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Value-Driven Enterprise Architecture Evaluation for the Joint Force Protection Advanced Security System

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VALUE-DRIVEN ENTERPRISE ARCHITECTURE EVALUATION FOR THE JOINT FORCE PROTECTION ADVANCED SECURITY SYSTEM

THESIS

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AFIT/GEM/ENV/09-M13

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THESIS

Presented to the Faculty
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In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Engineering Management

Craig Mills
Captain, USAF

March 2009

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Abstract

The U.S. military has placed a strong focus on the importance of operating in a joint environment, where capabilities and missions are shared between service components. Protecting U.S. forces is a major consideration in the joint environment. The Joint Force Protection Advanced Security System (JFPASS) architecture has been created to fill a critical gap in Joint Force Protection guidance for systems acquisition. The systems engineering (SE) field has made wide use of system architectures to represent complex systems. As fundamental SE principles become more widespread, analysis tools provide an objective method for the evaluation of the resulting architectural products.

This study used decision analysis to develop a standardized, yet adaptable and repeatable model to evaluate the capabilities of the JFPASS for any installation or facility belonging to the United States Department of Defense (DoD). Using the Value-Focused Thinking (VFT) methods, a value hierarchy was created by consulting with subject matter experts. The resulting model, named Value-Driven Enterprise Architecture (VDEA) score, provides an analysis tool, which enables DoD decision-makers to use JFPASS architecture products to quickly and easily evaluate the value provided by the system; VDEA provides insight into the overall quality and capability of the system. Through the scoring and sensitivity analysis functions, capability gaps and potential improvements can be identified. Future studies in this area will provide a vehicle for rating not only operational level systems, but also individual functional projects against other alternatives.

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Chapter 1. Introduction

The Joint Force Protection Advanced Security System (JFPASS) has been created to solve the prominent problem in today's military of protecting troops in a joint environment. There currently is not a comprehensive method to determine both the quality of architectural products and of the instantiated system. The Value-Driven Enterprise Architecture (VDEA) evaluation tool was created to fill this critical requirement.

1.1 General Background

Force protection has taken a prominent role in today's environment, following the attacks on the World Trade Center and Pentagon, the United States military has been deployed in a new kind of warfare. Given the unprecedented warfare tactics (irregular warfare) being employed by the enemy, protecting personnel and assets is just as important now as it has ever been. To combat the threats facing the U.S. military, a new emphasis has been placed on joint operations in which joint warfighting are essential to the current military culture. Therefore, the U.S. military is seeking to improve the trust and confidence between the separate services and better employ their individual core competencies to accomplish the mission of the United States more effectively (Office of the Chairman of the Joint Chiefs of Staff (CJCS), 2007; Joint Chiefs of Staff, 2004).

The new joint environment has created a need for guidance to govern the combined operations of the separate services (Office of the CJCS, 2007). There is only general guidance that dictates the scope and range of each separate service's responsibilities and individual service documents that dictate their specific Concepts of Operations (CONOPS). However, the combined library of guidance documents lacks overarching rules for how joint operations will be conducted and how the individual services will proceed in an environment where all operations are handled by a mix of service capabilities.

The systems engineering field has created several tools to represent complex systems, such as force protection systems. An important tool within the Department of Defense is system architecture. System architecture allows the user to represent an extremely complex system through a series of "views" which present the system through a number of perspectives. These architectures are used in the acquisition of a system and through its life-cycle to document its development. Judging the quality of the architecture and the systems that it represents, however, is a challenge. Several models have been created to evaluate different aspects of architecture, but few focus on the entire portfolio with the instantiated system in mind. These evaluation tools are generally based on the existing system, as opposed to the needs of the decision-maker. This effort combines the Operations Research field, with its Decision Analysis tools, with the Enterprise Architecture field and its Architecture Evaluation tools. Specifically, Value-Focused Thinking is used to evaluate Systems Architecture at the intersection of these ideas. Figure 1.1 shows a VENN Diagram of the research area.

