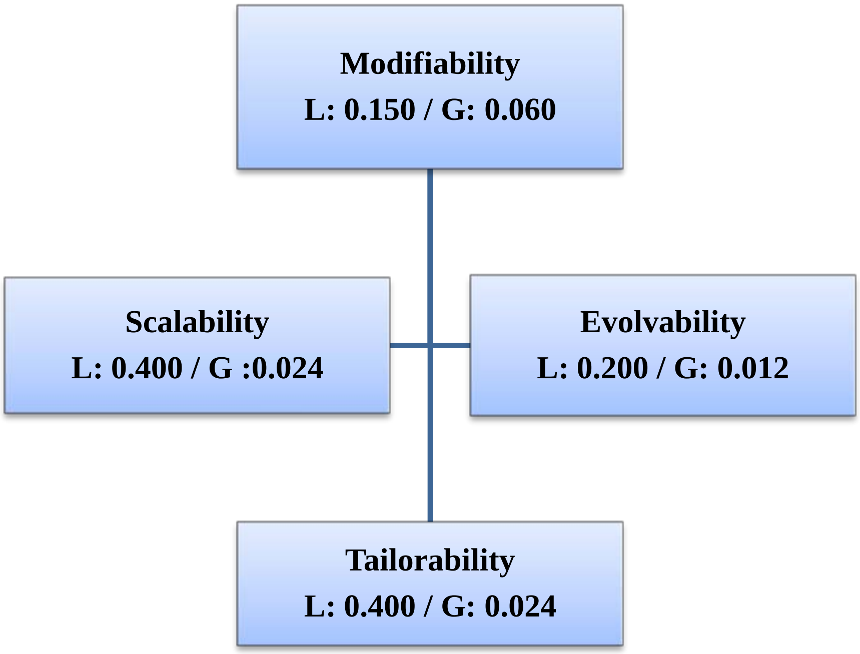

Figure 37. Local weights for Modifiability Sub-Values

3.6.1.4. Local Weights for Accountability Sub-Values

To determine how much weight *Compliancy*, *Traceability*, *Consistency*, and *SME Input* contribute to *Accountability*, the decision maker first indicated that *Traceability* and *Consistency* were less valued, though equally important, than *Compliancy* and *SME Input.* The decision maker also stated that *Compliancy* and *SME Input* were equally important and that they were 1.5 times more important than *Traceability* and *Consistency.* This corresponds to a 30 percent importance (0.3 out of 1.0) placed on both *Compliancy* and *SME Input*, and the remaining 40 percent split evenly (0.2 out of 1.0 each) between *Traceability and Consistency* as shown in Figure 38.

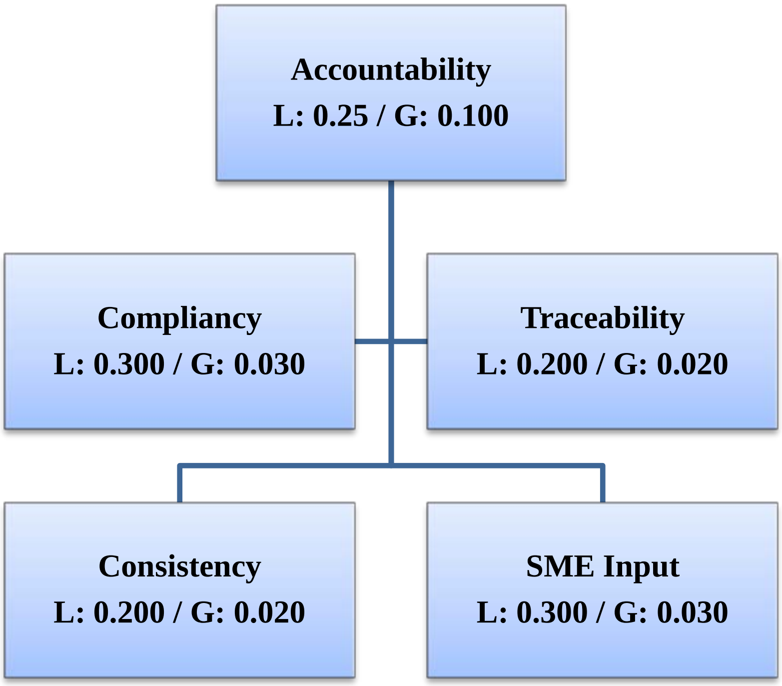

Figure 38. Local Weights for Accountability Sub-Values

3.6.1.5. Local Weights for Measurements

It should also be noted that six of the sub-values possessed multiple measures. All were of equal weight except the ACCESS measure which was valued twice as much as PRODUCT LOCATABILITY because a user could not locate the products if access was unavailable. Therefore, the ACCESS measure had a 0.67 weight compared to PRODUCT LOCATABILITY's 0.33.

3.6.2. Verification of Weights

To help the decision maker validate that proper weights were assigned to the values, tornado graphs were used to provide better visualization of the value rankings by the applied weights. The decision maker reviewed these decisions and validated that the values fell in the proper place in comparison at the global level. Initially, only the local weights were discussed. The graphs were then used to show the global weights so the decision maker could visually rank the importance of each value. A top-down approach was used, from the first-tier values and descending down the hierarchy. The top graph showing the global weights for the first-tier is shown in Figure 39. Note that the two weights sum to 1.0 (100 percent).

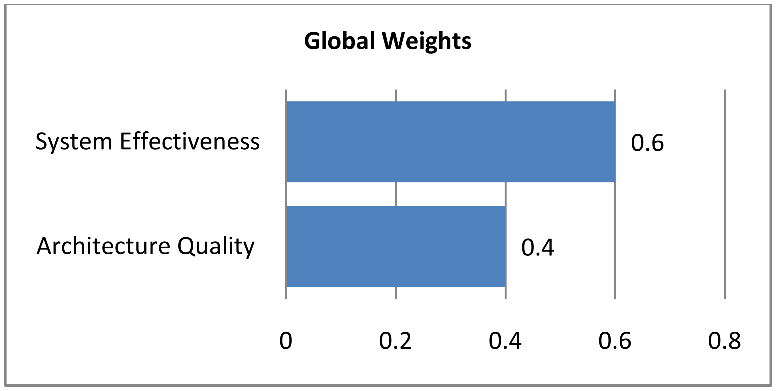

Figure 39. Tier 1 Global Weights

Accessibility, *Usability*, *Modifiability*, and *Accountability* were assigned the weights of 0.25, 0.35, 0.15, and 0.25 respectively. The graph displaying the global weights of the second tier of the *Architecture Quality Values* branch is shown in Figure 40. Again, note that the global weights sum to 0.4 (the total *Architecture Quality Value* weight).

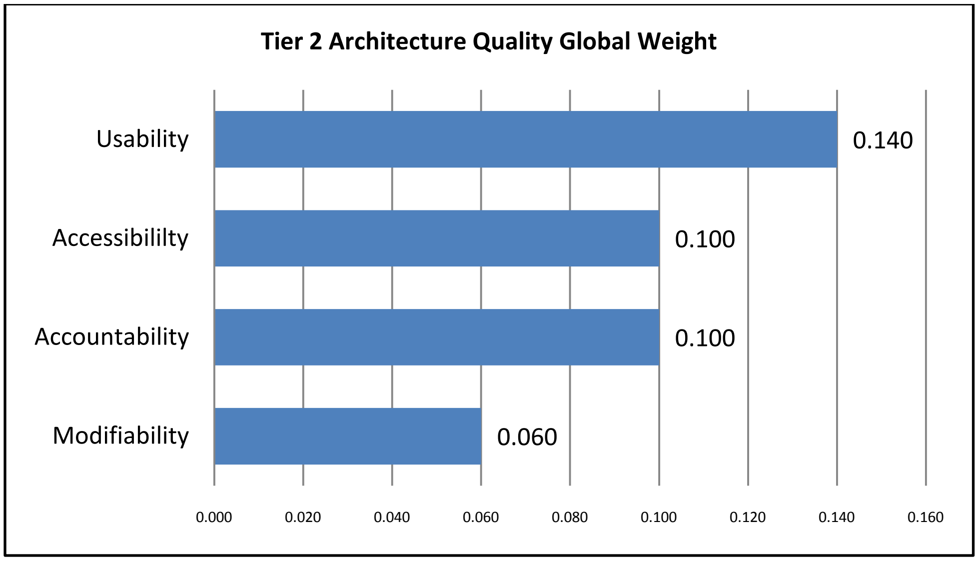

Figure 40. Tier 2 Architecture Quality Value Global Weights

The Tier 2 values were decomposed into their Tier 3 values for further verification as displayed in Figure 41. As shown, the attribute most valuable overall to an architecture is *Understandability* as the graph displays its rank as over two times as important as the next most valuable attribute *Longevity*. These graphs allowed the decision maker to adjust local weights to accurately reflect the importance rankings of the value categories.

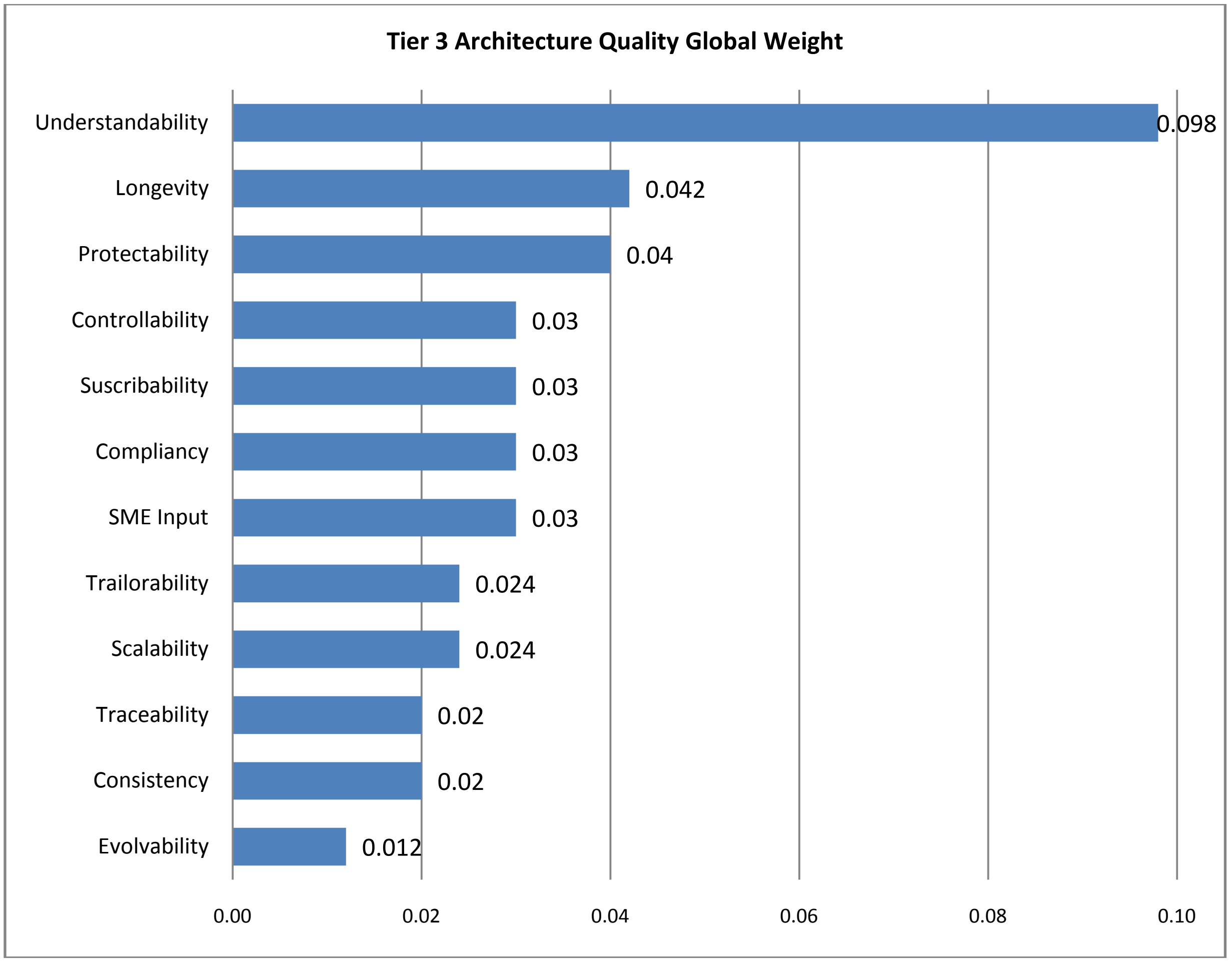

Figure 41. Tier 3 Architecture Quality Value Global Weights

3.7. Model Preliminary Validation Efforts

Additionally, because this thesis's focus within the overall portion of the joint force protection project was to produce a VDEA-Score model for evaluating architectures, the authors assessed the model's effectiveness by using another program's architecture. The authors reviewed the Air Force Architecture Repository for potential candidate architectures and selected the Information and Resource Support System (IRSS). This was a database environment for collaborative requirements and planning providing Air Force agencies access to planning, requirements, and financial data (Zechar, 2006). This particular architecture was chosen for its maturity and the relatively large number of available products (AV-1, AV-2, OV-1, OV-2, OV-3, OV-5, OV-6c, OV-7, SV-1, SV-5, SV-6, SV-7, SV-8, and TV-1). The results of this validation are presented in the next chapter.

3.8. Alternative Generation

One of the purposes of VFT is to facilitate comparison of alternatives to make better informed decisions. Because this joint force protection effort is a work-in-progress and only the initial architecture exists, no alternatives were available. Likewise, there was no need to generate actual alternatives at this point as the effort is focused on evaluating the current draft architecture to identify areas to improve before finalizing the products for Milestone B. Therefore, theoretical alternatives were generated based on the areas of improvement that were identified. This identification process results from the model evaluation and a subsequent analysis on the measures. This measurement analysis examines the impact of varying a single measure's score on the overall score while keeping the other measures' scores as evaluated. This analysis identifies the areas of strength and weakness by observing the greatest decrease or increase respectively by varying each measure's score. The measures showing the greatest potential increase in score are considered prime candidates for developing alternatives based on improving the architecture in the affected area. These alternatives are representative value scored architectures to demonstrate the higher scores attainable by improving in the noted areas. The results are presented in the next chapter.

3.9. Summary

The development of the complete *Architecture Quality Values* hierarchy within the VDEA-Score model was explained in this chapter. Additionally, brief descriptions of the additional model verification effort and the joint force protection alternative architecture generation process were provided. Analysis of the architectures, along with conclusions and recommendations, follow in the remaining chapters.

IV. Results and Analysis

With the value hierarchy defined, associated measures determined, value functions assigned, and appropriate weighting factors applied, the joint force protection Value Driven Enterprise Architecture Score (VDEA-Score) model was now complete. The deterministic and sensitivity analysis performed on the *Architecture Quality Value* hierarchy is presented in this chapter. The final VDEA-Score result for the *System Effectiveness Value* branch from Osgood (2009) is also provided to show the complete joint force protection VDEA-Score.

The primary analysis was completed using architecture views provided on 24 December 2008 by the 642d Electronic Systems Squadron (ELSS) for AFIT's evaluation: AV-1, OV-1, OV-2, OV-4, OV-5, OV-6c, SV-1, SV-2, SV-4, SV-6, SV-10c, and TV-1. With the exception of the OV READABILITY measure, the authors examined these twelve products as the evaluator applying the model to determine the VDEA-Score. Measurement analysis was conducted which lead to development of the theoretical alternative architectures as a comparison of score improvement for addressing deficient areas. Weight sensitivity analysis was also conducted varying the value weights. Finally, the VDEA-Score process was further verified by assessing the Information and Resource Support System (IRSS) architecture to determine its Tier I *Architecture Quality Value* VDEA-Score.

4.1. Joint Force Protection VDEA-Scoring

This section documents the initial results of the *Architecture Quality Value* model and provides feedback to the decision maker regarding the overall quality of their architecture. Specifically, this evaluation highlights the values and measures which earned the most value in the overall *Architecture Quality Value* VDEA-Score as well as the areas for improvement. The analysis also addresses the impact on the final rankings by measures having relatively high global weights. These results are summarized in Table 9 at the end of this section.

4.1.1. Access

The primary source for evaluating the ACCESS measure for the value of *Subscribability* is the AV-1. The evaluator found no information related to this measure within the AV-1, so the alternative proxy evaluation of the program’s repository was used. Based on the evaluator's experience requesting access to the program's repository web site, ACCESS was categorically evaluated as "3dy<access<1wk" resulting in a corresponding value score from the SDVF of 0.500.

4.1.2. Product Locatability

The primary source for evaluating the PRODUCT LOCATABILITY measure for the value of *Subscribability* is the AV-1. The evaluator found no information related to this measure within the AV-1, so the alternative proxy evaluation of the program’s repository was used. Based on the evaluator's experience navigating the program's repository web site, PRODUCT LOCATABILITY was categorically evaluated as "<5min" resulting in a corresponding value score from the SDVF of one.

4.1.3. Access Control

The primary source for evaluating the ACCESS CONTROL measure for the value of *Protectability* is the AV-1. The evaluator found no information related to this measure within the AV-1. Therefore, the alternative proxy evaluation of the program’s repository was used. Based on the evaluator's experience following the instructions to establish a user identification and password for the repository web site, ACCESS CONTROL was categorically evaluated as "Appropriate Control" resulting in a corresponding value score from the SDVF of one.

4.1.4. Document Protection

The primary source for evaluating the DOCUMENT PROTECTION measure for the value of *Controllability* is the AV-1. The evaluator found no information related to this measure within the AV-1. Therefore, the alternative proxy evaluation of the program’s repository was used. The evaluator accessed various documents and attempted to change them on the repository web site. This was unsuccessful as appropriate write protections were in place. Based on this experience, DOCUMENT PROTECTION was categorically evaluated as "Products Controlled" resulting in a corresponding value score from the SDVF of one.

4.1.5. File Management

The primary source for evaluating the FILE MANAGEMENT measure for the value of *Longevity* is the AV-1. The evaluator found no information related to this measure within the AV-1. Therefore, the alternative proxy evaluation of the program’s repository was used. Based on the evaluator's experience examining the file structure on the repository web site, the folders demonstrated organization but did not appear to demonstrate obvious implementation of an official file management system. Therefore, FILE MANAGEMENT was categorically evaluated as "System does not exist" resulting in a corresponding value score from the SDVF of zero.

4.1.6. File Format

For the FILE FORMAT measure, the AV-1 specified the tools to be used for development as Telelogic's System Architect and Microsoft Office. Additionally, the available products were produced by these tools. The evaluator considered these tools as accepted standards capable of producing “General File Formats” resulting in a value score of one.

4.1.7. Connections

For the CONNECTIONS measure, the evaluator reviewed each product and assessed the extent to which the connections which were sufficiently organized, easy to follow, and made sense to the reader. Two products stood out as not meeting these criteria. First, the SV-1 was noted to have a few merged needlines which were difficult to trace even when zoomed in to a high degree. Second, the SV-4 also had numerous needlines merging together as well as numerous unlabeled needlines making them difficult to trace. Therefore, CONNECTIONS was determined to meet 10 out of the 12 total products resulting in a corresponding value score from the SDVF of 0.620.

4.1.8. Architecture Redundancy

For the ARCHITECTURE REDUNDANCY measure, the evaluator did not note any entity, activities, links, etc., which appeared to unnecessarily accomplish the same goal. Therefore, ARCHITECTURE REDUNDANCY was evaluated categorically as "<1:10" resulting in a corresponding value score of one.

4.1.9. Architecture Economy

For the ARCHITECTURE ECONOMY measure, the evaluator noted no obvious instances of multiple activities or entities being used when they could be consolidated. This was a significantly subjective assessment because the evaluator lacked sufficient force protection experience to identify potential system-related instances. In terms of architecture description instances, the choice to show expanded detail for example within a system block on the SV-4 was considered by the evaluator to be appropriate within the architect's discretion. Therefore, ARCHITECTURE ECONOMY was evaluated by the binary category "No instances found" resulting in the value score of one.

4.1.10. OV Readability

For the OV READABILITY measure, a career security forces Subject Matter Expert (SME) from the Security Equipment Integration Working Group (SEIWG) provided additional insight for the evaluation from a security forces operational perspective. Each of the five OV products was examined. With the exception of the OV-5, the remaining products were determined overall to be easily read. The OV-5, by virtue of its extreme detail and large number of entities, required a significant amount of zooming in and alternating views to read. Therefore, OV READABILITY was determined to have "4 out of 5" readable products resulting in a corresponding SDVF value score of 0.930.

4.1.11. SV Readability

Like the previous measure, the SV READABILITY measure was applied to the five provided SV products. Two concerns were noted to reading these products. First, the SV-2 had several needlines with overlapping text. Secondly, it was noted the SV-4 required the use of a plotter to print out at a readable size or zooming and panning to read on the computer screen. However, the readability issue with the SV-4 was the overlapping text in the "Indigo Vision Control Center Software Client" block. Therefore, SV READABILITY was determined to have "3 out of 5" readable products resulting in a corresponding SDVF value score of 0.730.

4.1.12. Scale

The SCALE measure was applied to all available products to determine if doubling the number of nodes would greatly increase the complexity. This measure is a fairly subjective assessment by the evaluators who determined categorically "Most" of the products were scalable resulting in the value score of 0.600.

4.1.13. Decomposition

The DECOMPOSITION measure was evaluated by reviewing the number of decomposition levels in the OV-5. Because this product had seven levels of decomposition, the measure was determined to be categorically "3+" resulting in the value score of one.

4.1.14. Tool Format

The TOOL FORMAT measure was applied by reviewing the AV-1 for the tools used to create each provided view. Because Telelogic's System Architect was specified, the evaluator considered this a common tool which enforces DoDAF view consistency and allows easy editing by carrying changes through multiple views. Therefore, TOOL FORMAT was determined categorically to be "Input carries through multiple views" resulting in a value score of one.

4.1.15. DoDAF Compliancy

The DODAF COMPLIANCY measure was applied by examining each available view according to the DoDAF Vol II, version 1.5 (2008). The evaluator noted two exceptions. First, the OV-2 needlines show how information is exchanged (e.g., LAN, GIG), whereas the DoDAF specifically states these should show what information is exchanged (e.g., situational awareness). Secondly, the SV-6 contains a good amount of detail, but lacks a significant amount of the descriptive information called for in the DoDAF (e.g., no information on Information Assurance, Security, Nature of Transaction, or Performance). Therefore, the DODAF COMPLIANCY measure received "10 out of 12" products in compliance resulting in a corresponding SDVF value of 0.830.

4.1.16. Requirements Traceability

The REQUIREMENTS TRACEABILITY measure required reviewing the SV-5. However, an SV-5 was not provided, resulting in 0 percent corresponding to a value score of zero.