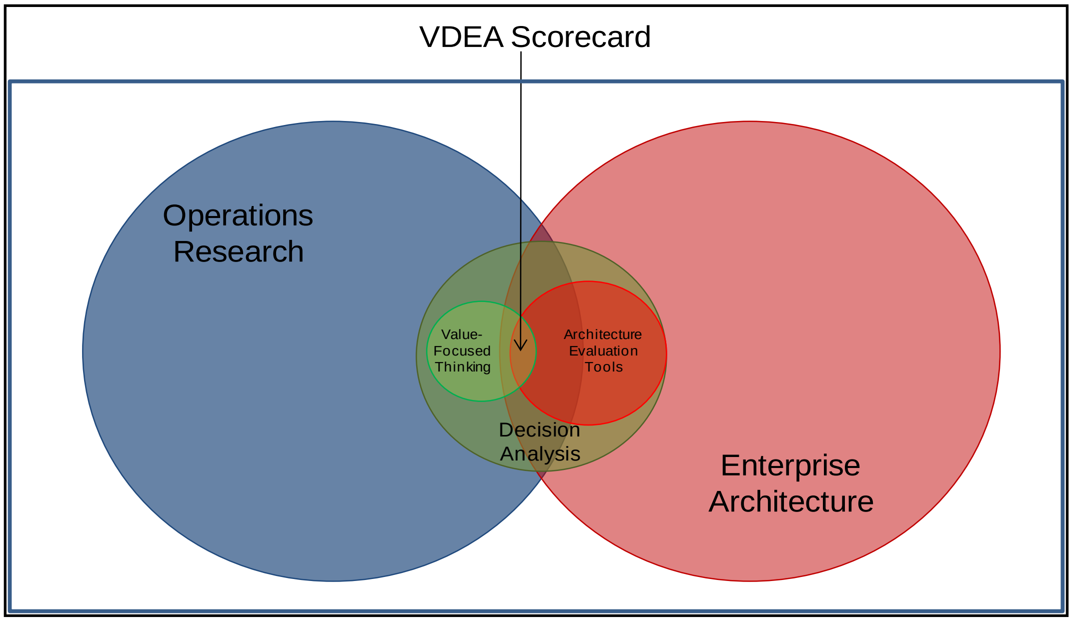


Figure 1.1. VDEA Venn Diagram

Value-Focused Thinking is an objective decision analysis approach intended to overcome the problem of multicriteria-decision making. It serves to eliminate assumptions and reveal the overarching values at the base of a particular decision. Using a set methodology such as this allows decision-makers to ensure that they are getting the end product that they require and are expecting to receive. Through an established process of identifying objectives; developing values, measures, and weights; and then applying functions to these values; a detailed numerical analysis can be performed to compare alternatives or to evaluate a single alternative and show areas lacking in the important values (Chambal, 2001).

1.2 Specific Background

To address growing problems of multi-service coordination within the joint community, a system was proposed which would integrate force protection. The JFPASS project began when a Joint Capability Technology Demonstration (JCTD) was performed for the Joint Force Protection Advanced Security System (JFPASS) program (Rains, 2008). The JCTD is intended to demonstrate the integration of various components via a combined command and control architecture. This architecture will encompass the entire range of Joint Force Protection functions. It is based upon the joint operational concepts of Detect, Assess, Warn, Defend and Recover (DAWDR) (IUBIP, 2006).

The goal of the JFPASS effort is to develop an architecture that will represent the JFPASS system and its Joint Capability Technology Demonstration (JCTD) as required by JCIDS (Chairman of the Joint Chiefs of Staff (CJCS), 2007). This research effort intends to create an evaluation tool to evaluate the enterprise architecture, based on stakeholder values. All aspects of this project are based on the direction given by the IUBIP and centered on the DAWDR construct. Specifically for this effort, the Detect, Assess, and Warn aspects of DAWDR are being investigated (Rains, 2008).

1.3 Research Problem

There is currently no method to evaluate the effectiveness of a force protection system based solely on architectural products. With the Air Force-wide focus on using architecture as a documentation method and a procurement tracking system, an evaluation method is required for DoD-specific architectures and specifically in this case for a force protection system architecture.

1.4 Research Objective and Questions

This thesis will determine specific Force Protection values and evaluate an existing enterprise architecture based on these values. The JFPASS architecture will be evaluated and an analysis returned including critical deficiencies and required improvements. This research will determine an appropriate evaluation method for existing architecture and a way to recommend future courses of action based on a set of existing products.