4.1.17. Internal Consistency

The INTERNAL CONSISTENCY measure required that each product be examined for any data inconsistencies within itself. Examining each entity, function, and needline, the evaluator noted two product exceptions: SV-1 and SV-4. First, the SV-1 had a needline label ("54") which was far removed from the actual associated needline. Second, the SV-4 had several discrepancies:

- From IA-4 Figure 3 (DfD, Discoverii Data Conversion), "Discoverii Video Motion JPEG (for AXIS only)" needline not on the master view
- From IA-4 Figure 7 (DfD, UGS Data Conversion), "Fetch TRSS generated Image" needline not on the master view

- From IA-4 Figure 7 (DfD, UGS Data Conversion), it was not clear that TRSS RICC and TRSS HHM were only part of the decomposed entity (e.g., should be a different color for consistency with other decomposed entities)
- From IA-4 Figure 9 (DfD, TASS Data Conversion), "TASS Power" needline not on the master view
- Numerous needline termination arrows depicted in different colors or styles (e.g., "PIR Detection" from PIR Sense Transmit to Vindicator shows an external input arrow head)
- Needline label "BFT Location ID reports RF" significantly distanced from associated needline

Therefore, INTERNAL CONSISTENCY was evaluated as "10 out of 12" products in compliance resulting in a corresponding SDVF value of 0.950.

4.1.18. External Consistency

For the EXTERNAL CONSISTENCY measure, each individual product was compared for data inconsistencies to every other product. The evaluator noted two product exceptions: OV-2 and SV-6. First, not all of the OV-2 operational nodes were depicted as system nodes in the SV-1. Specifically, the Combat Support Node was conspicuously absent. Secondly, the SV-6 was missing the "PIR Detection" needline described on the SV-4's PIR Sense Transmit to Vindicator blocks. Therefore, EXTERNAL CONSISTENCY was evaluated to have "10 out of 12" products in compliance resulting in a corresponding SDVF value of 0.950.

4.1.19. SME Effectiveness

For the SME EFFECTIVENESS measure, the AV-1 was reviewed for any information describing a plan for SME involvement with any requirement for experience. No information was found. Therefore, SME EFFECTIVENESS was evaluated as "No information provided" resulting in a value score of zero.

4.1.20. SME Involvement

For the SME INVOLVEMENT measure, the AV-1 was likewise reviewed for any information for the number of SMEs involved and specifically any different stakeholder organizations represented by them. While the AV-1 did note several stakeholder organizations in paragraph 2.c., it was only a list with no additional detail in terms of roles, responsibilities, or involvement. Therefore, SME INVOLVEMENT was evaluated as "No information provided" resulting in a value score of zero.

4.1.21. Joint Force Protection Architecture Quality VDEA-Score Summary

The final step in providing a single *Architecture Quality Value* VDEA-Score requires the summation of each of the individual value scores according to their respective global weights using the general additive value function of $v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i)$. Table 9 is provided as a summary of these individual scores with the resulting v_{AQ} of 0.287. Thus, the Tier I, *Architecture Quality Value* branch earned 0.287 points out of the total possible 0.400 joint force protection VDEA-Score points. This score translates to a local or normalized ($\|v_{AQ}\| = v_{AQ}/0.400$) 0.718 (or 71.8 percent) for its potential value in this portion of the model. Table 10 shows the detail of the value category scores by local value earned and percent of potential local value earned.

Table 9. Joint Force Protection Architecture Quality VDEA-Scoring

Measure	**Assessment**	**Global Weight** λ_i	**Value Score** $v_i(x_i)$	**Product** $\lambda_i v_i(x_i)$
Access	Proxy Eval of Repository: 3 day < access < 1 week	0.022	0.500	0.011
Product Locatability	Proxy Eval of Repository: < 5 minutes	0.011	1.000	0.011
Access Control	Proxy Eval of Repository: Appropriate Control	0.033	1.000	0.033
Document Protection	Proxy Eval of Repository: Products Controlled	0.033	1.000	0.033
File Management	Proxy Eval of Repository: System does not exist	0.021	0.000	0.000
File Format	General File Format	0.021	1.000	0.021
Connections	10 out of 12	0.013	0.620	0.008
Architecture Redundancy	0 redundancy instances found	0.013	1.000	0.013
Architecture Economy	No instances of possible consolidation found	0.013	1.000	0.013
OV Readability	4 out of 5	0.030	0.930	0.0279
SV Readability	3 out of 5	0.030	0.730	0.0219
Scale	Most scalable 2X	0.024	0.600	0.0144
Decomposition	3+ levels	0.024	1.000	0.024
Tool Format	Input carries thru multiple views	0.012	1.000	0.012
DoDAF Compliancy	10 out of 12	0.030	0.830	0.0249
Requirement Traceability	0% (no SV-5 provided)	0.022	0.000	0.000
Internal Consistency	10 out of 12	0.010	0.950	0.0095
External Consistency	10 out of 12	0.010	0.950	0.0095
SME Effectiveness	No info provided	0.015	0.000	0.000
SME Involvement	No info provided	0.015	0.000	0.000
	$v_{AQ}(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i) =$			**0.287**

Table 10. Architecture Quality Value VDEA-Score Value Earned

Value ($\lambda_{i-local}$)	**Local Value Earned**	**% of Potential Local Value**
Architecture Quality Values (.4)	0.287	**71.8%**
Accessibility (.25)	0.222	**88.8%**
Subscribability (.333)	0.222	66.7%
Protectability (.333)	0.333	100.0%
Controllability (.333)	0.333	100.0%
Usability (.35)	0.260	**74.2%**
Longevity (.3)	0.150	50.0%
Understandability (.7)	0.592	84.6%
Simplicity (.5)	0.349	69.8%
Readability (.5)	0.497	99.4%
Modifiability (.15)	0.126	**84.0%**
Scalability (.4)	0.240	60.0%
Tailorability (.4)	0.400	100.0%
Evolvability (.2)	0.200	100.0%
Accountability (.25)	0.110	**44.0%**
Compliancy (.3)	0.250	83.3%
Traceability (.2)	0.000	0.0%
Consistency (.2)	0.190	95.0%
SME Input (.3)	0.000	0.0%

4.1.22. Architecture Quality Value Score Analysis

Figure 42 shows graphically the VDEA-Score for *Architecture Quality Value*. This graph compares the value earned by the joint force protection architecture for *Architecture Quality Value* over the full potential *Architecture Quality Value*. Each colored block represents the value earned by each measure. The gaps (white spaces) highlight the measures earning less than full value as areas for improvement. The blocks are presented in order from left to right starting with the top row of the legend.

This comparison graph (Figure 42) reiterates the previously discussed evaluation results where the largest value gaps reside in the Tier II *Accountability* branch because no value was earned for REQUIREMENT TRACEABILITY, SME EFFECTIVENESS, and SME INVOLVEMENT. These three measures accounted for the lost 0.560 (56 percent) of the total potential local value for this Tier II branch. Figure 43 shows the *Accountability* branch earned 0.439 (almost 44 percent) of the total local potential value.

Overall, the majority of value was lost in the *Accountability* branch. The scores for the other branches were higher with *Accessibility*, *Usability*, and *Modifiability* branches earning 0.888, 0.742, and 0.840 of their potential Tier II branch value, respectively. Figures 44-46 graphically show the local value earned by each of these branches.

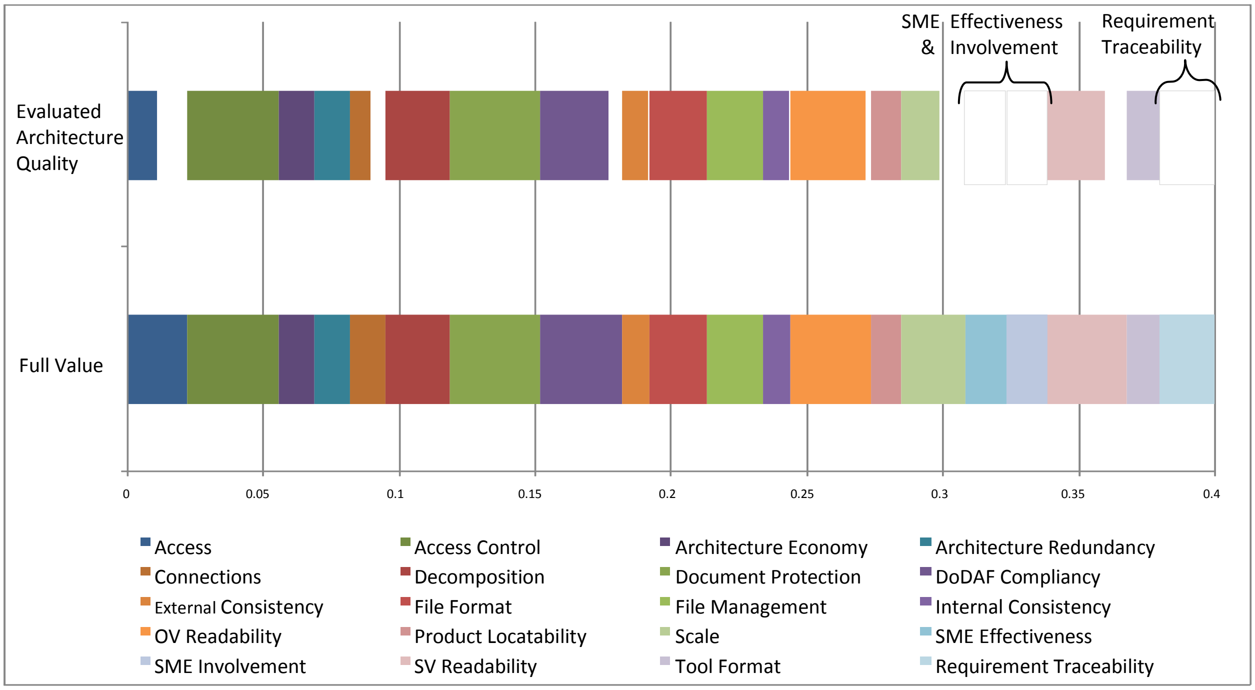

Figure 42. Joint Force Protection VDEA-Score vs Potential VDEA-Score

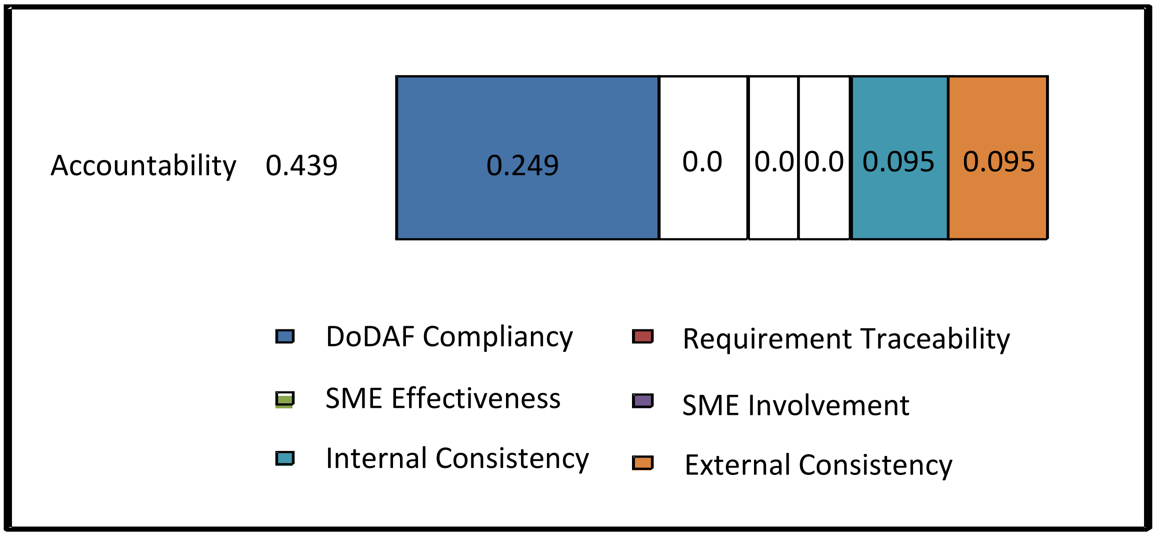

Figure 43. Accountability Local Measure Scores

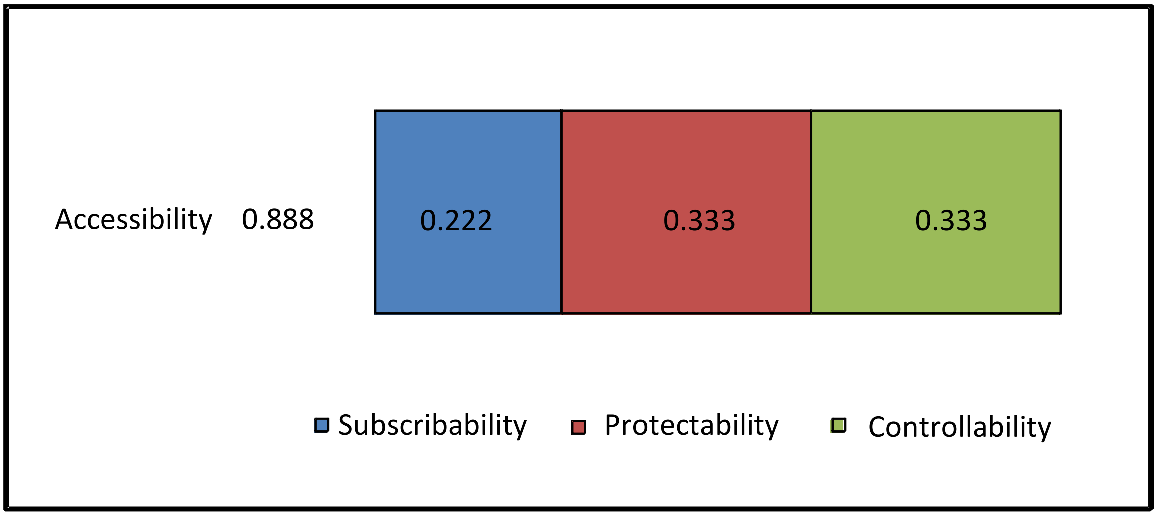

Figure 44. Accessibility Local Sub-Tier Value Scores

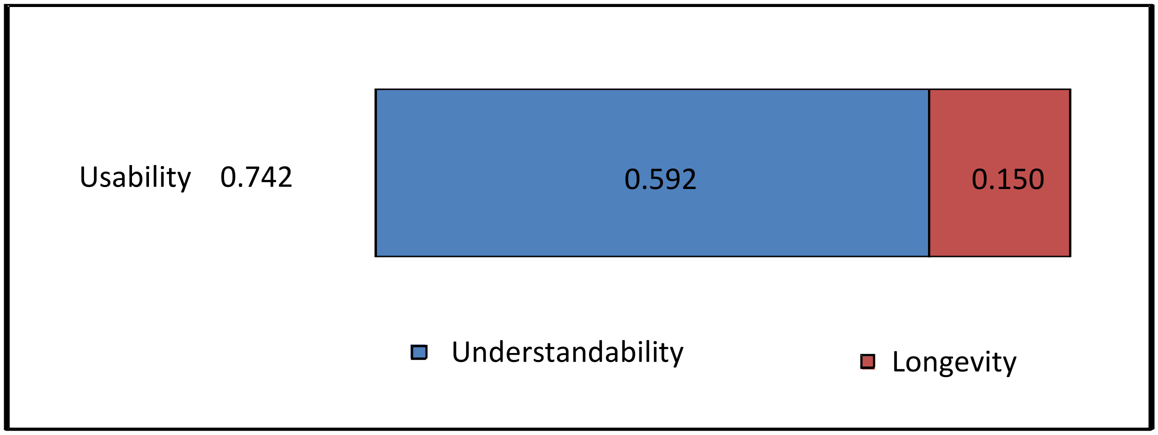

Figure 45. Usability Local Sub-Tier Value Scores

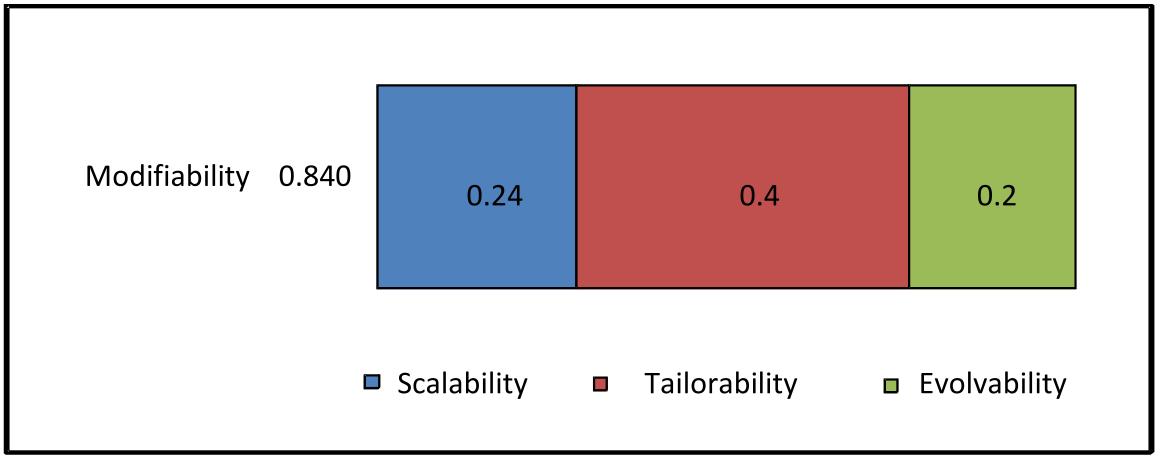

Figure 46. Modifiability Local Sub-Tier Value Scores

From this evaluation, several areas were identified to assist the program office with areas of improvement that could raise the overall *Architecture Quality Values* score. Most of the items noted in the previous analysis section only require minor changes to potentially increase the VDEA-Score to its full potential for this Tier I branch. The areas with the most work required in order of the authors' estimate of effort involved are:

1. Traceability - Requires development of an SV-5
2. Compliancy - Requires a number of additional data fields in the SV-6
3. Longevity - Requires development of a file management plan and documentation in the AV-1

While given full value in the evaluation, the areas of *Subscribability*, *Protectability*, and *Controllability* would also benefit from reference in the AV-1 to allow more direct evaluation. These were scored full value by proxy evaluation of the program's on-line repository. However, the AV-1 is a very flexible document allowing a multitude of useful information concerning the program and specifically the architecture. More detail regarding the SMEs in the AV-1 would increase the value in the overall score because these were scored zero.

It is also interesting to note that in a separate discussion outside the evaluation, the program office self-scored the SME EFFECTIVENESS as 0.5 and SME INVOLVEMENT as 0.8. Had this information been included in the AV-1, the Tier I *Architecture Quality Value* subtotal of the joint force protection VDEA-Score would have improved to 0.307 out of the 0.400 overall potential points. This would have resulted in a local value increase from 0.718 to 0.767.

4.1.23. Measurement Analysis

With the baseline scoring complete, analysis was conducted on each measure by varying the assessments from the lowest possibility to the highest possibility value to observe the effect each measurement result has on the overall score. Figure 47 shows the measurement analysis for OV READABILITY, a measure with a continuous S-curve value function. The original assessment for OV READABILITY was 4 out of 5. Therefore, these alternatives were generated by varying the results (i.e., x-axis) for OV READABILITY from zero to one in increments of 0.200 (1/5). If OV

READABILITY was maximized, the local score would have increased by 0.005, keeping results for all other measures constant. There was a possible 0.074 local change VDEA-Score varying the results from zero to one.

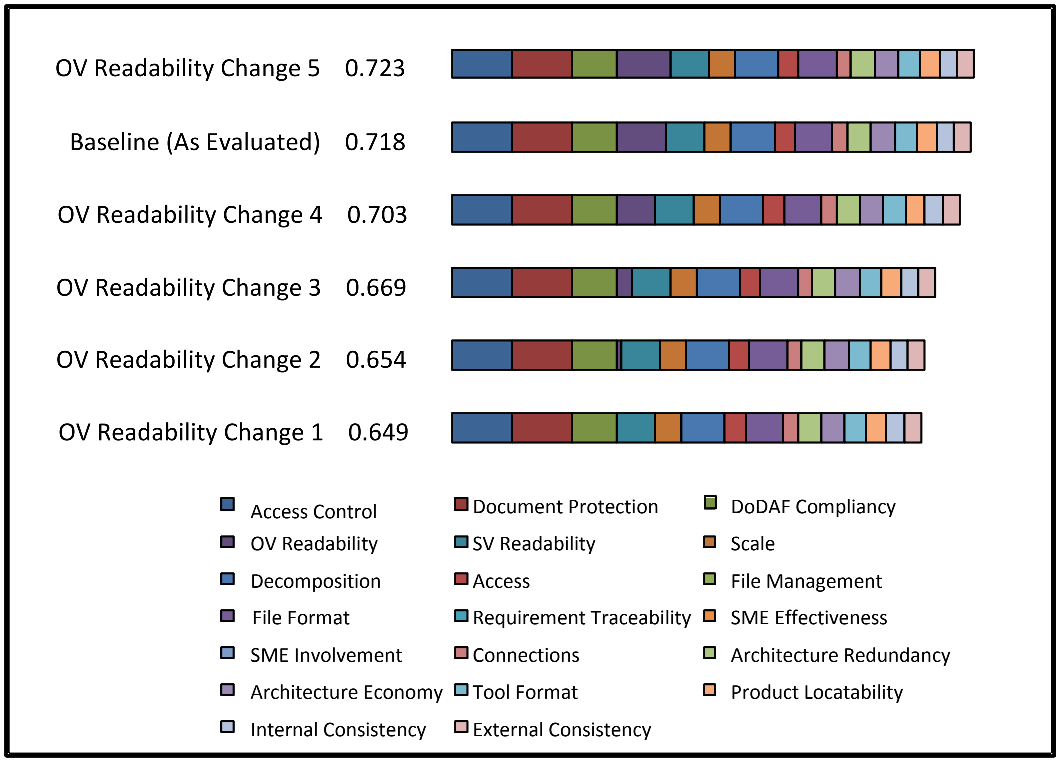

Figure 47. OV Readability Measurement Analysis (||v_{AQ}||)

Figure 48 shows the measurement analysis for SME INVOLVEMENT, a measure with a discrete, categorical value function. The five alternatives were generated by choosing each result from ‘No Involvement’(zero), to ‘Many Stakeholder SMEs from many organizations’(one). It was initially assessed ‘No Involvement’, therefore, overall value can only increase, depending on the extent to which it is improved. If SME INVOLVEMENT was to earn its full value, it would provide a 0.037 increase in local VDEA-Score, keeping results of all other measurements constant.