The questions this research effort will answer are: (1) How can VFT be applied to an evaluation of a set of architectural products? (2) What is the resulting value hierarchy to evaluate a force protection system? (3) What are the related weights and measures for the hierarchy? (4) How well does the provided architecture score based on this hierarchy and where are the shortfalls and potential areas of improvement?

1.5 Methodology

Value-Focused Thinking will be applied to architecture to evaluate its viability. To date, VFT has not been used to evaluate an architectural product. In fact, there is very little research on the topic of evaluating architecture and little to no peer-reviewed research regarding the analysis of a force protection system. Leveraging VFT, a methodology for architecture evaluation will be developed.

1.6 Scope

The scope of this thesis will be limited to the architectural products and the environment within which these products were intended to function. An extendable and defensible tool will be created to evaluate a set of static architectural products. The scope of the force protection environment includes worldwide military installations. It is limited, however, to the realm of joint operations. Therefore, battlespaces controlled by an individual service will not be addressed. For example, portside security will be addressed, but force protection at sea is not considered as this is a Navy-specific battlespace. Space assets will also not be included. Threats from the air will be taken into consideration, but the airspace operating environment will not be included. Since the Air Force maintains primary control over air space engagements (although all services operate within this environment), the protection of air assets is not a joint operation. Within the force protection area, the Detect, Assess, Warn, Defend Recover (DAWDR) construct will be included in the evaluation, although the Defend and Recover tenets are not of primary concern.

1.7 Review of Chapters/Research Approach

Chapter 2 consists of a review of the available force protection/facility protection material, as well as the DoD guidance governing the individual service's force protection efforts. It discusses how these documents relate to the research effort. Chapter 3 details the methodology used for this effort. Specifically, it discusses the 10-step VFT process employed here and how each step was used to create the resulting hierarchy, assign weights, create Single Dimension Value Functions (SDVF), and analyze the model. It also discusses the collection of relevant materials and communication with the decision making entity. Chapter 4 provides an actual evaluation of the architecture in question. It will show how the instantiated system architecture scored on the hierarchy and areas of improvement to produce a fully functional and effective force protection system. Chapter 5 discusses these findings and their applicability to the force protection mission. Chapter 5 also highlights the impact of this effort and details the future research required to continue this effort, as well as how it can be applied to other areas.

Chapter 2. Literature Review

This chapter presents important previous research pertinent to this effort. Joint force protection is presented to provide the context for the overall Joint Force Protection Advanced Security System (JFPASS) project. The field of systems engineering is discussed, as system architecture is the tool used to produce the product being examined. Decision analysis and Value-Focused Thinking were used to evaluate the provided architecture. The basis of the value generation step within Value-Focused Thinking was the affinity diagramming method, which is taken from the management and planning toolbox. Finally, net-centricity will be summarized as it applies to this project and its impact on the Department of Defense (DoD).

2.1 Joint Force Protection

The term Joint Force Protection (JFP) is used by the DoD to describe efforts related to protecting personnel, assets, and information among all service components. Currently, each service has its own tactics, techniques, and procedures (TTPs) for accomplishing this goal. Recent developments on the political world stage have caused the DoD to move toward a more joint environment, as opposed to the separate TTPs formerly used by the services. This idea is outlined in the National Military Strategy, which states that "achieving the objectives of protect, prevent, prevail requires connected joint operating concepts (JOCs)" (Joint Chiefs of Staff, 2004). Furthermore, Joint Document 1-02, the Department of Defense Dictionary of Military and Associated Terms, defines force protection as,

> Preventive measures taken to mitigate hostile actions against Department of Defense personnel (to include family members), resources, facilities, and critical information. Force protection does not include actions to defeat the enemy or protect against accidents, weather, or disease. (Joint Chiefs of Staff, 2008, p. 214)

The Protection Joint Functional Concept (PJFC) (Department of Defense, 2004) goes on to state that the actions involved in force protection (FP) are intended to conserve the force's fighting potential so that it may be applied at the appropriate time to accomplish the mission at hand (Department of Defense, 2004). The U.S. definition also aligns very closely with the North Atlantic Treaty Organization (NATO) definition of force protection (NATO Standardization Agency, 2008). This connection allows better communication among multi-national forces.