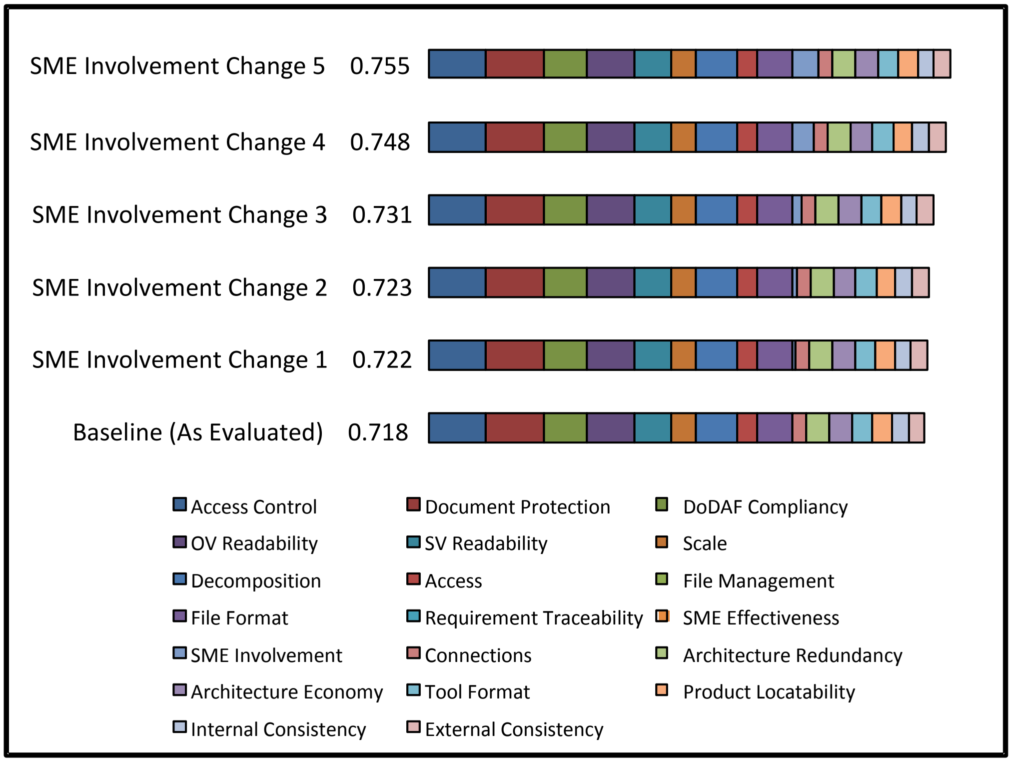

Figure 48. SME Involvement Measurement Analysis ($\|v_{AQ}\|$)

These two graphs (Figures 47 and 48) were provided as an example of the analysis performed similarly for the remaining eighteen measures. Graphs for these measures are presented in Appendix E. The measurement analysis results are summarized in Table 11. This table lists each measure followed by the resulting local *Architecture Quality Value* scores for a measurement score of zero, the current evaluated score, a score of one, and the delta change in overall local score between the high and low scores. The scores in italics highlight areas of strength where the evaluated measure scored the highest value. The underlined scores highlight areas of weakness where the evaluated measure scored the lowest value.

Table 11. Measurement Analysis Results ($||v_{AQ}||$)

Measure	Low	Current	High	Delta
Access	0.690	0.718	0.746	0.056
Product Locatability	0.690	***0.718***	***0.718***	0.028
Access Control	0.634	***0.718***	***0.718***	0.084
Document Protection	0.634	***0.718***	***0.718***	0.084
File Management	**0.718**	**0.718**	0.770	0.052
File Format	0.665	***0.718***	***0.718***	0.053
Connections	0.698	0.718	0.730	0.032
Architecture Redundancy	0.685	***0.718***	***0.718***	0.033
Architecture Economy	0.685	***0.718***	***0.718***	0.033
OV Readability	0.649	0.718	0.723	0.074
SV Readability	0.664	0.718	0.738	0.074
Scale	0.682	0.718	0.742	0.060
Decomposition	0.658	***0.718***	***0.718***	0.060
Tool Format	0.688	***0.718***	***0.718***	0.030
DoDAF Compliancy	0.655	0.718	0.730	0.075
Requirement Traceability	**0.718**	**0.718**	0.768	0.050
Internal Consistency	0.694	0.718	0.719	0.025
External Consistency	0.694	0.718	0.719	0.025
SME Effectiveness	**0.718**	**0.718**	0.755	0.037
SME Involvement	**0.718**	**0.718**	0.755	0.037

4.2. Alternative Architecture Evaluation

Based on these findings, theoretical architectures were conceived to provide a comparison of VDEA-Score improvement if the corresponding improved products were available. These options were determined to address the areas in need of the most improvement. With the exception of the products noted as changed, all other measurement values were the original evaluated scores. The architectures considered were:

1. Evaluated with full value for OV and SV READABILITY
2. Evaluated with full value for REQUIREMENTS TRACEABILITY (assumed validated SV-5 existed)
3. Evaluated with program office self-scored SME Input values (assumed improved AV-1)
4. Evaluated with program office self-scored SME Input values and full REQUIREMENTS TRACEABILITY value (assumed improved AV-1 and validated SV-5)

Figure 49 shows the resulting Tier I *Architecture Quality Value* branch improvements in the local value score ($\|v_{AQ}\|$) based on these theoretical architecture changes. These results provide an idea of the amount of improvement in the VDEA-Score that he program office may achieve based on improvements in the respective areas. This insight may be useful to prioritize limited resources to concentrate on the areas of greatest improvement.

As shown in Figure 49, the addition of an SV-5 in addition to providing greater detail regarding *SME Input* within the AV-1 would increase the local score by nearly 0.100 points. This alternative represents score changes of one for REQUIREMENTS TRACEABILITY and of 0.5 and 0.8 for SME EFFECTIVENESS and SME INVOLVEMENT, respectively, based on the program office's self-evaluation. It should also be noted that the addition of an SV-5 may affect the scores in other areas as well, such as SV READABILITY and DODAF COMPLIANCY. However, for purpose of showing how only these alternative improvements would increase the *Architecture Quality Value* local score, the other scores were kept constant with the original baseline evaluation.

Adding either a fully validated SV-5 (changing REQUIREMENTS TRACEABILITY to one and leaving both SME EFFECTIVENESS and SME INVOLVEMENT assessed as zero) or adding more detail regarding *SME Input* into the AV-1 (changing SME EFFECTIVENESS to 0.5 and SME

INVOLVEMENT to 0.8 while leaving REQUIREMENTS TRACEABILITY assessed as zero) would raise the local scores about 0.050 (or 5 percent) in both cases.

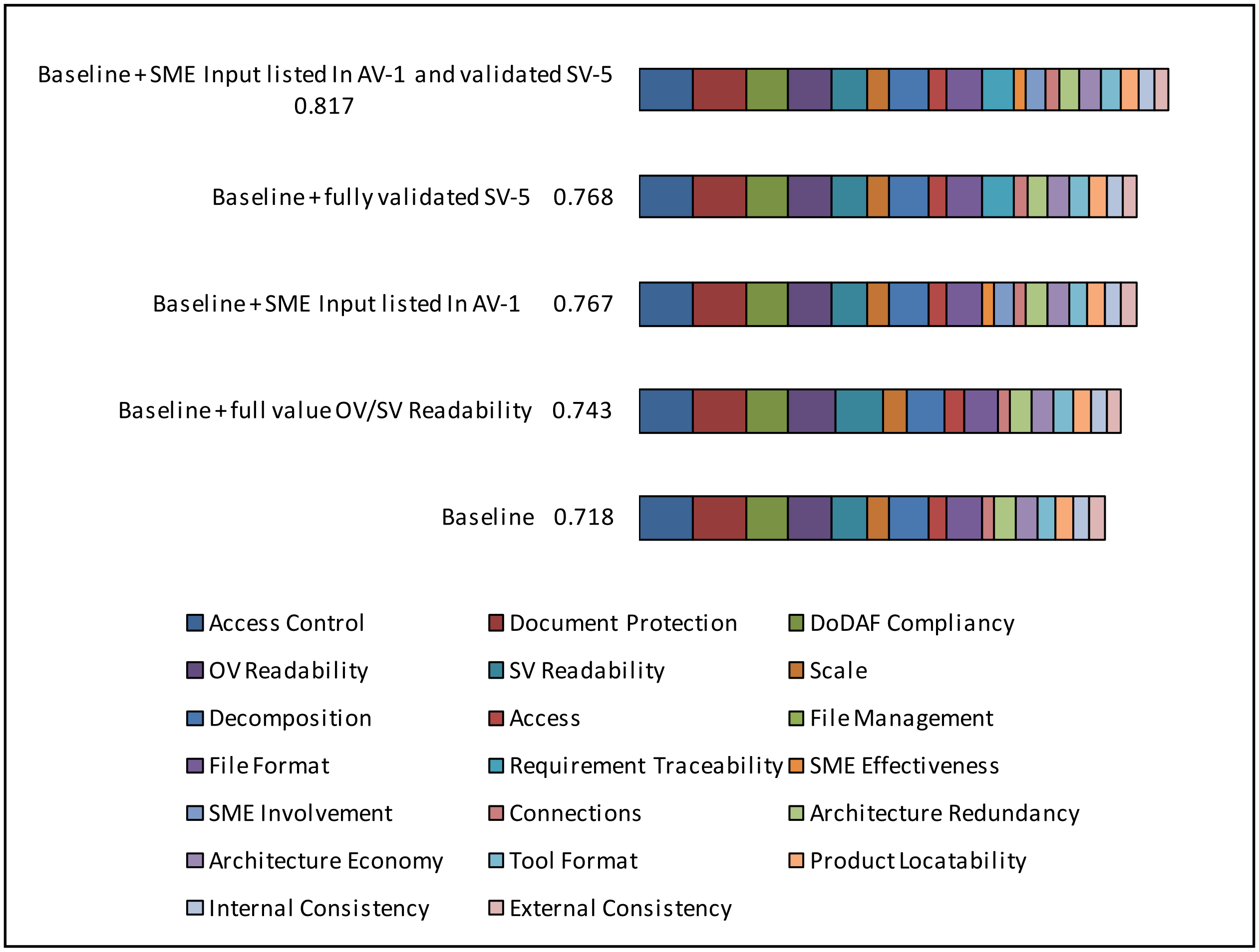

Figure 49. Local Architecture Quality Evaluation of Alternatives ($||v_{AQ}||$)

As previously stated, the *Usability* branch earned 0.742 of its total Tier II local value (74.2 percent). Most of the value lost was from the OV READABILITY and SV READABILITY areas. This was the basis for the other alternative. However, due to its relatively lower global weight, maximizing both of these categories only raises the total value by roughly 0.025 points (2.5 percent).

While most Tier I *Architecture Quality Value* branch measures earned the majority, if not all, of their value, these alternative VDEA-Score results provide an idea of the amount of value improvement the program office may achieve by acting upon the recommendations. This insight may be useful to prioritize limited resources to concentrate on the areas of greatest improvement.

4.3 Value Weight Sensitivity Analysis

Because this is a single alternative evaluation, value weight sensitivity analysis provides the opportunity for the decision maker to gauge what effect a value or measure has on the overall score if all other values or measures were ignored. For any value with a high score, increasing its weight increases the overall score. For example, *Accessibility*, the best performing second-tier value, earned 0.888 of its total potential value. At its current weight of 0.250, the overall Tier I *Architecture Quality Values* branch local score is 0.718 ($\|v_{AQ}\| = 0.287/0.400 = 0.718$). Figure 50 supports the notion that if the weight placed on this value is increased, the overall score increases because this value performed well. If the weight was increased to one, therefore eliminating the other second-tier values, the graph shows the overall local value at 0.888. Likewise, if the weight was lowered from 0.250 to zero, thereby eliminating it as a second-tier value, the overall local score decreases to 0.661. Given the baseline evaluation, if the decision maker increases *Accessibility*'s weight, the largest positive impact on the overall *Architecture Quality Value* score occurs.

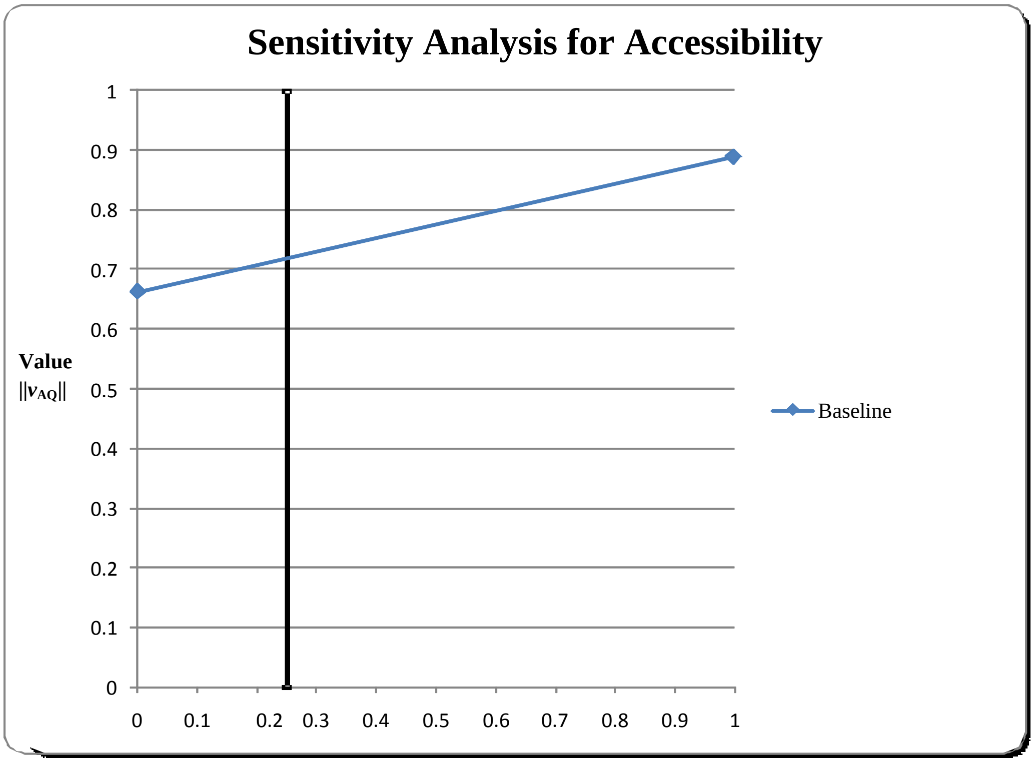

Figure 50. Accessibility Weight Sensitivity Analysis for $||v_{AQ}||$

On the other hand, if a value scored low, increasing its weight would decrease the overall score. *Accountability*, the worst performing second-tier value, earned 0.439 of its potential local value. At its current weight of 0.250, the local *Architecture Quality Values* score is 0.718, as displayed in Figure 51. If the weight increased to one, basically eliminating the other three second-tier values, the local *Architecture Quality Values* score drops to 0.439. If its weight was dropped to zero, the overall local score rises from 0.718 to 0.811. Given the baseline evaluation, if the decision maker increases *Accessibility*'s weight, the largest negative impact on the overall

Architecture Quality Value score occurs. Likewise, decreasing *Accessibility*'s weight would provide an *Architecture Quality Value* score increase.

Given that both *Usability* and *Modifiability* values scored high, increasing the weight increases the overall score. *Usability* as shown in Figure 52 had only slight score changes with only a 0.050 change in local Tier I *Architecture Quality Value* score between a zero weight and full weight. In comparison to the steeper slopes of the other Tier II value's sensitivity lines, this indicates *Usability* is approximately insensitive to changes in weight. Therefore the decision maker would see very little score change regardless of changes in *Usability*'s weight. *Modifiability* as shown in Figure 53 had a larger change of 0.120 in local Tier I *Architecture Quality Value* score between a zero weight and full weight. This means the decision maker would achieve a higher score with an increased *Modifiability* weight, but the gain is not as large as is possible with *Accessibility*.

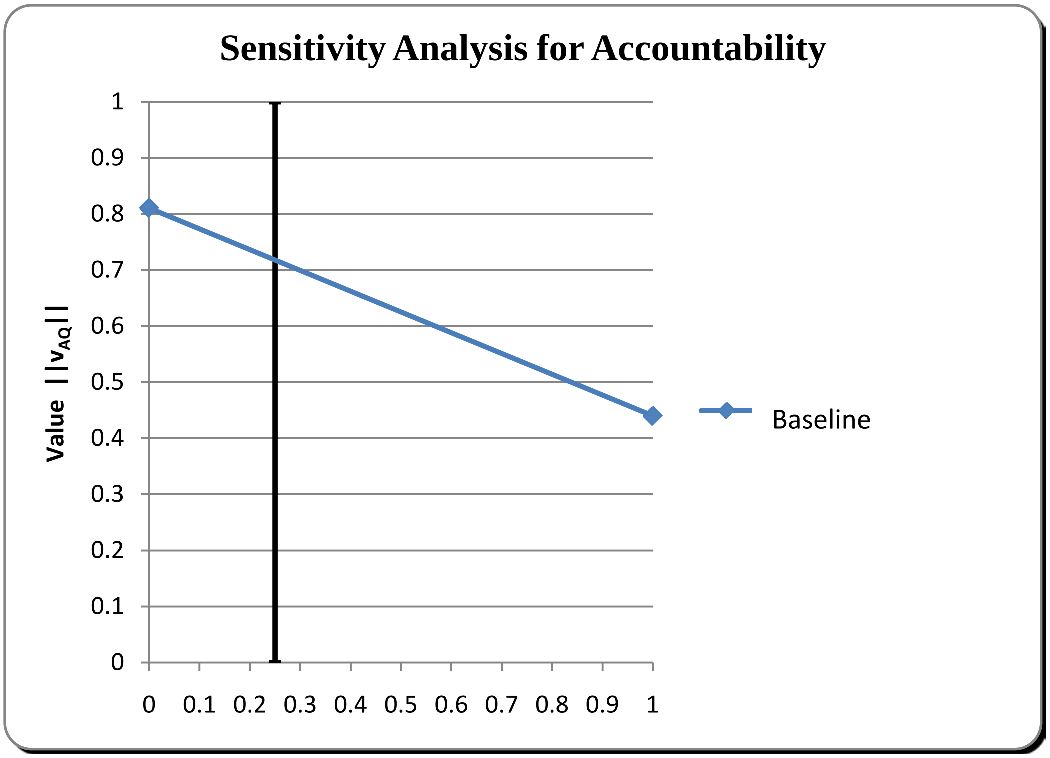

Figure 51. Accountability Weight Sensitivity Analysis for $||v_{AQ}||$

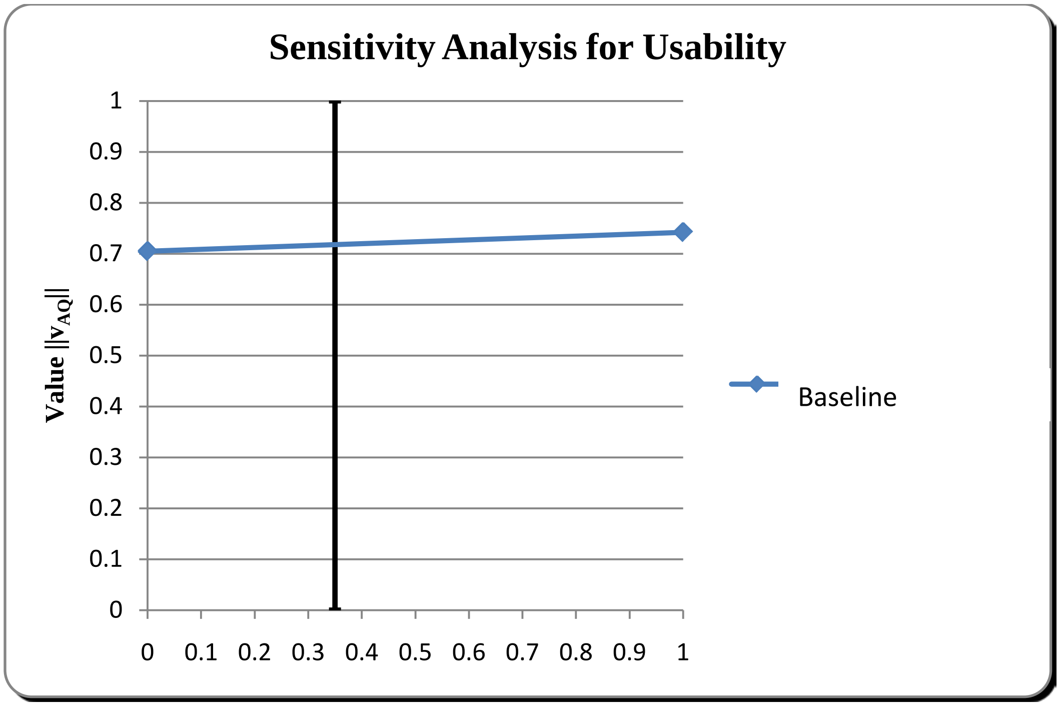

Figure 52. Usability Weight Sensitivity Analysis for $||v_{AQ}||$

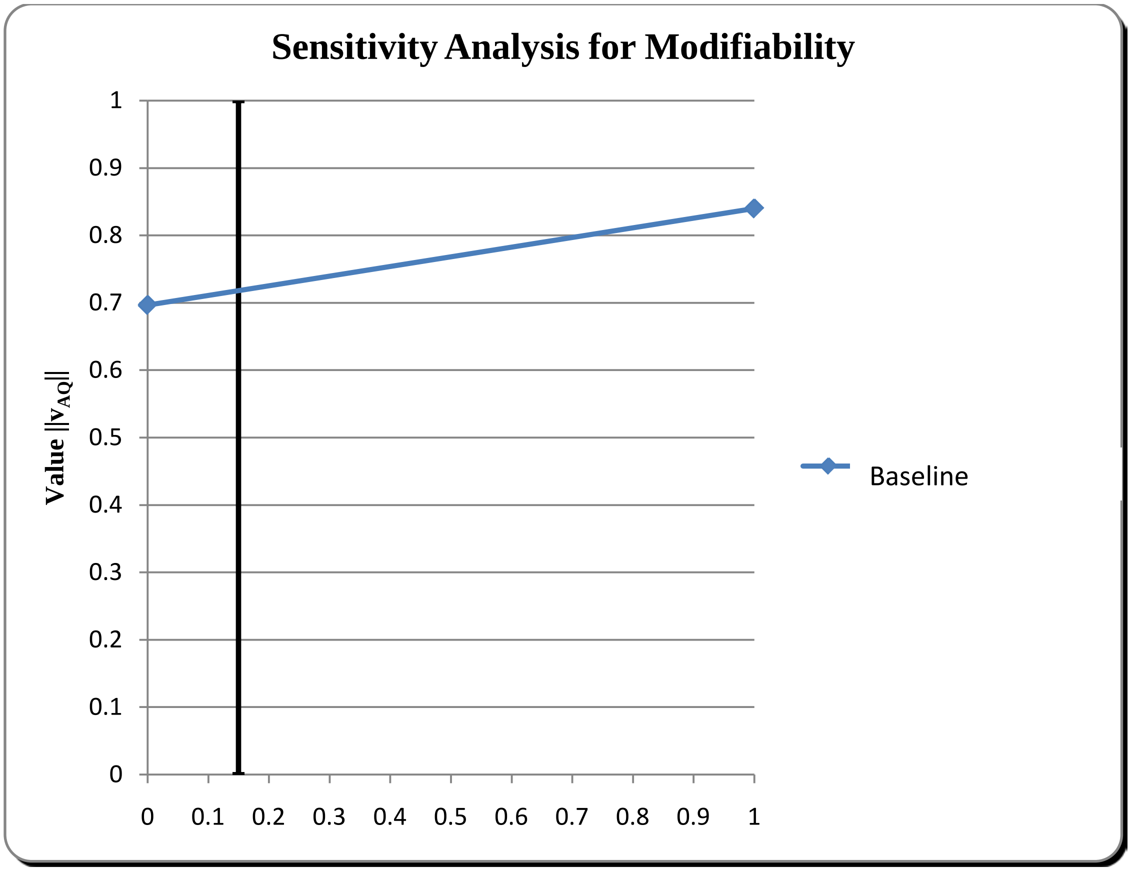

Figure 53. Modifiability Weight Sensitivity Analysis for $\|v_{AQ}\|$

Tables 15 through 18 in Appendix F summarize the weight sensitivity analysis results for each of the values and measures in numerical format showing the maximum positive and negative change in local Tier I *Architecture Quality Value* branch VDEA-Score as individual weights are changed. Table 12 also summarizes these results showing the values which had positive ($+\Delta\|v_{AQ}\|$), negative ($-\Delta\|v_{AQ}\|$), or no effect ($\Delta\|v_{AQ}\| \leq 0.050$) on the score with increased weight. In general, should the joint force protection decision maker wish to increase the Tier I *Architecture Quality Value* branch VDEA-Score by changing the assigned weights, the values listed with a positive effect in Table 12 may be increased in weight to accomplish this goal. Specifically, increasing the *Accessibility* weight (most positive contributor) while decreasing the *Accountability* weight (most negative contributor) would yield the largest score increase.

Table 12. Value Weight Sensitivity Effect on $||v_{AQ}||$

Value	Positive Effect	No Effect	Negative Effect
Accessibility	X		
Subscribability			X
Controllability		X	
Protectability		X	
Usability		X	
Longevity			X
Understandability	X		
Simplicity		X	
Readability		X	
Modifiability	X		
Scalability			X
Tailorability		X	
Evolvability		X	
Accountability			X
Compliancy	X		
Traceability			X
Consistency	X		
SME Input			X

Sensitivity analysis was also performed on the proposed alternatives discussed in the previous section. In a situation where the alternatives vary significantly from each other, sensitivity analysis shows how changes in the weights affect the ranking of alternatives. This allows the decision maker the opportunity to see which alternatives provide the most value either by adjusting the weights or keeping the weights as assigned. While the generated alternatives increase score, the weight sensitivity results for each of the alternatives vary in only a couple of areas.

The sensitivity analysis for the Tier II *Usability* branch (Figure 54) demonstrates that both of the alternatives with the SV-5 addition decrease in overall score if *Usability*'s Tier II local weight is increased from 0.35. This is due to the fact that these alternatives have higher scores for *Accountability*. If *Usability*'s weight is increased, the weight for *Accountability*, as well as *Accessibility* and *Modifiability*, decreases proportionally, thereby making the value earned in those areas less important. Three of the four alternatives converge at the same point when the value is increased to one because, with the exception of the alternative with full OV and SV READABILITY added to the baseline evaluation, the value earned under *Usability* is identical for each. The alternative with full OV and SV READABILITY has a higher value score when the Tier II *Usability* value is increased to one because both OV and SV READABILITY measures are captured within the Tier III *Understandability* branch. This is the only alternative with a higher *Usability* score compared to the baseline as evaluated. Note that the alternative "Baseline + SME Input listed in AV-1" approximately equals the "Baseline + fully validated SV-5" alternative. Therefore, this SV-5 alternative was eliminated from the following analysis charts because these two lines would overlap.

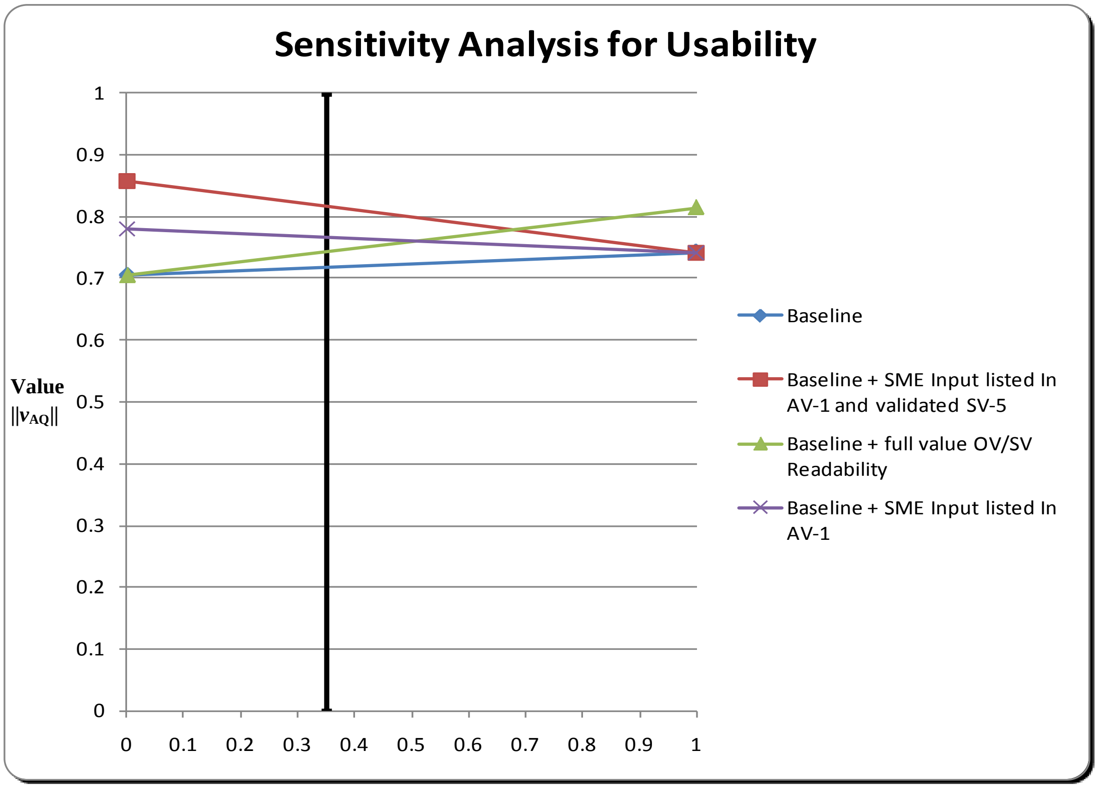

Figure 54. Usability Weight Sensitivity Analysis (Alternatives)

The sensitivity analysis for *Accountability* (Figure 55) shows that the alternative with SME Input added to the AV-1 as well as a fully validated SV-5 behaves conversely for this measure as its weight is increased. This is due to *Accountability*'s increasing total value if these two improvements are made. As noted previously, this area scored low for the baseline. Thus, increasing *Accountability*'s weight decreases the overall score. The alternative with appropriate SME information added to the AV-1 decreases as well when the weight is increased. In this case, the *Accountability* value earned is not enough of an improvement (the value gap is still present for *Traceability*) to make a significant difference. Finally, the analyses for *Accessibility* (Figure 56) and *Modifiability* (Figure 57) behave similarly in the sense that all of the alternatives have increasing slopes. This is due to the initial high value earned in both of these branches. Because no alternatives produced any extra value earned under these two branches (they all scored exactly the same for both *Accessibility* and *Modifiability*), they all converge at the same point if the weight is increased to one for both Tier II values. In summary, recommendation rankings are insensitive to Tier II value weight adjustments making them robust.

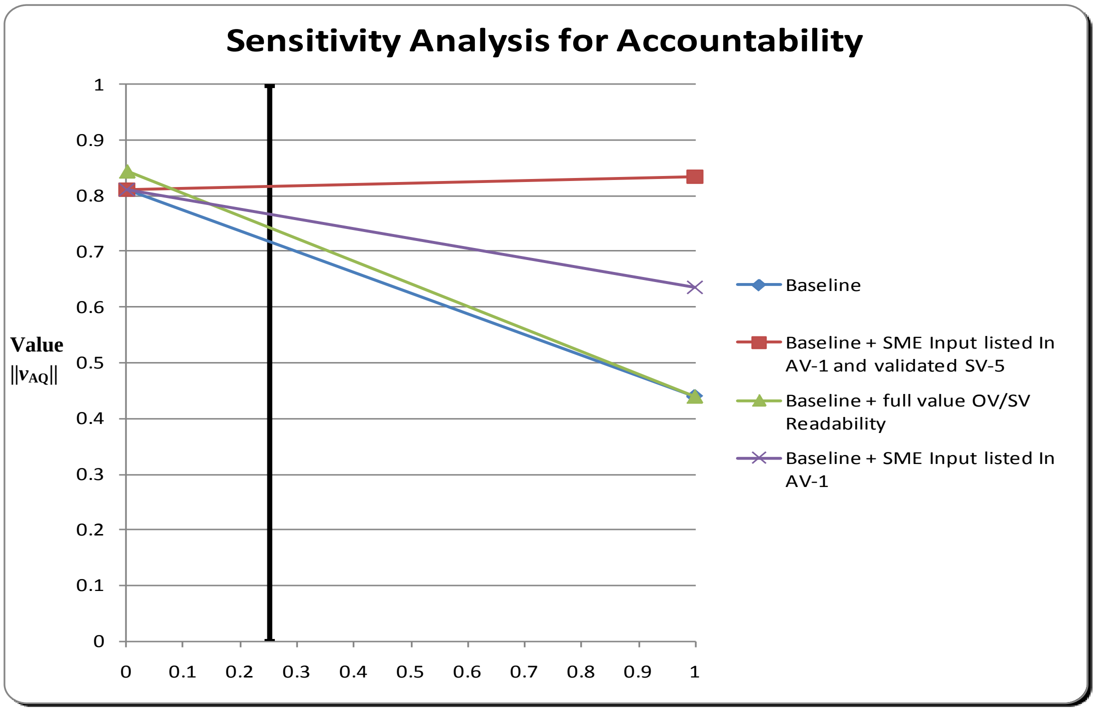

Figure 55. Accountability Weight Sensitivity Analysis (Alternatives)

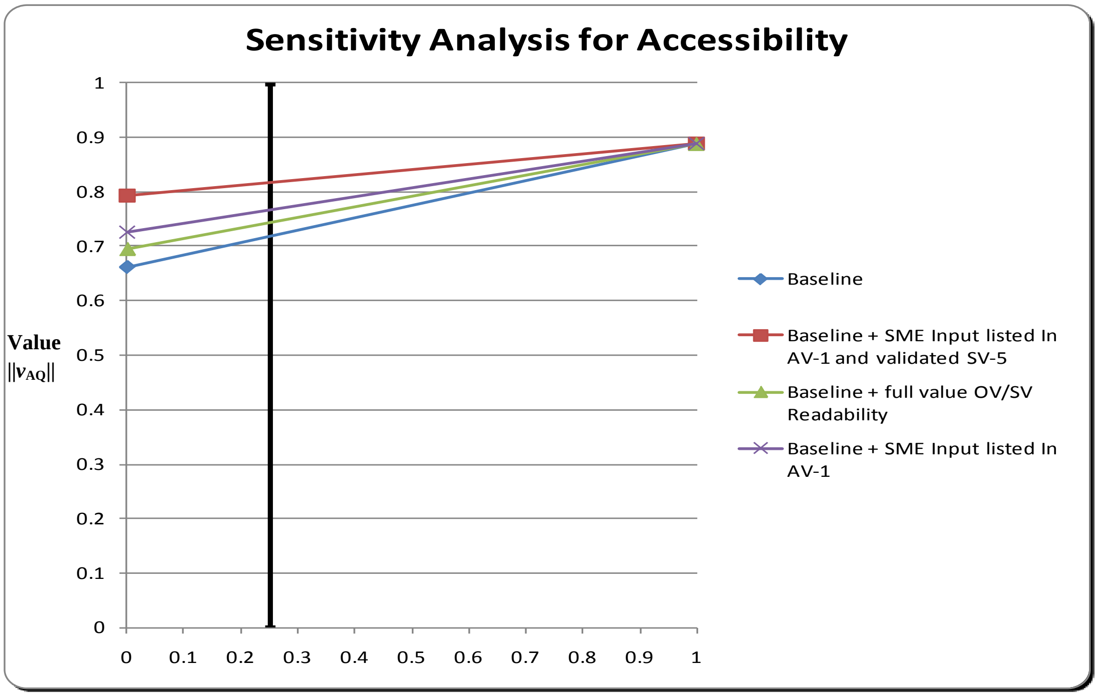

Figure 56. Accessibility Weight Sensitivity Analysis (Alternatives)

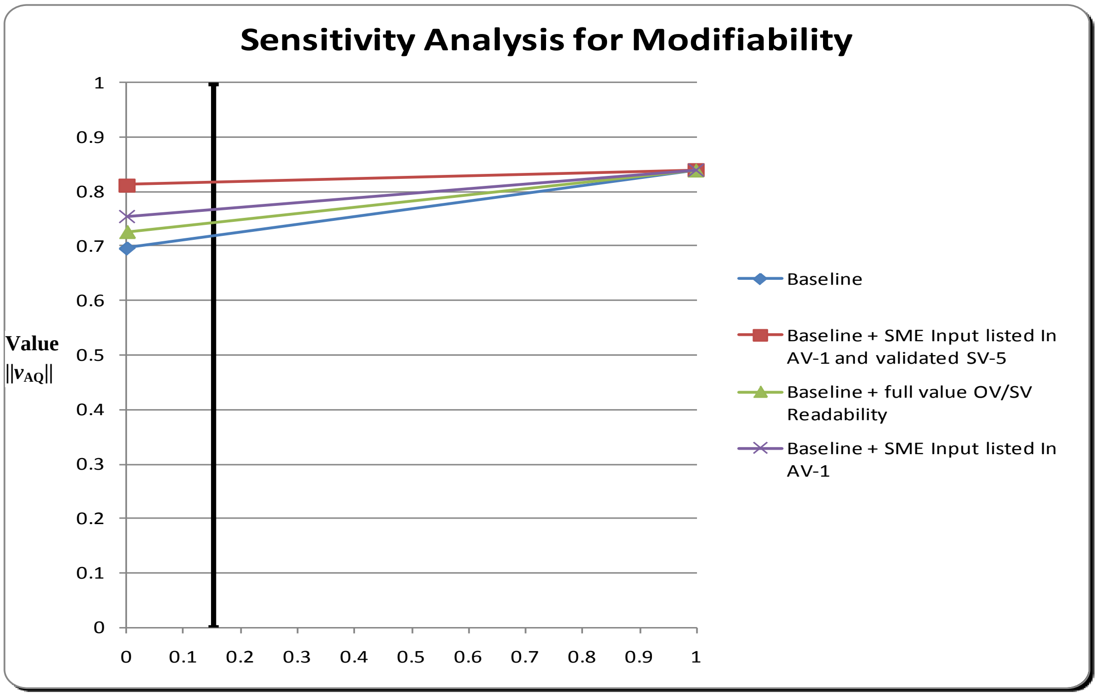

Figure 57. Modifiability Weight Sensitivity Analysis (Alternatives)

4.4. Complete Joint Force Protection VDEA-Score

The complete VDEA-Score combines the *System Effectiveness Value* (v_{SE}) branch with the *Architecture Quality Value* (v_{AQ}) branch. Through similar analysis, as previously presented in this chapter, Mills (2009) determined the *System Effectiveness Value* branch earned 0.248 out of 0.600 for a 41.3 percent local value. Therefore, the combined joint force protection VDEA-Score was $v(x) = v_{SE}(x) + v_{AQ}(x) = 0.248 + 0.287 = 0.535$. This combined score is useful for noting areas of improvement and may serve as the baseline measure for future architecture iterations.

4.5. Additional Model Evaluation: IRSS

The focus of this specific thesis was a VDEA-Score model for evaluating architecture products. It was understood that the Tier I *System Effectiveness Value* branch with its more specific focus on joint force protection may require modification from system to system. However, it is hoped that the *Architecture Quality Values* branch is more universal even down to the measurement level. To test this, the authors preliminarily validated the effectiveness of the *Architecture Quality Values* hierarchy using the IRSS architecture. The results for the IRSS analysis are provided in this section.

4.5.1. IRSS Architecture Quality Branch VDEA-Score Measure Results

As mentioned in previous analysis, the primary source for evaluating the ACCESS measure is the AV-1, and like the joint force protection evaluation, potentially valuable information was missing from this product. The evaluator found no mention of repository use. However, the products were available in the Air Force Architecture Repository on the Air Force

Knowledge website, thus providing immediate access for those with Air Force Portal access. Therefore ACCESS was evaluated categorically as "< 5 minutes" resulting in a value score of one.

As mentioned in the previous measure, no pertinent description in the AV-1 was available for PRODUCT LOCATABILITY, ACCESS CONTROL, DOCUMENT PROTECTION, or FILE MANAGEMENT. Therefore, the proxy evaluation of the Air Force repository was used. This resulted in the following categorical evaluations: PRODUCT LOCATABILITY evaluated as "Locatable in < 5 minutes;" ACCESS CONTROL evaluated as “Appropriate Control;" DOCUMENT PROTECTION evaluated as "Products Controlled;" and FILE MANAGEMENT evaluated as "System Exists, all products maintained." These categories each resulted in value scores of one.

The AV-1 discussed the tools used for development. These tools were Microsoft Office related with all products provided in those formats. The evaluator therefore determined the FILE FORMAT category of "General File Format" applied resulting in a value score of one. Regarding CONNECTIONS, all products were presented in a high-level, simplistic fashion. The links between entities were easy-to-follow and well-organized. This resulted in the evaluation of "15 of 15" products comply with the value score of one. For ARCHITECTURE REDUNDANCY and ARCHITECTURE ECONOMY, the evaluator found no unnecessary duplication of information and no need to consolidate entities or activities within the products. Therefore, ARCHITECTURE REDUNDANCY and ARCHITECTURE ECONOMY were respectively evaluated categorically as "1 in > 500" and "None found." These categories correspond to value scores of one for each.

Reviewing the OV and SV products for readability, the evaluators rated the six OV products as easy to read. Thus, "6 out of 6" was assessed for OV READABILITY resulting in a value score of 1. The SVs, as a whole, were presented in a very easy to read, almost simplistic fashion. However, the evaluator determined that the SV-6 was not intuitive enough as to determine which OV-3 events were being described. Therefore, SV READABILITY was assessed "5 out of 6" leading to a value score of 0.950.

As with the joint force protection architecture, the SCALE measure was applied to all available IRSS products to determine if doubling the number of nodes would greatly increase the complexity. Even though this measure is a fairly subjective assessment, several instances in the documentation specifically addressed the need and ability to expand significantly. This provided extra confidence to the evaluators who determined categorically "All" of the products were scalable resulting in the value score of one.

The evaluators reviewed the IRSS OV-5 for the DECOMPOSITION measure. The OV-5 product had up to five levels of decomposition. Thus the DECOMPOSITION measure was determined to be categorically "3+" resulting in a value score of one.

According to the AV-1, the tools used for the IRSS architecture development are all Microsoft Office based. Because many of these allow inputs to be carried throughout the instant view (e.g. find and replace in Microsoft Word) but not to others, the evaluator assessed TOOL FORMAT categorically as "Input gets reflected in instant view but not others." This category resulted in a value score of 0.600.

The *Accountability* value category was evaluated last. As a whole, every product appeared in compliance with DoDAF standards. Therefore, the evaluators assessed the “15 out of 15” DODAF COMPLIANCY measure resulting in a value score of one. A complete SV-5 was present with all of the requirements being met by specific activities or functions. Therefore, the REQUIREMENTS TRACEABILITY measure received a “100%” assessment resulting in a value score of one. Each entity, function, and need line were examined within every product for any internal inconsistencies. Finding none, the evaluator assessed "15 out of 15" for INTERNAL

CONSISTENCY resulting in a corresponding value score of one. Each individual product was then compared in relation to every other product for any external inconsistencies. Again the evaluator found none, thus assessing "15 out of 15" for EXTERNAL CONSISTENCY resulting in a corresponding value score of one.

By simply examining the AV-1, no knowledge of how effective SMEs were in developing the IRSS architecture was found. Specifically, no mention of the use of SMEs or their experience was located so no knowledge of the developmental team was captured. Therefore, the evaluator assessed "No information provided" for SME EFFECTIVENESS resulting in a value score of zero.

For the SME INVOLVEMENT measure, the AV-1 was again reviewed. As a single service project, the categories were tailored to major commands (MAJCOMs) for IRSS versus services for the force protection evaluation. While not specifically mentioned as SMEs, the document does describe the IRSS Requirements Review Board with specific membership of 14 different Air Force MAJCOM-level organizations who were also identified as users. Therefore, the evaluator made the assumption these organizations would provide SME-type input but did not give credit for multiple SMEs from the multiple organizations because that could not be deduced. As such, SME INVOLVEMENT was assessed as "4+ organizations" with the resulting value score of 0.8.

4.5.2. IRSS Architecture Quality VDEA-Score Summary

The final step in providing a single *Architecture Quality Value* VDEA-Score requires the summation of each of the individual value scores according to their respective global weights using to the general additive value function of $v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i)$. Table 13 is provided as a summary of these individual scores with the resulting score. The graph shown in Figure 58 shows the detail of these measure scores in comparison to the full potential value. This 0.378 score out of 0.400 possible represents approximately 95 percent of its total potential VDEA-Score for Tier I *Architecture Quality Value*.