The military's current method of assessing FP in a facility is through the use of Joint Staff Integrated Vulnerability Assessment (JSIVA) teams. These teams of force protection experts visit military installations to determine their level of protection. As part of this assessment, they provide the required training and feedback to enhance protection postures at these installations. The JSIVA program provides a comprehensive assessment tool for operational facilities, but they have no method for evaluating FP systems under design (Cirafici, 2002).

2.1.1 National Policy

Joint force protection concepts are drawn from the national strategic objective. National guidance regarding force protection and military operations come in several tiers. The National Security Strategy (NSS) is the Presidential directive which guides all efforts to secure and defend the United States. It discusses international strategy as well as the United States' goal of improving the quality of life not only within the U.S., but in other countries as well. It also discusses the strategic objective of eliminating terrorism by winning the War on Terrorism (Office of the President of the United States of America, 2002).

The National Defense Strategy (NDS) directly supports the NSS by establishing objectives by which the goals of the NSS will be accomplished and measured. The NDS provides the link between the DoD and other government agencies as they relate to the security objectives of the nation. The objectives set forth by the NDS are to: (1) secure the United States from direct attack, (2) secure strategic access and retain global freedom of action, (3) establish security conditions conductive to a favorable international order, and (4) strengthen alliances and partnerships to contend with common challenges (Office of the Secretary of Defense, 2008). These objectives provide the direction for the National Military Strategy (Office of the Secretary of Defense, 2008).

The National Military Strategy (NMS) provides the focus for military activities by specifying the overall objectives set forth in the NSS and NDS. To this end, the NMS refers specifically to three guiding ideas. “Protect the United States” refers specifically to what has become known as “Homeland Security.” The NMS establishes homeland security as the first priority of the United States. The armed forces are responsible for securing the nation, both at home and abroad. The military accomplishes missions outside the U.S. to counter threats as they occur at their source. They must then secure strategic approaches to the U.S. to ensure enemy forces cannot gain direct access to the country. Lastly, they must employ force as directed on home soil in the case of direct attack. “Prevent conflict and surprise attack” is the second idea specified in the NMS. This refers mainly to strengthening alliances and creating a security environment in which aggressions from adversaries is discouraged. Preventing this conflict is a goal which requires global action and attention to any adversary who may pose a threat to the United States. “Prevail against adversaries” is the objective that refers specifically to the military’s mission of swiftly defeating adversaries in campaigns and wars. This objective includes the ability to integrate all available technologies, capabilities, and information in overlapping campaigns (Joint Chiefs of Staff, 2004).

Accomplishing the objectives of protect, prevent, and prevail requires the use of Joint Operational Concepts (JOCs). The NMS focuses largely on the concept of a Joint Service. The desired attributes of a joint force are one that is: fully integrated; expeditionary; networked, decentralized, and adaptable; has decision superiority; and is capable of lethality. The scope of security for the joint force is defined in the NMS as:

> 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 U.S. global interests. The non-linear nature of the current security environment requires multi-layered active and passive measures to counter numerous diverse conventional and asymmetric threats. These include conventional weapons, ballistic and cruise missiles and WMD/E. They also include threats in cyberspace aimed at networks and data critical to U.S. information-enabled systems. Such threats require a comprehensive concept of deterrence encompassing traditional adversaries, terrorist networks and rogue states able to employ any range of capabilities. (Joint Chiefs of Staff, 2004, p. 18)

By defining joint force security, the National Military Strategy provides the context for joint force protection. It establishes a focus on joint operations and on directing the actions of the military. The NMS implies a need to protect those who are accomplishing the mission. This implication is explored in more depth in the implementation of the objectives set forth in the NMS by joint guidance documents.

2.1.2 Joint Guidance Documents

In addition to national policy, several joint documents have been created to help guide the development of the joint force. Each of these documents is targeted toward a specific audience for a specific purpose. There is overlap to each of them, but their guidance is standard across the documents. The recurring theme is that the service components must learn to operate effectively in a joint environment. Each of the following documents gives information critical to operating jointly.