Table 13. IRSS Architecture Quality Value Scoring

Measure	**Assessment**	**Weight** λ_i	**Value Score** $v_i(x_i)$	**Product** $\lambda_i v_i(x_i)$
Access	Proxy Eval of Repository: Access < 5min	0.022	1.000	0.022
Product Locatability	Proxy Eval of Reposity: Locatable < 5min	0.011	1.000	0.011
Access Control	Proxy Eval of Repository: Appropriate Control	0.033	1.000	0.033
Document Protection	Proxy Eval of Repository: Write-Protected	0.033	1.000	0.033
File Management	Proxy Eval of Repository: System exists	0.021	1.000	0.021
File Format	General File Formats	0.021	1.000	0.021
Connections	15 out of 15	0.013	1.000	0.013
Architecture Redundancy	0 redundancy instances found	0.013	1.000	0.013
Architecture Economy	No instances of possible consolidation	0.013	1.000	0.013
OV Readability	6 out of 6	0.030	1.000	0.030
SV Readability	5 out of 6	0.030	0.950	0.0285
Scale	All Scalable 2x	0.024	1.000	0.024
Decomposition	3+ levels	0.024	1.000	0.024
Tool Format	Input carries instant view	0.012	0.600	0.0072
DoDAF Compliancy	15 out of 15	0.030	1.000	0.030
Req't Traceability	15 out of 15	0.022	1.000	0.022
Internal Consistency	15 out of 15	0.010	1.000	0.010
External Consistency	15 out of 15	0.010	1.000	0.010
SME Effectiveness	No info provided	0.015	0.000	0.000
SME Involvement	Multiple Organizations	0.015	0.800	0.012

$$\boldsymbol{v_{AQ}}(\boldsymbol{x}) = \sum_{i=1}^{n} \lambda_i v_i(x_i) = \quad \mathbf{0.378}$$

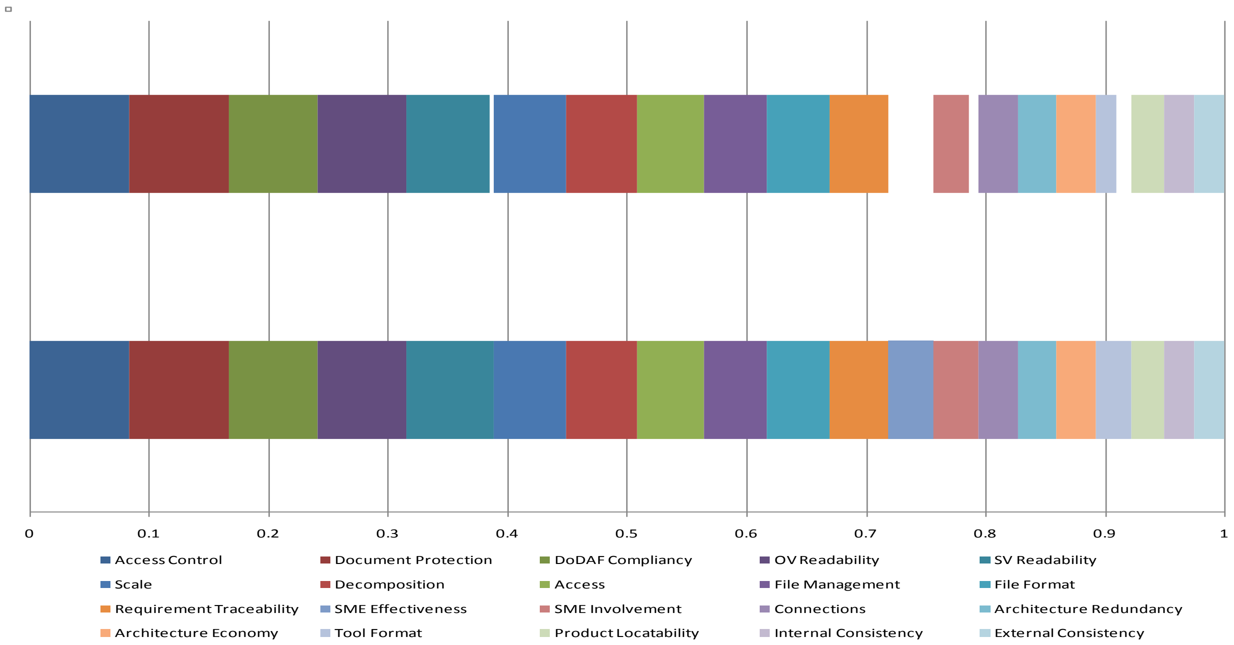

Figure 58. IRSS Evaluated $||v_{AQ}||$ over Potential $||v_{AQ}||$

As noted in the joint force protection evaluation, *SME Input* was again identified as the key area of improvement. It is also quite likely that in practice the program has significant SME support which would increase their score had it been identified in their AV-1. Similar to the joint force protection evaluation, more detail in the AV-1 regarding the use of the official Air Force repository would have provided more direct measurement for the three *Accessibility* value measures and *Longevity*. Overall, this higher VDEA-Score reflects the architecture's maturity (final product as opposed to the draft joint force protection architecture) and narrower program focus (multi-user database for only the Air Force as opposed to the joint force protection architecture's joint nature encompassing many disparate subsystems).

In the course of this second case study, the *SME Involvement* measure was highlighted as requiring modification. With the initial development focused on the joint force protection architecture, the original *SME Involvement* measure was defined in terms of number of services involved. With the IRSS architecture, the single-service nature of the architecture required a change in definition to number of stakeholder organizations making the measure more widely applicable.

V. Conclusions and Recommendations

This chapter summarizes the research and findings of the Value-Driven Enterprise Architecture Score (VDEA-Score) analysis for enterprise architecture evaluation using weighted stakeholder value categories. The answers to the initial research questions are summarized followed by recommendations to the sponsor for architecture improvements. Finally, the strengths and weaknesses of the model and suggested future research are also presented.

5.1. Answers to Research Questions

Early in this thesis, four major research questions were posed. These were:

1. What are the "best" methods to evaluate and measure the overall quality of an architecture?
2. What are the major categories and sub-categories that should be considered when evaluating an architecture?
3. What are the major categories and sub-categories that should be considered when evaluating force protection processes?
4. How do these categories and sub-categories rank in terms of importance?
5. How well does current joint force protection architecture meet the weighted values of the force protection community?

While a variety of approaches to evaluate and measure architecture quality exist, no single, "best" approach was found. The research team found an architecture can be viewed as an incumbent solution to a decision situation. Using principles from Value-Focused Thinking (VFT) provided the optimal foundation for development of the VDEA-Score to evaluate and measure the overall quality of this architecture solution. Through extensive research, a comprehensive list of '-ilities' was developed. This listing was further grouped into categories assessed as valuable to the project goals. With input and validation from the decision maker, these categories were transformed into sets of attributes deemed most valuable to the decision maker to evaluate both architecture quality and force protection processes. These resulting two sets formed the two major branches of the overall value hierarchy: *System Effectiveness Values* and *Architecture Quality Values*. One or more measures associated with each of the lowest-tier values were developed to enable evaluation. This answered the aforementioned research questions two and three.

Because these values were not equally important, weights were assigned in terms of importance to each value and measure contained within the hierarchy in answer to question four. These weights allowed computation of an overall score that acts as "value earned," as opposed to acting as a "grade." This score evaluated both the quality of the instantiated system being represented and its ability to perform its stated mission (system effectiveness) and the intrinsic quality of the products in terms of documentation standards and desired attributes (architecture quality).

To answer question five, the resulting VDEA-Score model was used to evaluate the joint force protection architecture. The overall joint force protection VDEA-Score was assessed to be 0.535 out of the potential 1.000. In other terms, 53.5 percent of the total value to this point was earned. The primary focus of this thesis was on the *Architecture Quality Values* branch, which earned 0.287 out of a possible 0.400 points, or 71.8 percent of its possible value. Due to the fact that the joint force protection architecture is still in early draft stages, areas for improvement were highlighted through this evaluation. This score further acts as a reference point for the decision maker to use to compare future architecture iterations. Specific recommendations to gain more value in regards to the joint force protection architecture quality follow in the next section.

5.2. Recommendations

Intended to aid the decision maker in determining which steps to take next, recommendations were developed based on the overall score as well as the deterministic and sensitivity analysis. The majority of measures within the *Architecture Quality Values* branch were evaluated using an aggregate of available views. There were only three views that served as the single source for evaluating any given measure: the AV-1, SV-5 and OV-5.

The AV-1, in particular, was the sole source for evaluating 9 of the 20 measures. Additions to the AV-1, primarily relating to detailed information pertaining to *SME Input*, could provide an increase of 0.049 of the local or normalized Tier I *Architecture Quality Value* VDEA-Score from 0.718 to 0.767 points. This assumed the program office self-evaluated scores of 0.5 and 0.8 for SME EFFECTIVENESS and SME INVOLVEMENT, respectively (if these two measures were maximized, the jump would be even higher). Improving these two measure scores would provide significant additional earned value to the Tier II value component in need of most work: *Accountability* (the lowest scoring of the four second-tier values). Sensitivity analysis also confirms this low score would cause the largest loss in value if the decision maker decided to increase *Accountability*'s weight.

Although not providing any score increase, other additions to the AV-1 may improve direct evaluation of the architecture. Information related to steps taken to control access and protection of the architecture products as well as methods of development for electronic products could be placed in the AV-1 to ease direct and indirect evaluation of Tier II value *Accessibility*.

Another cause for value lost in *Accountability* was due to zero value earned in *Traceability*. This was directly related to the absence of the Operational Activity to Systems Function Matrix (SV-5)--the sole source for the REQUIREMENTS TRACEABILITY measure. The SV-5 is a good way to show which systems are performing certain functions, thus allowing traceability from operational requirements to system functions. Like the previous recommendation, this also provides a 0.050 increase in the normalized Tier I *Architecture Quality Value* VDEA-Score from 0.718 to 0.768.

Merely improving the AV-1 or creating the SV-5 would theoretically provide value. However, operational requirements are not listed in the AV-1. If the evaluator is not aware of the operational requirements, the SV-5 provides nothing regarding requirements traceability. Therefore, the authors recommend updating the AV-1 and completing the SV-5 starting with operational requirements documentation which provides a nearly 0.100 increase of the normalized total *Architecture Quality Value* from 0.718 to 0.817. Further, the creation of the SV-5 may provide additional increase or decrease in value for other measures such as DODAF COMPLIANCY and SV READABILITY which rely on the ratio of products in accordance to the total number of products. These possibilities were not accounted for when conducting the analysis. However, assuming the best case that the SV-5 would be readable, consistent with the other views, and compliant with DoDAF standards, the normalized total *Architecture Quality Value* would increase to 0.826.

Correcting minor issues related to DODAF COMPLIANCY provided less of an increase in value earned but should be considered. Per DoDAF Vol II, version 1.5 (2008), the SV-6 needs more description of the data, and the OV-2 needs the information being exchanged among entities. Even though this measure earned 0.830 of its local potential value, it is one of the highest weighted measures. Improving this score would increase the contribution *Accountability* gives to the Tier I *Architecture Quality Value* score.

To increase value earned for *Usability*, the problems with merged and unlabeled connections within the SV-1 and SV-4 as well as the lack of a file management system need to be resolved. Fixing the SV-1 and SV-4 needlines would improve the sub-tier CONNECTIONS measurement. Implementing an official file management system along with documenting it in the AV-1 would improve the FILE MANAGEMENT measurement.

5.3. Model Strengths

By starting with a comprehensive list of "ilities," the Value-Focused Thinking approach behind the VDEA-Score methodology was beneficial to transform these "ilities" into an organized and simple value hierarchy useful to multiple enterprise architecture evaluations. In the case of the *Architecture Quality Values* branch, the values, measures, and value functions represent aspects important to any architecture. This branch was intentionally separated to enable its reuse to apply to any system's architecture. Thus, the VDEA-Score Tier I *Architecture Quality Values* is very portable. The value hierarchy may also be a good starting point for measuring *System Effectiveness Values* but will likely need to be revised at Tier III.

Because all values are not equally important, each value has an associated weight. Given that different decision makers likely have different perspectives on each value's importance, these weights can easily be tailored. This flexibility further enhances the model's reusability for any system architecture.

As with any evaluation process, repeatability is important to ensure credibility of results. The measures for each of the *Architecture Quality Values* were designed and defined to enable different evaluators to apply this model and determine the same results. This enhances the credibility as well as the usefulness by not requiring a specialized consultant to conduct the evaluation.

Through the application to the two systems presented in this thesis, the Tier I *Architecture Quality Value* branch of the VDEA-Score's repeatability, tailorability, and portablity were demonstrated. Further, this model was useful in identifying the architectural areas of strength and weakness to our sponsor to enable product improvement. The separate analysis of IRSS provided initial indication that the evaluation tool can be applied to a variety of systems at different levels of acquisition development.

5.4. Model Weaknesses

While this model's usefulness was verified across two systems, the sample set of only two architectures does not provide sufficient validation. Additionally, only the joint force protection decision maker was involved. Therefore, the actual tailorability of applying different weights according to a different decision maker was not tested. The repeatability of the evaluation was also not demonstrated in this effort because only the authors served as evaluators with the exception of the OV READABILITY measure. As was discovered in the OV READABILITY evaluation, a tradeoff in values (e.g., the larger amount of detail required to make the OV-5 useful for the complex joint force protection architecture while sacrificing readability) may also preclude achieving a full value VDEA-Score.

Even though sufficient measures were developed through this effort, the significant portion of qualitative and categorical measures is a known weakness of this model. More direct measures may be possible and tailorable to specific programs. In particular, the following measures have specific weaknesses identified by the authors.

- SCALABILITY: This was a very subjective assessment of a product's ability to double in size without significantly increasing complexity.
- ARCHITECTURE ECONOMY: This was a very subjective binary assessment of any multiple steps unnecessarily used to represent the same activity. Without interviewing the architect, it was difficult to determine solely from the products if any instances were truly unnecessary or were purposely described in multiple steps.
- SME INVOLVEMENT: In the case of joint force protection, a larger number of SMEs involved was termed beneficial. However, more is not always better as more individuals may also mean more differing perspectives requiring more work to reconcile differences.
- FILE MANAGEMENT: This measure was defined to allow a proxy evaluation of an official architecture repository (e.g., DARS) to score full value if not described in the products. Because only one product version is kept in the repository, this measure may not completely capture the usefulness of an actual file management plan. Thus, access to drafts for coordination or historical versions is not possible.
- ACCESS CONTROL, FILE FORMAT, CONNECTIONS, ARCHITECTURE ECONOMY, ARCHITECTURE REDUNDANCY, OV READABILITY, SV READABILITY, SCALE, TOOL FORMAT, and SME EFFECTIVENESS: These are constructed, proxy measures. This represents half of the total *Architecture Quality Value* measures which conflicts with the goal to minimize this type of measure in favor of natural, direct measures.

It is also important to note the VDEA-Score model is focused on the visualization aspects (products and views) of the DoDAF. As the DoDAF transitions from this product-centric approach to a data-centric one, the VDEA-Score measures may need refining. In particular, addressing the Core Architecture Data Model (CADM) and the data itself versus its visualization may be required. The authors also note this model is a descriptive evaluation of a program's architecture. For insight into a potential prescriptive approach for programs with limited architectural development resources to develop the most effective architecture products, the reader should refer to the third thesis associated with this effort (Osgood, 2009).

5.5. Future Research

To address these identified weaknesses, the authors recommend future research to enhance the VDEA-Score. Additional application to other system architectures is recommended for validation of the VDEA-Score model's applicability to any system architecture. Both joint and single service (from different services) system architectures should be evaluated. These additional architecture evaluations should also involve different decision makers for demonstration of the VDEA-Score's tailorability. Because only the authors served as the evaluators, use of additional evaluators scoring the same architectures independently is also recommended to confirm the repeatability.

Developing more direct measures for existing value components would likely expand the objectivity and quantifiability of the VDEA-Score. As noted by the high score for the IRSS architecture, more direct measures or additional discrimination within measure categories may provide more discrimination in the overall VDEA-Score. This would reduce the likelihood of a 100 percent score situation which provides no assistance to the program office in identifying areas of improvement.

Because many of the OV and SV architecture products involve entities and needlines, these may be interpreted as nodes and paths. Therefore, network flows (Ahuja et al., 1993) and graph theory (West, 1996) may be applied to incorporate the concepts of shortest path, most connected node, cliques, etc. As an example of graph theory application, inconsistencies in architecture design “could be looked up by the paths length checking in the combined graph which depicts the structural relationship of OV2 and OV5” (Liu, 2007).

Additionally, the DoDAF continues to evolve with the DoD net-centric transformation and advances in enabling technologies such as services within Service Oriented Architecture (SOA). The DoDAF transition from a product-centric focus in DoDAF version 1.5 to a data-centric focus in DoDAF version 2.0 may require more research into new VDEA-Score measures which account for this change. As a potential starting point for this research, the Architecture Verification and Integration for DoDAF (AVID) prototype from Trident Technology Solutions (Reber, 2009) should be examined.

Specific to the 642 ELSS, the authors also suggest future research. Besides the development of architecture, the program office receives numerous proposals from industry for new force protection equipment. As an additional tool to aid the program office, future research is suggested building on the VDEA-Score methodology for the evaluation of these new industry proposals for system component acquisition.

5.6. Conclusion

The VDEA-Score methodology demonstrated to the sponsor and the authors the usefulness of this new tool for evaluating the quality of system architecture. It is important to remember the VDEA-Score is not a "grade" but merely a tool to highlight areas of strength and illuminate areas for improvement. Overall, this evaluation identified important areas of improvement providing new insight to the sponsor of the possible paths to high quality architecture as the building block to actual system development. This baseline score can be used to compare future iterations of their architecture. In addition to this thesis, the results of the

VDEA-Score research were captured in an outbrief to the 642d ELSS, papers accepted for the 2009 Industrial Engineering Research Conference (Mills et al., 2009b) and Conference on Systems Engineering Research (Cotton et al., 2009), as well as the Mills (2009) and Osgood (2009) theses.

Appendix A. Ilities Table

The following table lists the “ilities” considered for this effort as determined by the associated references and through brainstorming. The Disposition column describes which ones were used (bold italics), which ones were covered by the ones used, and which ones were discarded. Legend: AQ=Architecture Tier 1; SE=System Tier 1; Sub=Sub-tier

Literature Reference

"Ility"	Wikipedia, 2009	Haskins, 2006	Ross, Hastings, 2006	Ross, 2006	McManus, 2007	Voas, 2004	Dalgren, 2007	Bottella, 2004	SEI 2003	Daniels, 2005	Richards, 2006	Lehto, 2005	Ross, Rhodes, 2008	Schultz, 1999	Total Referenced	Disposition
accessibility	X														1	AQ 1
accountability	X														1	AQ 2
accuracy	X							X							2	AQ 4 Sub 1 Covered
adaptability	X		X	X		X	X	X						X	7	SE 1 Sub 3 Covered
administrability	X														1	AQ 1 Sub 3 Covered
affordability	X									X		X			3	SE 1 Sub 2 Covered
agility	X			X										X	3	SE 1 Sub 3 Covered
analysability								X							1	AQ 2 Sub 2.2 Covered
analytic extensibility											X				1	AQ 2 Sub 2.2 Covered
anticipation														X	1	AQ 3 Sub 3 Covered
applicability											X				1	SE 1 Sub 1 Covered
attractiveness								X							1	Discarded
auditability	X														1	AQ 4 Sub 3 Covered
autonomy														X	2	Discarded
availability	X	X				X			X			X			5	AQ 2 Sub 1 Covered
business horizontalization												X			1	Discarded
capacity												X			1	Discarded
capability	X														1	SE 1
changeability					X			X					X		3	AQ 3 Sub 2 Covered
clarity											X				1	AQ 2 Sub 2.2 Covered

	Literature Reference															
"ility"	Wikipedia, 2009	Haskins, 2006	Ross, Hastings, 2006	Ross, 2006	McManus, 2007	Voas, 2004	Dalgren, 2007	Bottella, 2004	SEI 2003	Daniels, 2005	Richards, 2006	Lehto, 2005	Ross, Rhodes, 2008	Schultz, 1999	Total Referenced	**Disposition**
co-existence								X							1	SE 3 Sub 2 Covered
communication															0	SE 3 Sub 1
commonality												X			1	SE 3 Sub 2 Covered
compatibility	X													X	2	SE 3 Sub 2 Covered
complexity															0	AQ 2 Sub 2.1 Covered
compliancy	X							X							2	AQ 4 Sub 1
composability	X														1	Discarded
configurability	X														1	AQ 3 Sub 2 Covered / SE Sub 3 Covered
consistency											X				1	AQ 4 Sub 4
constructability															0	SE 1 Sub 2 Covered
controllability												X			1	AQ 1 Sub 3
credibility	X														1	AQ 4 Sub 3 Covered
customizability	X														1	AQ 3 Sub 2 Covered
data integrity															0	AQ 4 Sub 4 Covered
decentralization														X	1	Discarded
degradability	X														1	SE 2 Sub 1.2 Covered
demonstrability	X														1	Discarded
dependability	X														1	SE 2 Sub 1
deployability	X														1	SE 1 Sub 2 Covered
diagnoseability															0	SE 2 Sub 2.2 Covered
distributability	X														1	AQ 1 Sub 1 Covered
durability	X			X											2	AQ 2 Sub 1 Covered

	Literature Reference															
"ility"	Wikipedia, 2009	Haskins, 2006	Ross, Hastings, 2006	Ross, 2006	McManus, 2007	Voas, 2004	Dalgren, 2007	Bottella, 2004	SEI 2003	Daniels, 2005	Richards, 2006	Lehto, 2005	Ross, Rhodes, 2008	Schultz, 1999	Total Referenced	**Disposition**
effectiveness															0	System Branch
efficiency						X		X							2	SE 1 Sub 2 Covered
environmental cost												X			1	SE 2 Sub 2 Covered
evolvability	X														1	AQ 3 Sub 3
executeability											X				1	SE 1 Sub 2 Covered
extensibility	X														2	AQ 3 Sub 1 Covered
fail safe				X											1	Discarded
fault tolerability						X		X				X			3	SE 2 Sub 1.2 Covered
feasibility															0	SE 1 Sub 2 Covered
fidelity	X														1	SE 2 Sub 1.2 Covered
flexibility	X		X	X	X		X			X		X	X	X	9	SE 1 Sub 3
functionality								X				X			2	SE 1 Sub 1 Covered
integrability														X	1	SE 3 Sub 2 Covered
installability	X							X				X			3	SE 1 Sub 2 Covered
interchangeability	X														1	SE 3 Sub 2
Internationalizability															0	SE 3 Sub 2 Covered
interoperability	X							X		X				X	4	SE 3
learnability	X							X				X			3	Discarded
longevity															0	AQ 2 Sub 1

	Literature Reference															
"ility"	Wikipedia, 2009	Haskins, 2006	Ross, Hastings, 2006	Ross, 2006	McManus, 2007	Voas, 2004	Dalgren, 2007	Bottella, 2004	SEI 2003	Daniels, 2005	Richards, 2006	Lehto, 2005	Ross, Rhodes, 2008	Schultz, 1999	Total Referenced	**Disposition**
maintainability	X	X		X		X		X				X			6	SE 2
manageability	X														1	AQ 1 Sub 3 Covered
manufacturability				X											1	SE 1 Sub 2 Covered
maturity								X							1	SE 1 Sub 2 Covered
mobility	X														1	SE 1 Sub 3 Covered
modifiability									X						1	AQ 3
modularity	X			X										X	3	SE 1 Sub 3 Covered
nomadicity	X														1	Discarded
openness															0	AQ 1 Sub 3 Covered
operability	X			X				X							3	SE 1 Sub 2 Covered
Performance									X			X			2	SE 1 Sub 1 Covered
Personalizability															0	AQ 3 Sub 2 Covered
portability	X					X		X							3	Discarded
practicality															0	SE 1 Sub 2
precision	X														1	AQ 4 Sub 1 Covered
predictability	X														1	Discarded
produceability															0	SE 1 Sub 2 Covered
profitability												X			1	Discarded
protectability															0	AQ1 Sub 2
purposefulness											X				1	SE 1 Sub 1
quality				X											1	Overall VDEA Score

	Literature Reference															
"ility"	Wikipedia, 2009	Haskins, 2006	Ross, Hastings, 2006	Ross, 2006	McManus, 2007	Voas, 2004	Dalgren, 2007	Bottella, 2004	SEI 2003	Daniels, 2005	Richards, 2006	Lehto, 2005	Ross, Rhodes, 2008	Schultz, 1999	Total Referenced	Disposition
readability															0	AQ 2 Sub 2.2
recoverability	X							X							2	SE 2 Sub 2.2
redundancy														X	1	SE 2 Sub 1.2 Covered
relevance	X														1	SE 1 Sub 1 Covered
reliability	X	X		X		X	X	X		X		X		X	9	SE 2 Sub 1.2
repairability				X								X			2	SE 2 Sub 1.1 Covered
repeatability	X														1	AQ 3 Sub 1 Covered
replaceability								X							1	SE 1 Sub 2 Covered
reproducibility	X														1	AQ 3 Sub 1 Covered
resiliency															0	SE 2 Sub 2
resource utilisation								X							1	SE 1 Sub 2 Covered
responsiveness	X														1	SE 1 Sub 3 Covered
reusability	X					X									2	AQ 3 Sub 2 Covered
robustness	X		X	X	X		X						X	X	7	SE 1 Sub 1 Covered
safety				X		X									2	SE 1 Sub 2 Covered
scalability	X		X	X	X	X	X				X		X	X	9	AQ 3 Sub 1
seamlessness	X														1	Discarded
securability	X									X					2	AQ 1 Sub 2 Covered
security						X		X	X						3	AQ 1 Sub 2 Covered
serviceability	X											X			2	SE 2 Sub 1.1 Covered
simplicity	X											X		X	3	AQ 2 Sub 2.1

"ility"	Literature Reference															Disposition
	Wikipedia, 2009	Haskins, 2006	Ross, Hastings, 2006	Ross, 2006	McManus, 2007	Voas, 2004	Dalgren, 2007	Bottella, 2004	SEI 2003	Daniels, 2005	Richards, 2006	Lehto, 2005	Ross, Rhodes, 2008	Schultz, 1999	Total Referenced	
stability	X							X							2	SE 2 Sub 1.2 Covered
standardization															0	AQ 4 Sub 1 Covered
stakeholder involvement															0	AQ 4 Sub 2 (translated to SME Input value)
subscribability															0	AQ 1 Sub 1
supportability		X													1	SE 2 Sub 1.1
survivability	X				X										2	SE 2 Sub 2.1
susceptability															0	SE 2 Sub 2.1 Covered
sustainability	X			X		X									3	SE 2 Sub 1.1 Covered
suitability								X							1	SE 1 Sub 2 Covered
tailorability	X														1	AQ 3 Sub 2
testability	X			X		X		X		X		X			6	Discarded
timeliness	X							X				X			3	Discarded
traceability															0	AQ 4 Sub 3
trainability															0	Discarded
transactionality															0	Discarded
understandability	X							X							2	AQ 2 Sub 2
Upgradeability							X								1	AQ 3 Sub 3 Covered
usability	X					X		X	X						4	AQ 4
utility															0	SE 1 Sub 1 Covered
vulnerability		X													1	AQ 1 Sub 2 Covered
versatility					X								X		2	SE 1 Sub 3 Covered
Total in Reference	61	5	4	17	6	14	6	28	5	6	8	21	5	15		

Appendix B. VDEA-Score Evaluation Sheet

Accessibility

Subscribability

	Access					
1	Do stakeholders have electronic access to products?	No means to gain access	> 1 week to gain access	3 days < access granted < 1 week	5 mins < access granted < 3 days	access granted < 5 mins
	Product Locatability					
2	Can stakeholders easily locate electronic products?	Can not locate products	> 5 minutes to locate products	< 5 minutes to locate products		
	Protectability					
	Access Control					
3	Are access control measures implemented to appropriate level of protection?	No plan or plan inadequate	Plan exists, but not implemented	Appropriate protection implemented		
	Controllability					
	Document Protection					
4	Are the products appropriately write protected?	No plan for write protection	Plan exists, but not implemented	Plan exists, all products controlled		

Usability

Longevity

	File Management				
5	Has an official file management system for keeping products been established?	No official file management system	System exists, but incomplete/not maintained	System exists with all products and is maintained	
	File Format				
6	To what degree is there a reasonable expectation that the electronic products will be available in the future?	No electronic products or no longer accessible	Only accessible with one type of proprietary software	File format proprietary but available to common viewer	Accessible through open source applications
	Understandability				
	Simplicity				
	Connections				
7	What percentage of products contain links between entities that are easy to understand?	Percentage			
	Architecture Redundancy				
8	What is the ratio of unnecessary duplication per items of information?	> 1 : 10	Between 1 : 10 and 1 : 100	Between 1: 100 and 1: 500	Between 0 and 1: 500
	Architecture Economy				
9	Are multiple steps unnecessarily being used to represent the same activity?	No	Yes		
	Readability				
	OV Readability				
10	What percentage of Operational Views are presented clearly and concisely?	Percentage			
	SV Readability				
11	What percentage of System Views are presented clearly and concisely?	Percentage			

Modifiability

	Scalability				
	Scale				
12	Can architecture scale be doubled while retaining its desired function	No views could be doubled	Some views could be doubled	Most views could be doubled	All views could be doubled
	Tailorability				
	Decomposition				
13	How many levels of decomposition are present in OV-5?	None	1 level	2 levels	3+ levels
	Evolvability				
	Tool Format				
14	In general, to what degree are products developed with a tool that enforces DoDAF view consistency and allows for easy editing?	The product has to be completely rebuilt	One input gets reflected in single reference (e.g. no find and replace in .ppt)	One input gets reflected in instant view references but not other views (e.g. word)	One input gets reflected in all relevant views (e.g. System Architect)

Accountability						
	Compliancy					
	DoDAF Compliancy					
15	What percentage of architecture products comply with DoDAF standards?	Percentage				
	Traceability					
	Traceability					
16	What percentage of requirements are met by functions/activities (evaluate SV-5)?	Percentage				
	Consistency					
	Internal Consistency					
17	What percentage of available architecture products have no internal inconsistencies?	Percentage				
	External Consistency					
18	What percentage of available architecture products have no external inconsistencies?	Percentage				
	SME Input					
	SME Effectiveness					
19	How effective are SME's in architecture development?	No Plan	Plan exists, but no SME's identified	SME's identified	Id'd SME's with average <5 yrs exp	Id'd SME's with average >5 yrs exp
	SME Involvement					
20	How many SMEs across different stakeholder organizations are involved with architecture	None	One stakeholder organization	Two stakeholder organizations	Three stakeholder organizations	More than four stakeholder organizations

Appendix C. Measure Summary Table

This table provides a summary of the *Architecture Quality Value* branch measures.

Table 14. Measure Summary Table

Value	Measure	SDVF Type	Min	Max
Subscribability	ACCESS	Category	No Access	Access < 5 min.
Subscribability	PRODUCT LOCATABILITY	Category	Cannot locate	< 5 min to locate
Protectability	ACCESS CONTROL	Category	No protection/ No plan	Appropriate protection
Controllability	DOCUMENT PROTECTION	Category	No write protection	All products controlled
Longevity	FILE MANAGEMENT	Category	No system	Current system
Longevity	FILE FORMAT	Category	Not electronic	General File Format
Simplicity	CONNECTIONS (Percentage)	Monotonically Increasing Exponential	0%	100%
Simplicity	ARCHITECTURE REDUNDANCY	Category	1 found in <10 entities	1 found in >500 entities
Simplicity	ARCHITECTURE ECONOMY	Binary	Yes (found)	None found
Readability	OV READABILITY (Percentage)	Monotonically Increasing S-Curve	Not Readable	All Easy to Read
Readability	SV READABILITY (Percentage)	Monotonically Increasing S-Curve	Not Readable	All Easy to Read
Scalability	SCALE	Category	No views can be scaled 2X	All views can be scaled 2X
Tailorability	DECOMPOSITION	Category	None	3+ levels
Evolvability	TOOL FORMAT	Category	Complete product rebuild	One input carries thru multi views
Compliancy	DODAF COMPLIANCY (Percentage)	Monotonically Increasing Linear	0%	100%
Traceability	REQUIREMENT TRACEABILITY (Percentage)	Monotonically Increasing Exponential	0% (No SV-5)	100% (Complete, Validated SV-5)
Consistency	INTERNAL CONSISTENCY (Percentage)	Monotonically Increasing S-Curve	0%	100%
Consistency	EXTERNAL CONSISTENCY (Percentage)	Monotonically Increasing S-Curve	0%	100%
SME Input	SME EFFECTIVENESS	Category	No plan to involve SME's	SMEs id'd with 5+ yrs. experience
SME Input	SME INVOLVEMENT	Category	None	Multiple SME's/ multiple orgs

Appendix D. System Effectiveness Weighted Hierarchy

Figure 59 shows the Tier I *System Effectiveness Value* branch hierarchy with local and global weights.

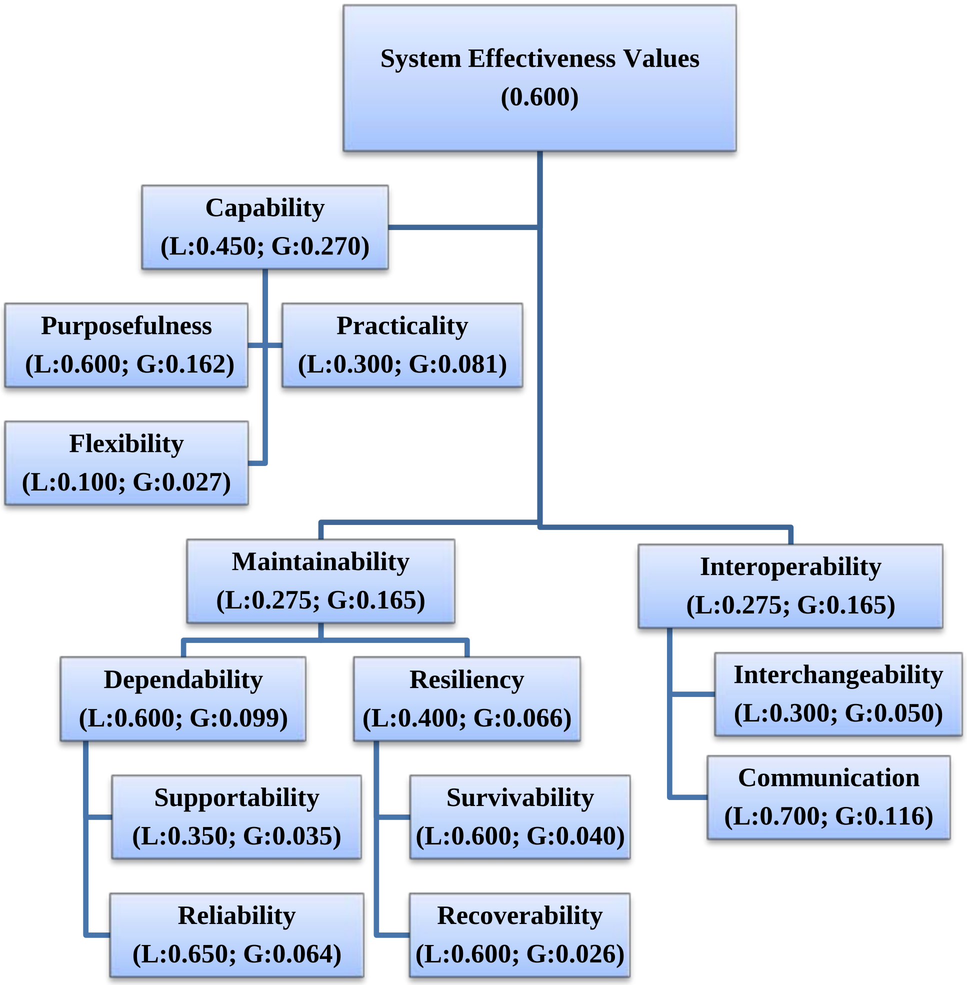

Figure 59. Weighted System Effectiveness Value Branch

Appendix E. Measurement Analysis Graphs

As discussed in Chapter IV, the following graphs represent the measurement analyses performed by varying the results for each measure from lowest possible assessment to highest possible assessment. The graphs are presented in order.

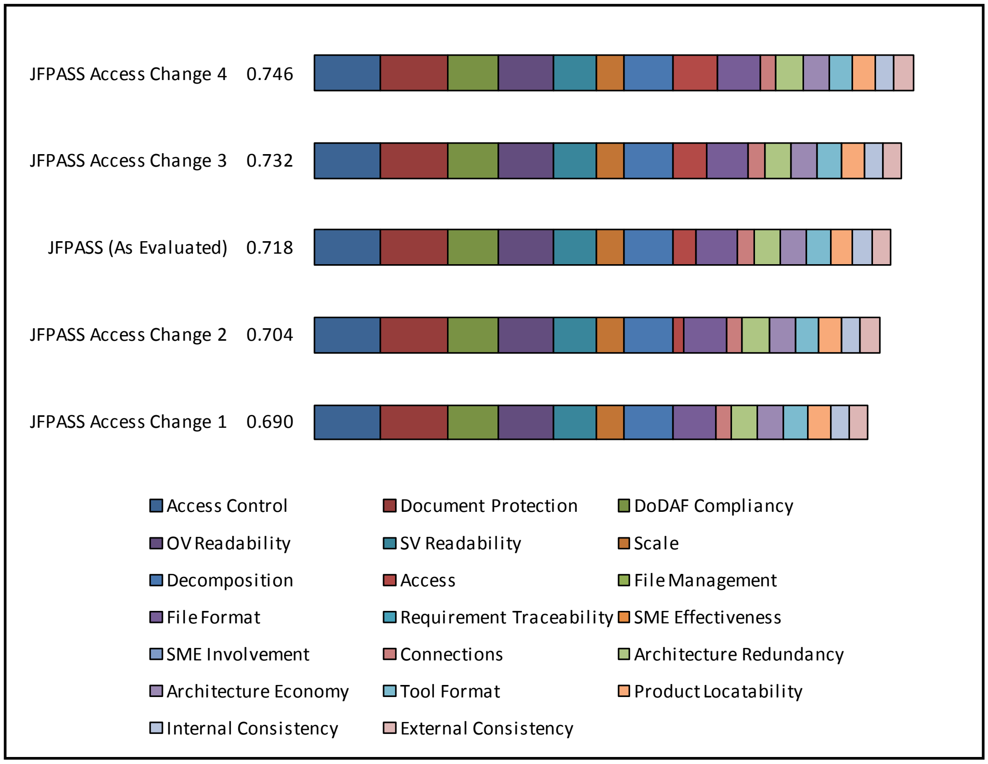

Figure 60. Access Measurement Analysis

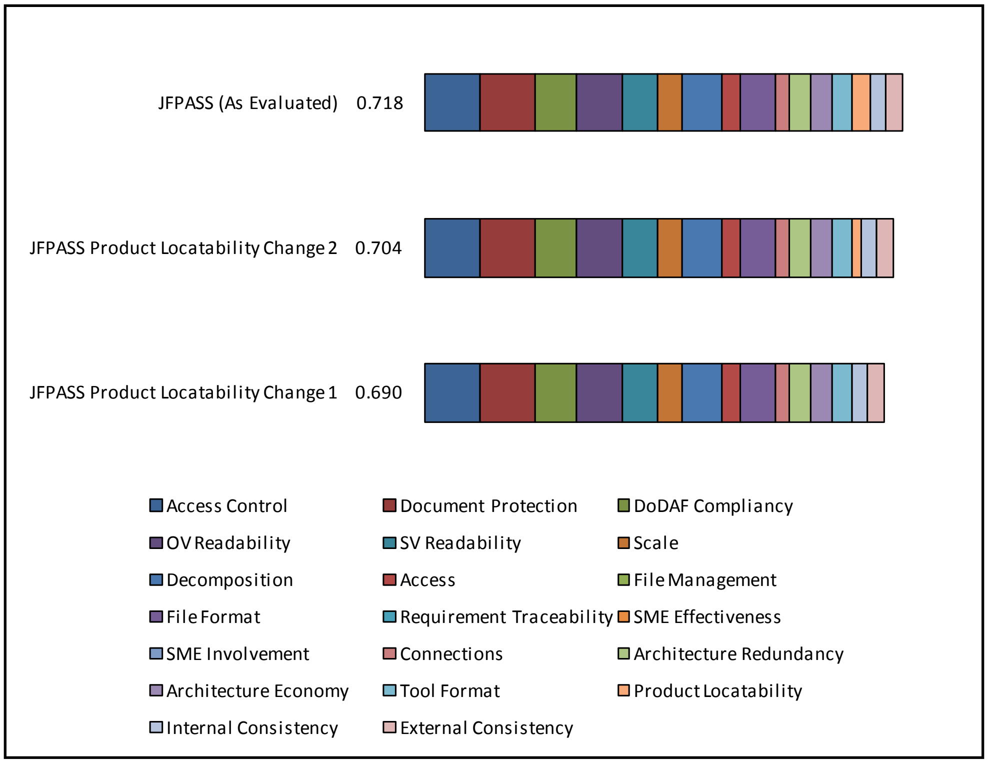

Figure 61. Product Locatability Measurement Analysis

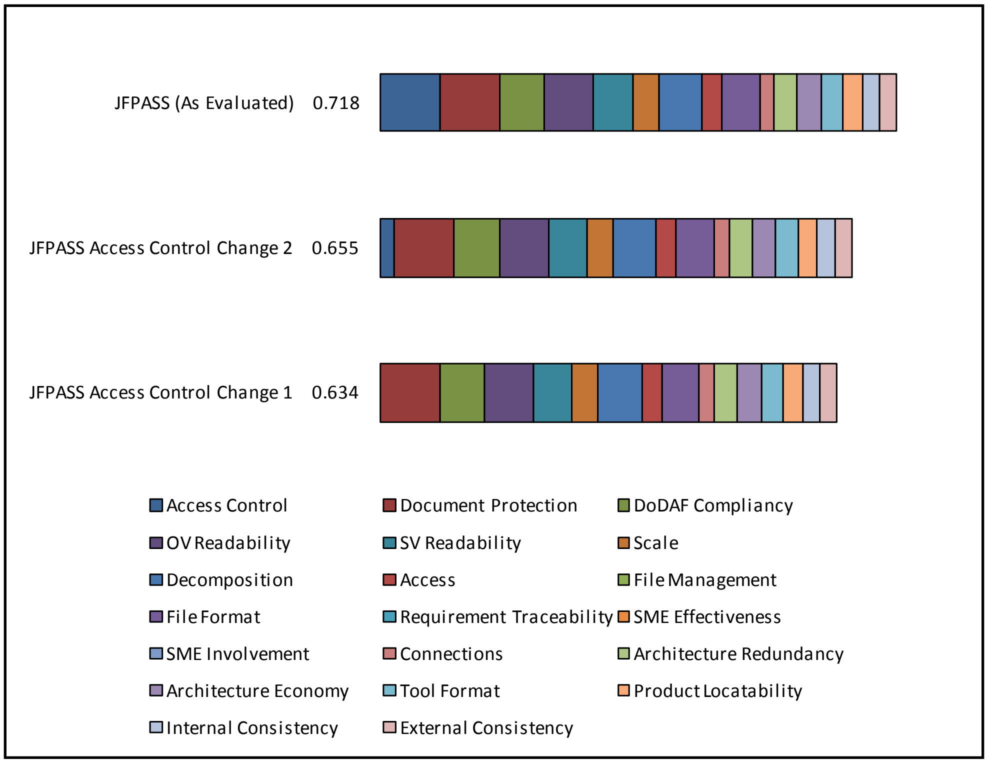

Figure 62. Access Control Measurement Analysis

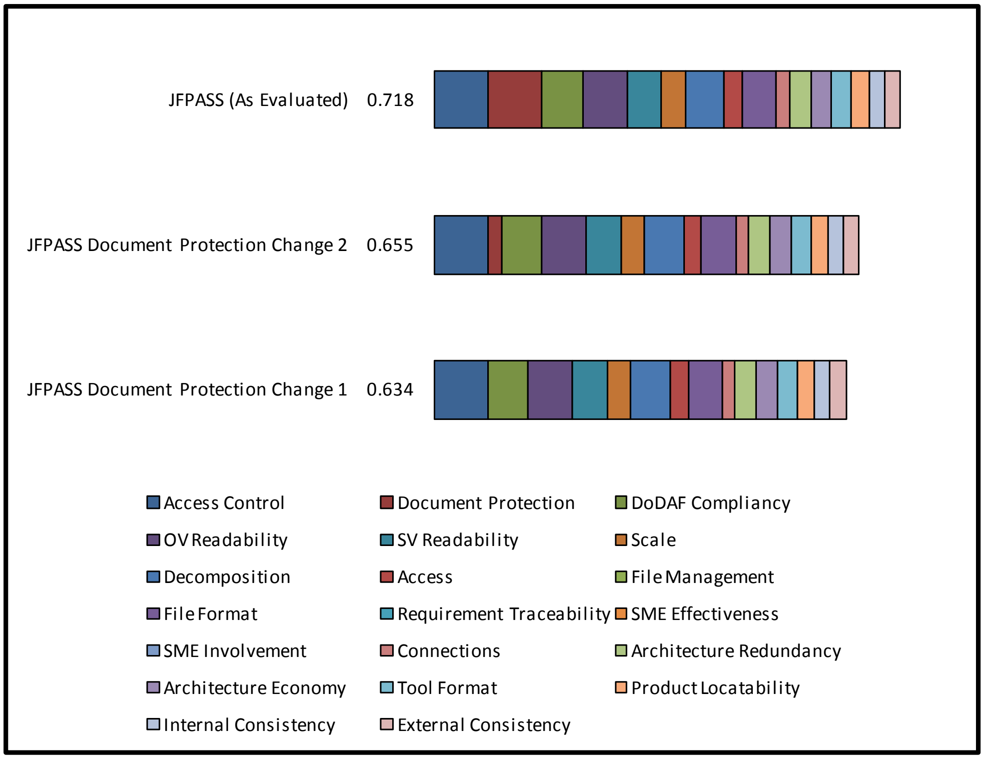

Figure 63. Document Protection Measurement Analysis

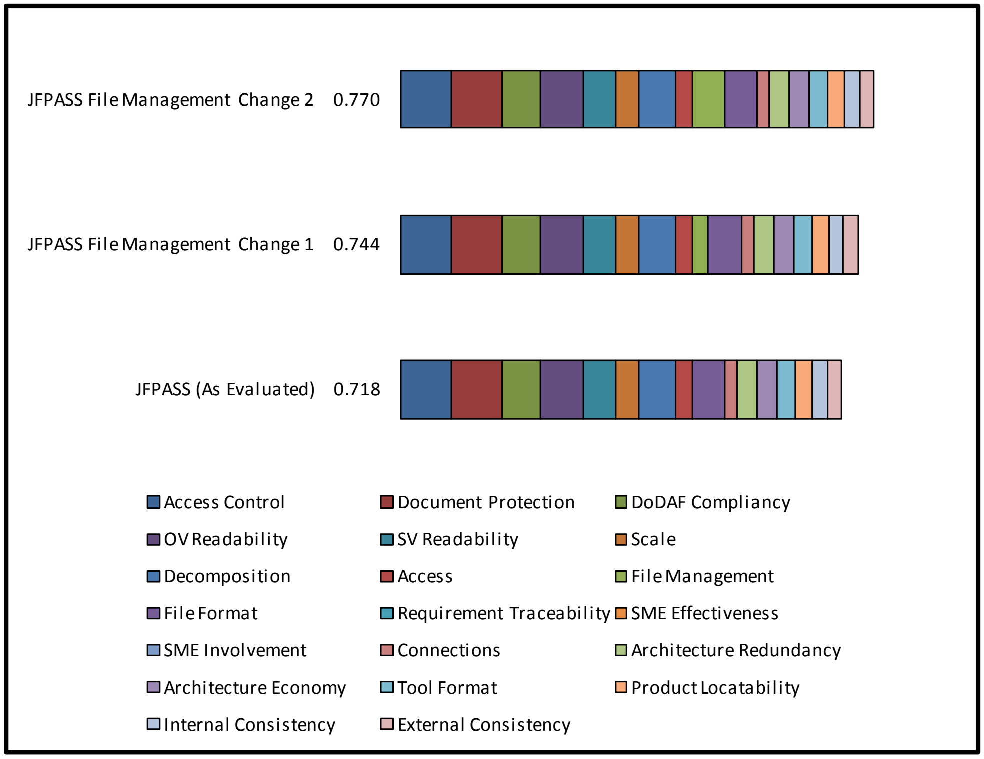

Figure 64. File Management Measurement Analysis

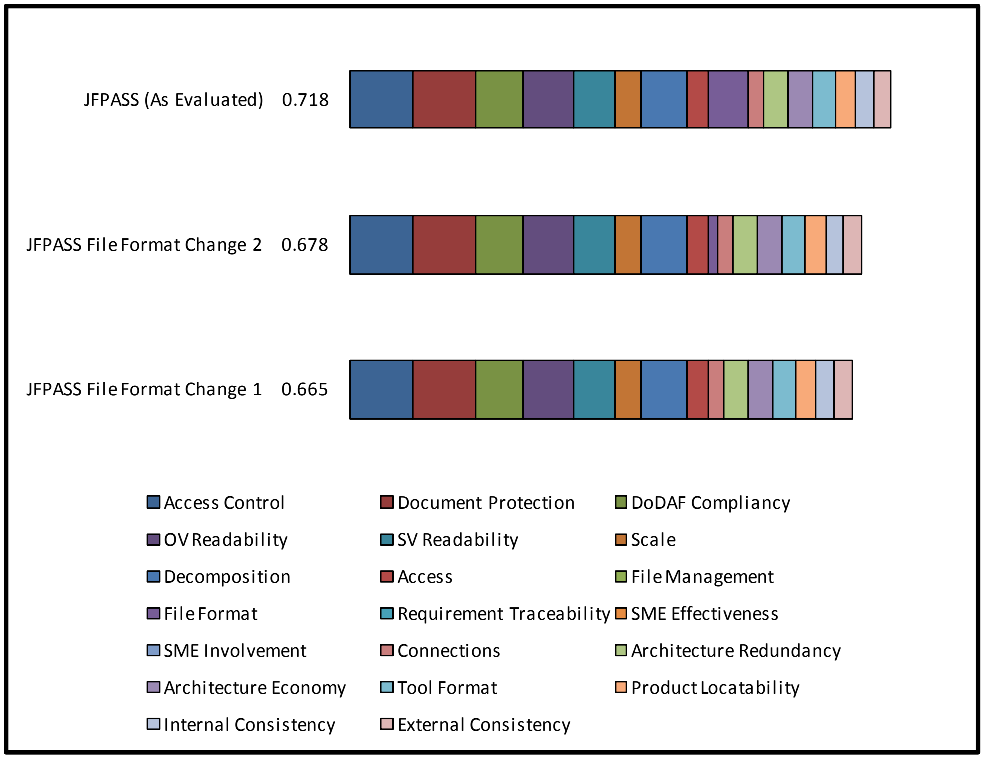

Figure 65. File Format Measurement Analysis

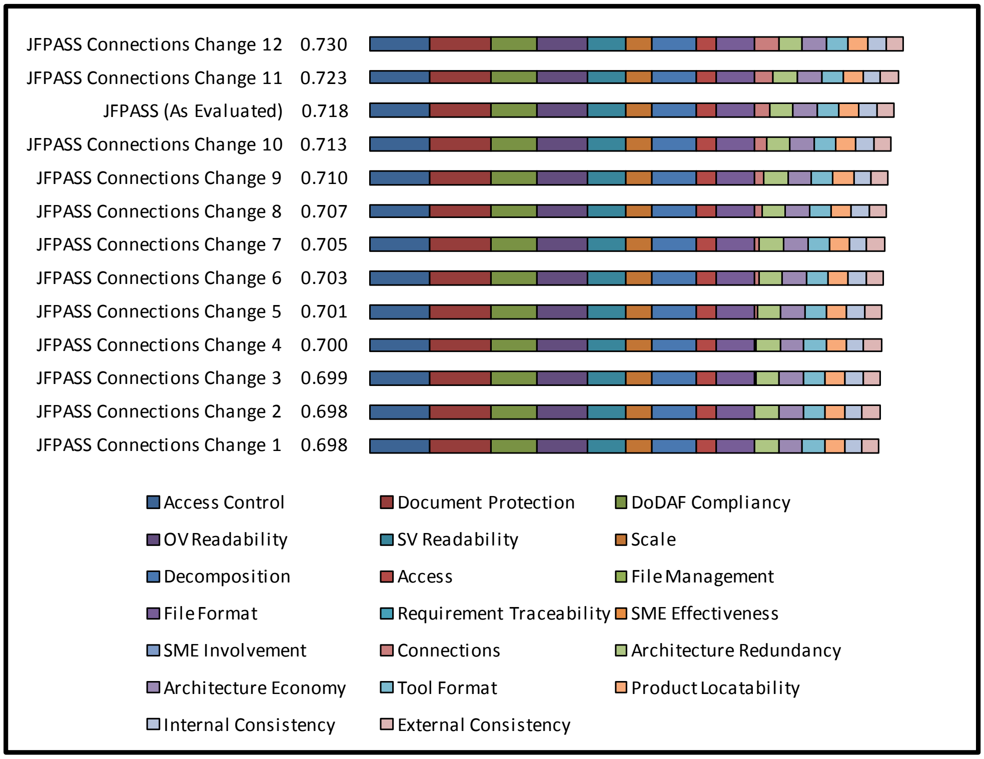

Figure 66. Connections Measurement Analysis

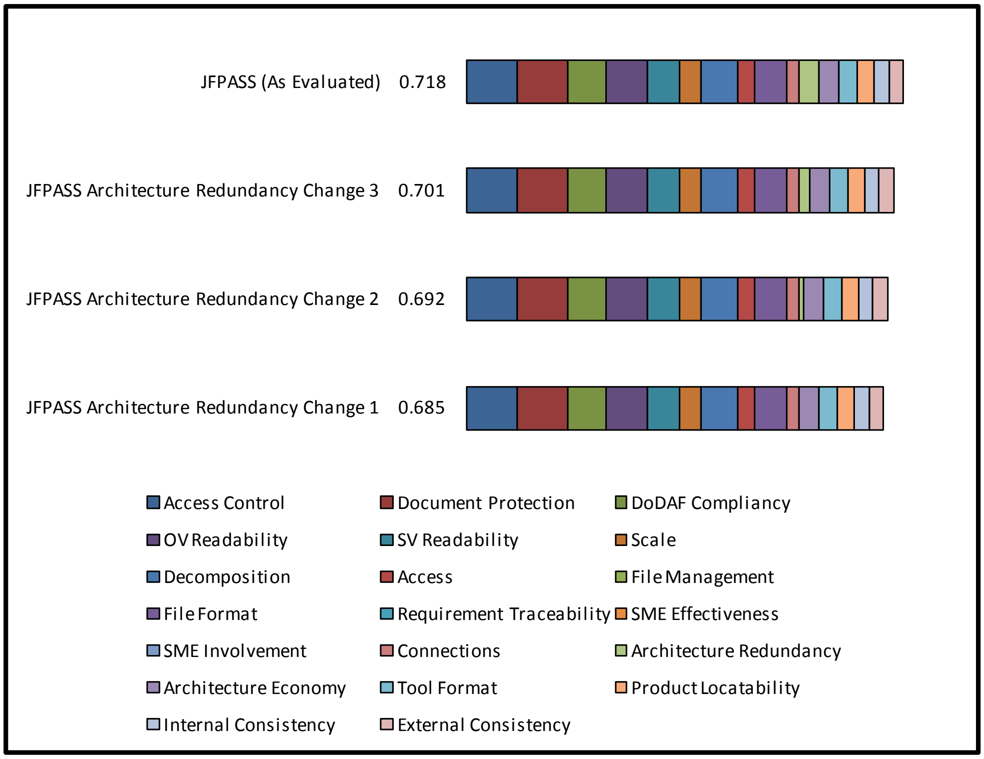

Figure 67. Architecture Redundancy Measurement Analysis

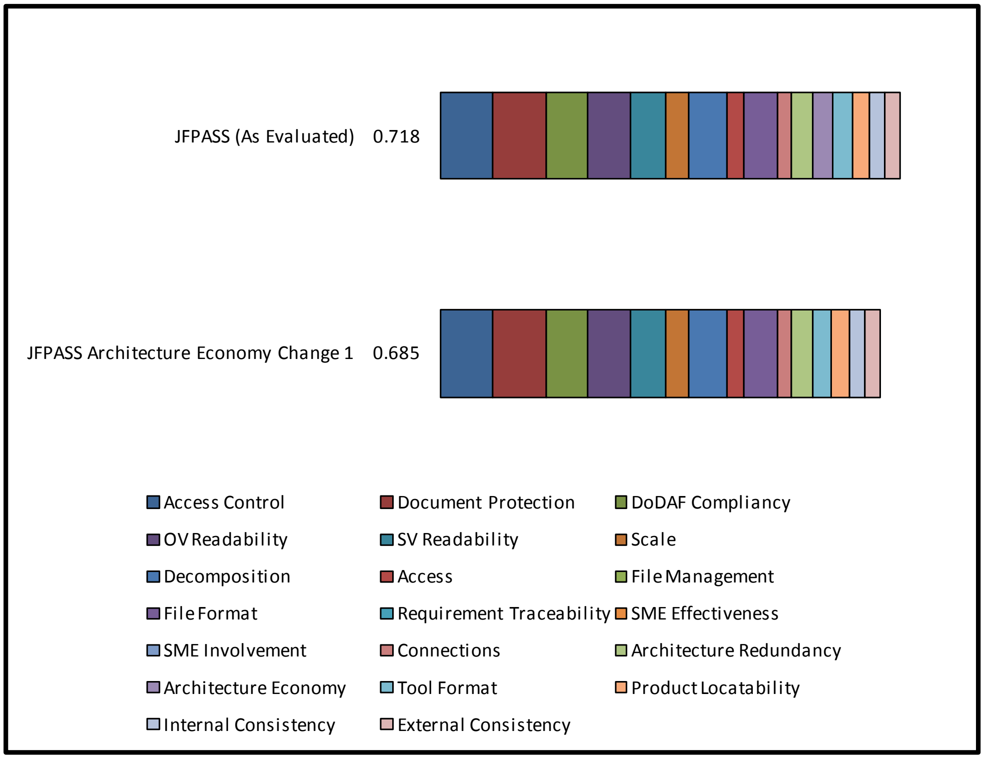

Figure 68. Architecture Economy Measurement Analysis

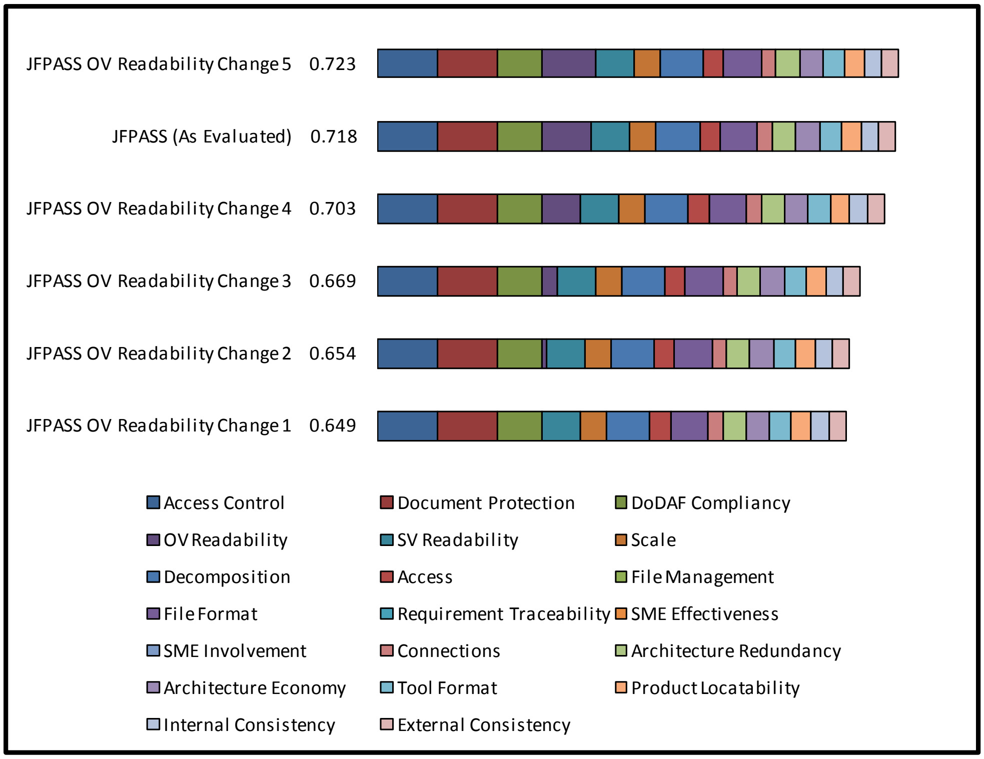

Figure 69. OV Readability Measurement Analysis

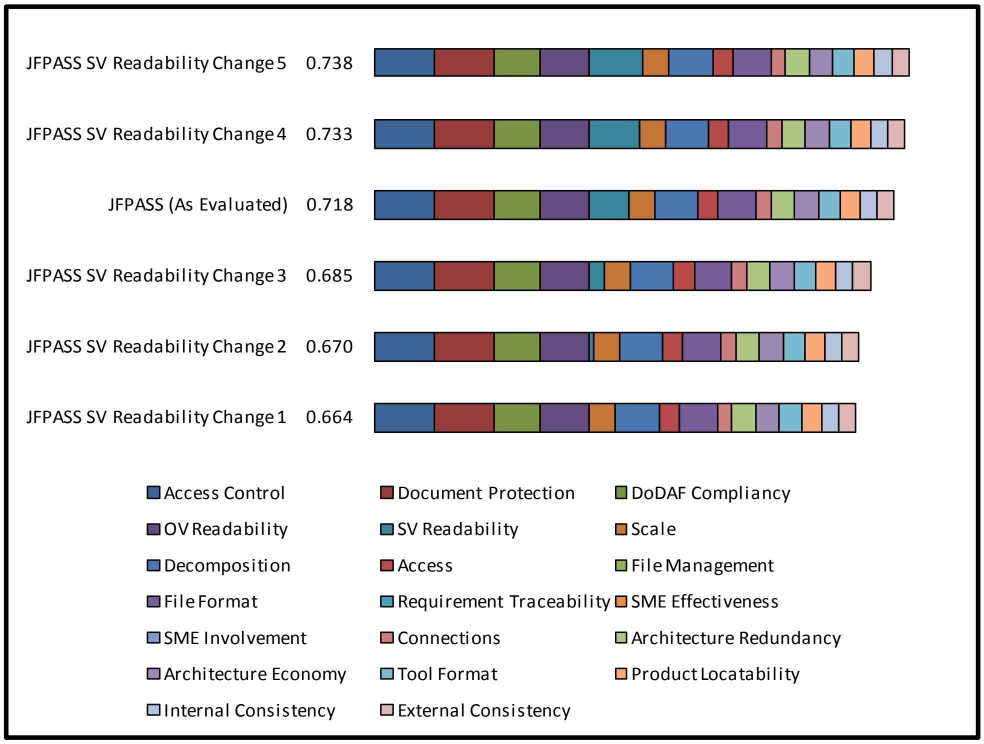

Figure 70. SV Readability Measurement Analysis

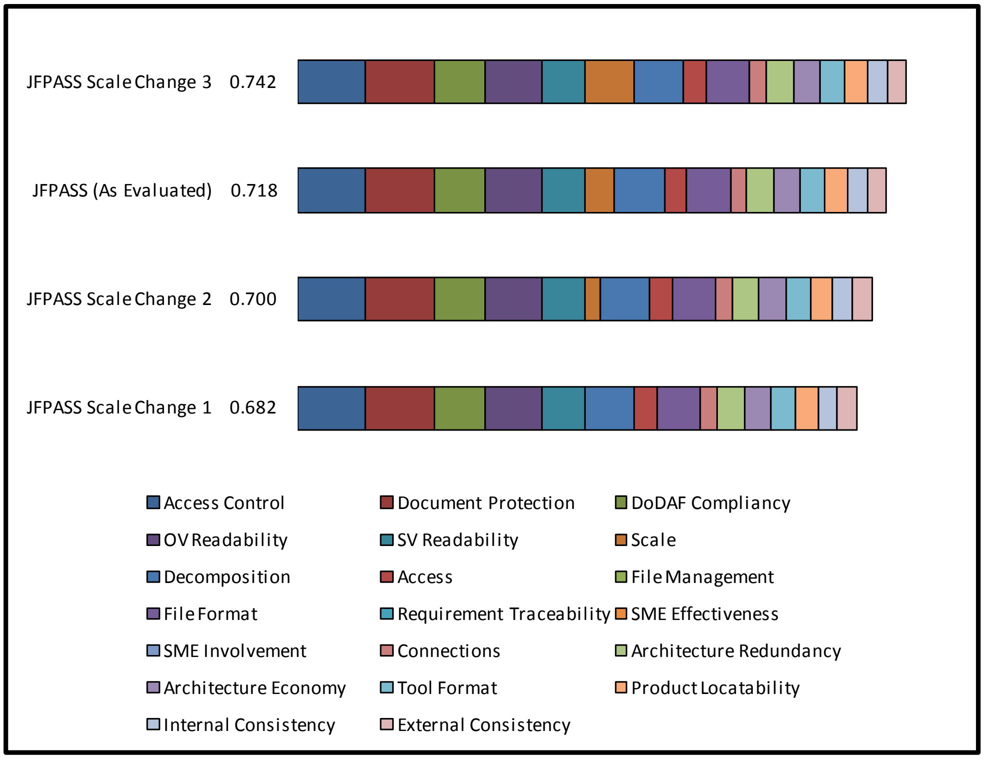

Figure 71. Scale Measurement Analsysis

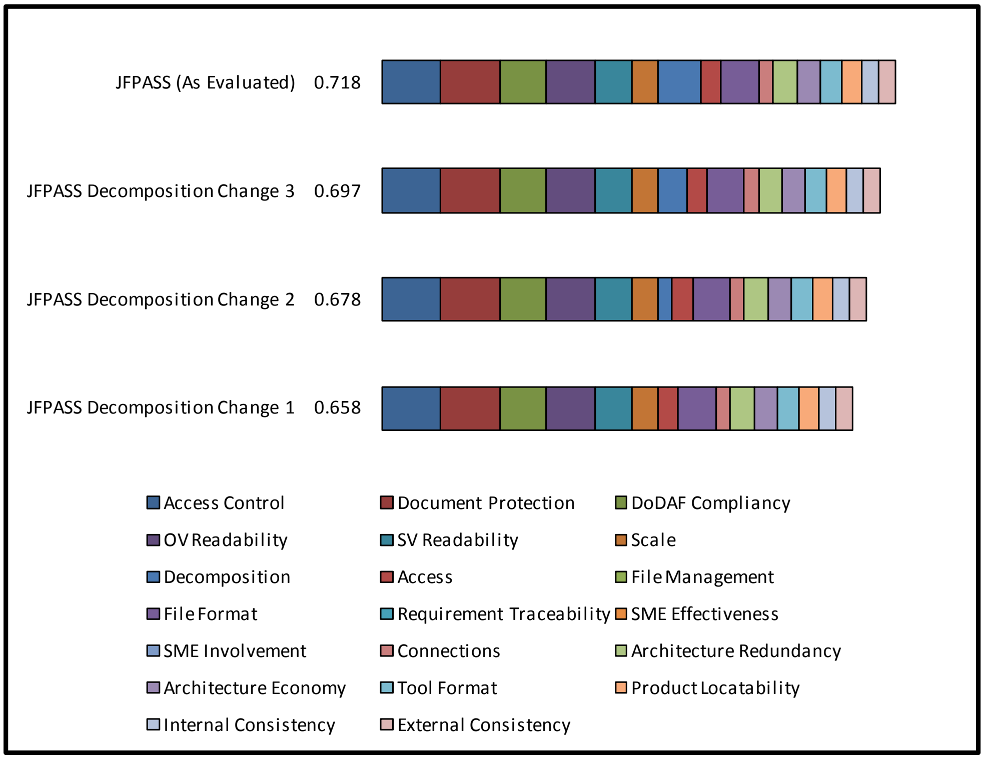

Figure 72. Decomposition Measurement Analysis

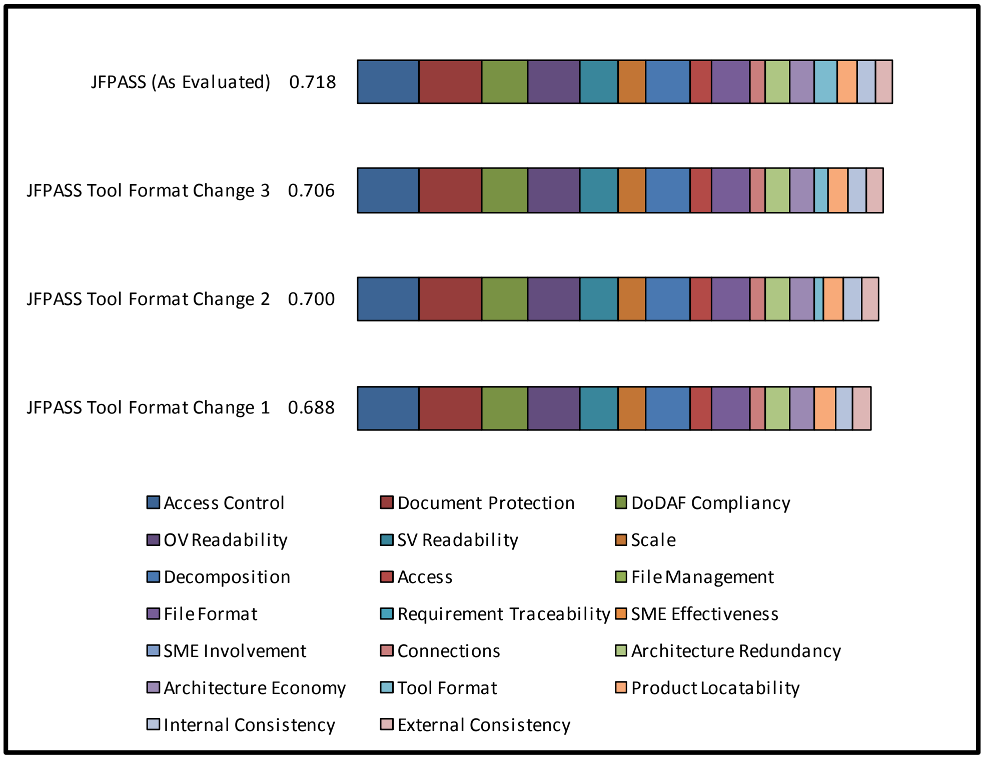

Figure 73. Tool Format Measurement Analysis

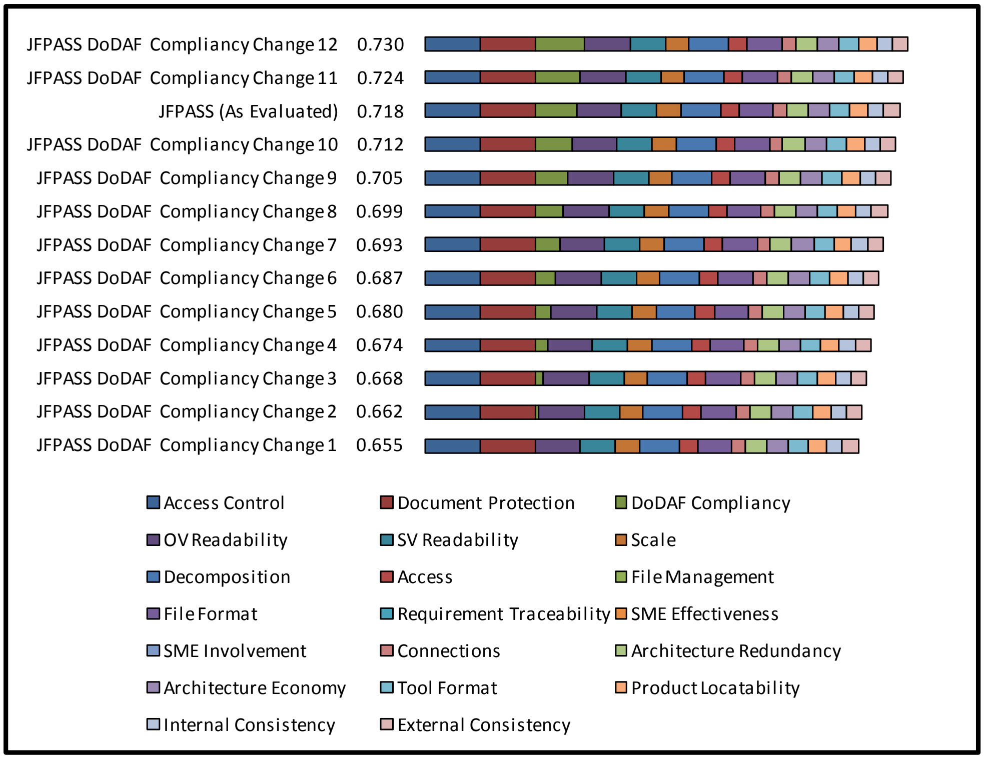

Figure 74. DoDAF Compliancy Measurement Analysis

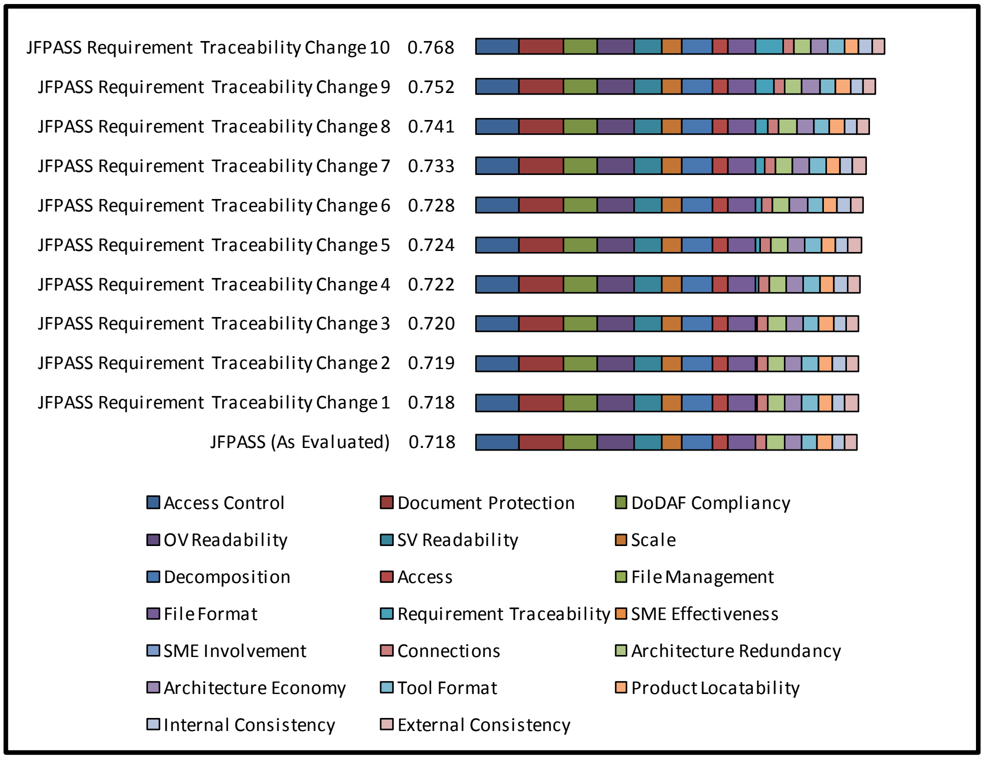

Figure 75. Requirement Traceability Measurement Analysis

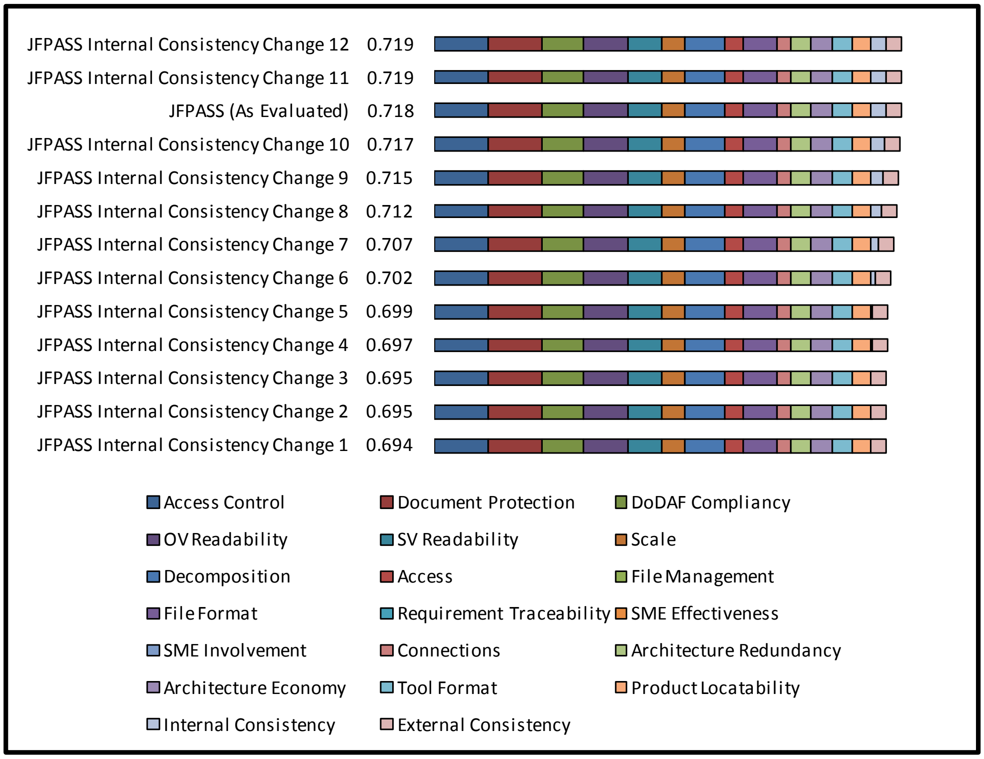

Figure 76. Internal Consistency Measurement Analysis

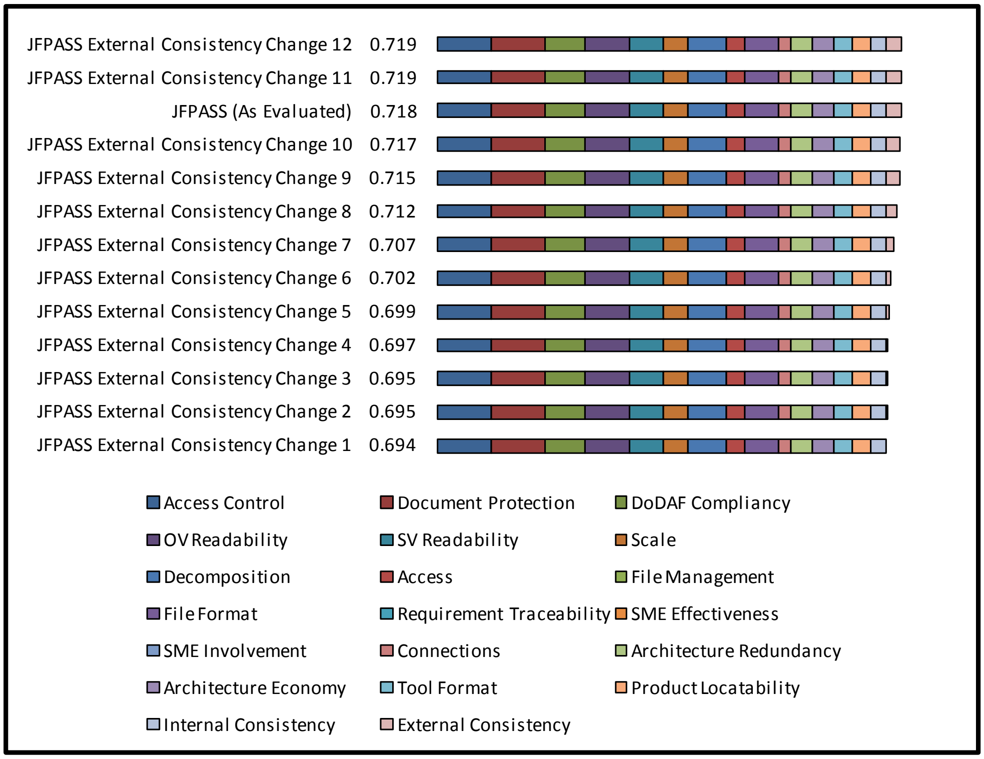

Figure 77. External Consistency Measurement Analysis

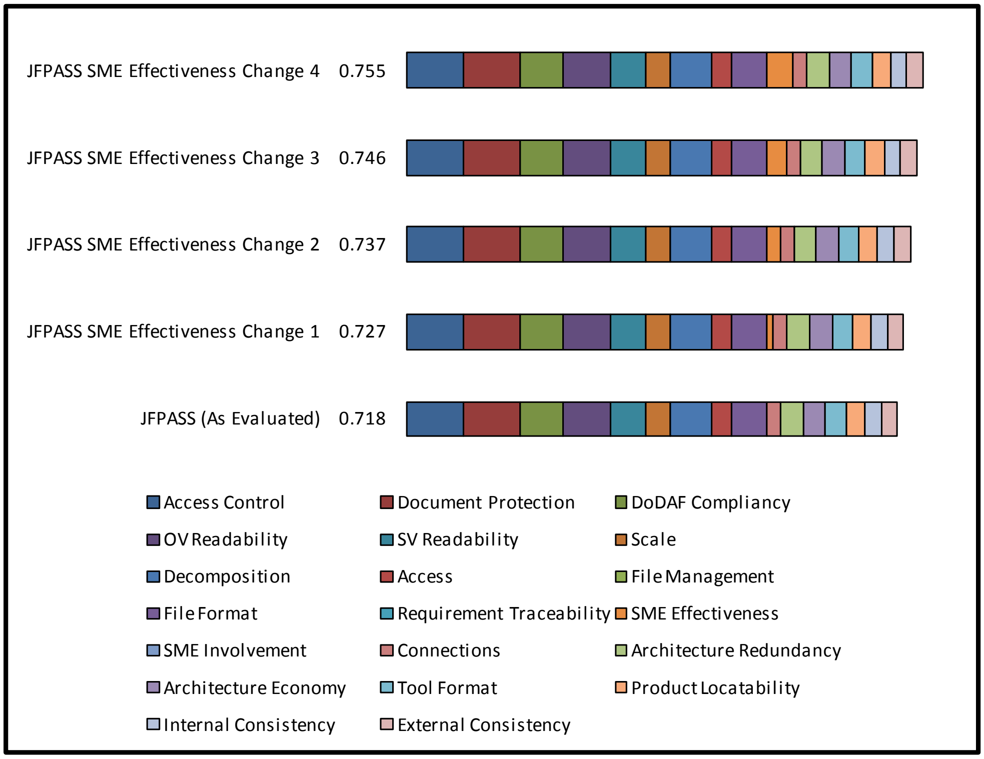

Figure 78. SME Effectiveness Measurement Analysis

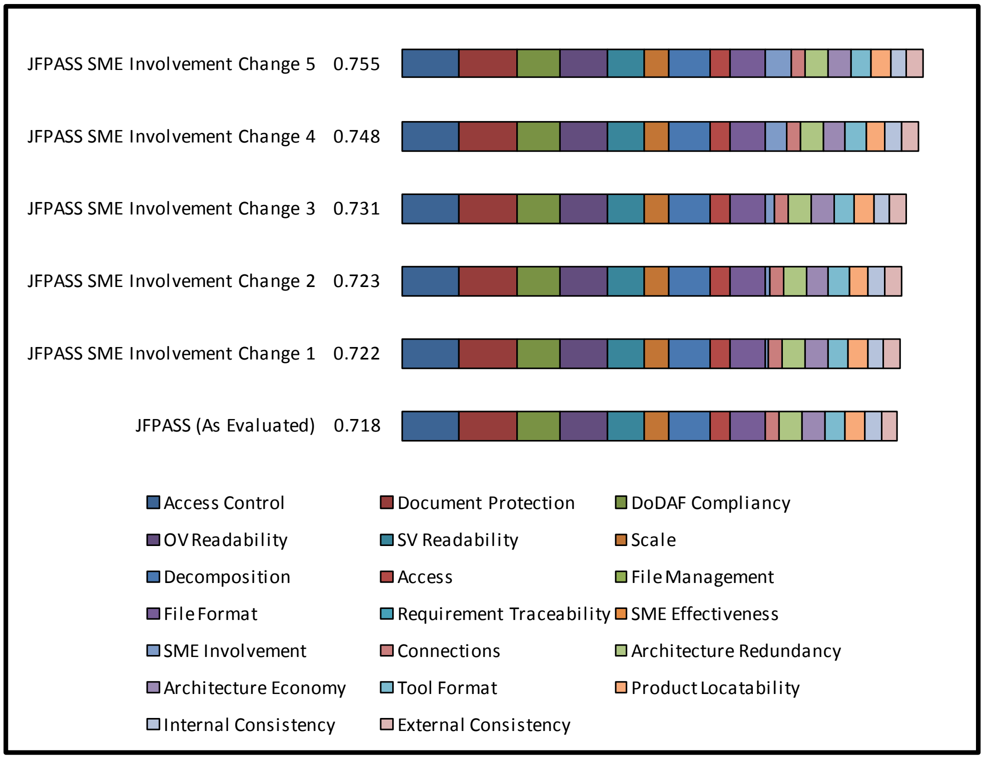

Figure 79. SME Involvement Measurement Analysis

Appendix F. Weight Sensitivity Analysis Summary Tables

Tables 15 through 18 summarize the weight sensitivity analysis results for each of the values and measures. The ‘Max Negative Change’ and ‘Max Positive Change’ columns represent how the overall score would be affected if the weight was adjusted in either direction. For example, the value *Accessibility* has a local weight of 0.250. Decreasing its weight towards zero would eliminate it as one of the second-tier values and lower the overall possible *Architecture Quality Values* from 0.718 to 0.660 points. Increasing the weight to one, thus making *Accessibility* the only second-tier value, would raise the overall *Architecture Quality Values* score to 0.880 points. Note that no change occurred for REQUIREMENT TRACEABILITY, SME EFFECTIVENESS, and SME INVOLVEMENT because their parent values of *Traceability* and *SME Input* both earned zero value. Similarly, the results for *Consistency* did not change because INTERNAL and EXTERNAL CONSISTENCY scored the same and had equal weights.

Table 15. Accessibility Sensitivity Results

	Assigned $\lambda_{i-local}$	Sensitivity Line Slope	Max Negative Effect		Max Positive Effect	
			$\lambda_{i-local}$	$\| v_{AQ-New} - v_{AQ-Base} \|$	$\lambda_{i-local}$	$\| v_{AQ-New} - v_{AQ-Base} \|$
Accessibility	0.250	+0.220	0.000	-0.060	1.000	+0.160
Subscribability	0.330	-0.090	1.000	-0.070	0.000	+0.020
Access	0.667	-0.040	1.000	-0.020	0.000	+0.020
Product Locatability	0.333	+0.050	0.000	-0.020	1.000	+0.030
Controllability	0.330	+0.040	0.000	-0.020	1.000	+0.020
Document Protection	1.000	+0.080	0.000	-0.080	1.000	No Change
Protectability	0.330	+0.040	0.000	-0.020	1.000	+0.020
Access Control	1.000	+0.080	0.000	-0.080	1.000	No Change

Table 16. Usability Sensitivity Results

	Assigned $\lambda_{i-local}$	Sensitivity Line Slope	Max Negative Effect		Max Positive Effect	
			$\lambda_{i-local}$	$\| v_{AQ-New} - v_{AQ-Base} \|$	$\lambda_{i-local}$	$\| v_{AQ-New} - v_{AQ-Base} \|$
Usability	0.350	+0.038	0.000	-0.014	1.000	+0.024
Longevity	0.300	-0.130	1.000	-0.100	0.000	+0.030
File Management	0.500	-0.100	1.000	-0.060	0.000	+0.040
File Format	0.500	+0.100	0.000	-0.060	1.000	+0.040
Understandabilty	0.700	+0.120	0.000	-0.080	1.000	+0.040
Simplicity	0.400	+0.020	0.000	-0.010	1.000	+0.010
Connections	0.330	-0.040	1.000	-0.030	0.000	+0.010
Architecture Redundancy	0.330	+0.020	0.000	-0.010	1.000	+0.010
Architecture Economy	0.330	+0.020	0.000	-0.010	1.000	+0.010
Readability	0.600	-0.020	1.000	-0.010	0.000	+0.010
OV Readability	0.500	+0.040	0.000	-0.020	1.000	+0.020
SV Readability	0.500	-0.030	1.000	-0.020	0.000	+0.010

Table 17. Modifiability Sensitivity Results

	Assigned $\lambda_{i-local}$	Sensitivity Line Slope	Max Negative Effect		Max Positive Effect	
			$\lambda_{i-local}$	$\| v_{AQ-New} - v_{AQ-Base} \|$	$\lambda_{i-local}$	$\| v_{AQ-New} - v_{AQ-Base} \|$
Modifiability	0.150	+0.140	0.000	-0.020	1.000	+0.120
Scalability	0.400	-0.060	1.000	-0.020	0.000	+0.030
Scale	1.000	+0.040	0.000	-0.040	1.000	No Change
Tailorability	0.400	+0.040	0.000	-0.020	1.000	+0.020
Decomposition	1.000	+0.060	0.000	-0.060	1.000	No Change
Evolvability	0.200	+0.030	0.000	-0.010	1.000	+0.020
Tool Format	1.000	+0.030	0.000	-0.030	1.000	No Change

Table 18. Accountability Sensitivity Results

	Assigned $\lambda_{i-local}$	Sensitivity Line Slope	Max Negative Effect		Max Positive Effect	
			$\lambda_{i-local}$	$\lVert v_{AQ-New} - v_{AQ-Base} \rVert$	$\lambda_{i-local}$	$\lVert v_{AQ-New} - v_{AQ-Base} \rVert$
Accountability	0.250	-0.370	1.000	-0.270	0.000	+0.080
Compliancy	0.300	+0.140	0.000	-0.040	1.000	+0.100
DoDAF Compliancy	1.000	+0.070	0.000	-0.070	1.000	No Change
Traceability	0.200	-0.130	1.000	-0.100	0.000	+0.030
Requirements Traceability	1.000	0.000	0.000	No Change	1.000	No Change
Consistency	0.200	+0.140	0.000	-0.030	1.000	+0.110
Internal Consistency	0.500	0.000	0.000	No Change	1.000	No Change
External Consistency	0.500	0.000	0.000	No Change	1.000	No Change
SME Input	0.300	-0.160	1.000	-0.100	0.000	+0.060
SME Effectiveness	0.500	0.000	0.000	No Change	1.000	No Change
SME Involvement	0.500	0.000	0.000	No Change	1.000	No Change

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14. ABSTRACT

This research presents a methodology to evaluate the quality of a system's architecture using principles drawn from Value-Focused Thinking (VFT) and resulting in a Value-Driven Enterprise Architecture Score (VDEA-Score). This is an overall numerical architecture quality score useful to a system's management team to identify the advantages and disadvantages of a system design and associated architecture documentation or to track its quality across discrete evaluation epochs. This effort determined which aspects of the architecture are most valuable to the stakeholder in the areas of (1) the system effectiveness values (quality of the instantiated system being represented and its ability to perform its stated mission) and (2) the architecture quality values (intrinsic quality of the products themselves in terms of documentation standards and desired attributes). The results are reported across three theses. In this thesis, the architecture documentation quality aspects are specifically addressed by examining various "ilities" (e.g., usability, modifiability, accessibility, etc.) regarded as essential to any architecture. The evaluation methodology was tested against architectures from two enterprises including the sponsor's enterprise of joint force protection. An overall architecture documentation quality score is reported for both enterprises useful for identifying areas for potential improvement.

15. SUBJECT TERMS

Value Driven Enterprise Architecture Score (VDEA-Score), Value-Focused Thinking (VFT), Architecture Evaluation, Architecture Quality, ilities

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