2.1.2.1 Joint Publication 1

Joint Publication 1 (JP1) is the overarching guidance for all other joint publications. It provides the guidance for the unified operations of all branches of service by bridging policy and doctrine. This common perspective is employed by all commanders to ensure that each service component is working toward the same goal. This document directs the services to operate jointly by relying on each other's skills and capabilities. JP1 states that despite the U.S. military's ability to conduct warfare, the military must also focus on the strategic security environment to ensure the viability of its warfighting capability (Office of the CJCS, 2007).

2.1.2.2 Joint Publication 3-0

Joint Publication 3-0 (JP3) extends the guidance in JP1 to include planning and execution across the range of military operations typically found in the joint environment. In JP3, protection is included as a critical joint function. Four primary protection functions are outlined as active defensive measures, passive defensive measures, applying technology and procedures, and emergency management and response (Office of the CJCS, 2008). JP3 also extends force protection to include friendly nations and other allied organizations. It also discusses health protection as a subsection of FP.

JP3 states that the protection function itself includes several tasks. Each task directly relates to the Detect, Assess, Warn, Defend, Recover (DAWDR) construct and concept of protecting personnel, assets, and information. Air, space, and missile defense; protection of noncombatants; physical security; antiterrorism; and eight other tasks comprise the protection function (Office of the CJCS, 2008). These protection tasks show the full range of force protection.

2.1.2.3 Protection Joint Functional Concept

The Protection Joint Functional Concept (PJFC) is a DoD governing document regarding protection of friendly personnel, information, and assets. It is intended to guide future joint operations within all service components. The PJFC defines protection as “the ability to sense adversary activities, understand their impact on Joint Force operations, and make timely and appropriate decision to execute capabilities to neutralize or mitigate adversary effects” (Department of Defense, 2004). This document identifies the three key areas for protection: Personnel, Assets, and Information. They are defined by the protection construct shown in Figure 2.1.

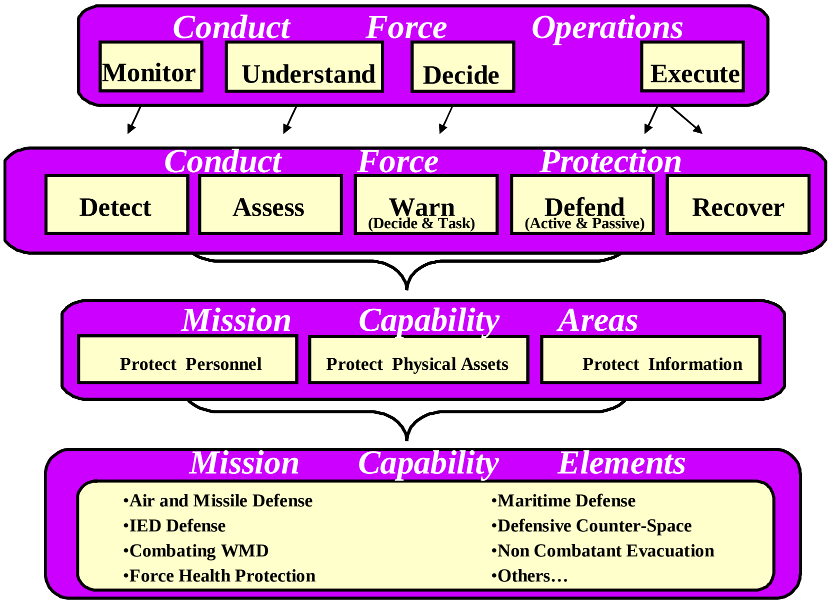


Figure 2.1. The Protection Construct (Department of Defense, 2004)

This construct defines the five key aspects of force protection: Detect, Assess, Warn, Defend, and Recover (DAWDR). The joint force commander must be able to effectively execute each of the DAWDR tenets in a joint environment. The PJFC also provides the context and overall guidance for each of the other Joint Functional Concepts, such as Battlespace Awareness, Command and Control, and Force Application. It also addresses the Mission Capability Areas (MCAs) and Mission Capability Elements (MCEs), which are the specific protection tasks which enable the joint force to execute its mission (Department of Defense, 2004). The hierarchy described in Figure 2.1 provides the context for joint force protection. Specifically, it defines the scope of joint force protection as falling within the DAWDR construct. It then specifies DAWDR to include personnel, assets, and information, providing a more specific scope for the objective of force protection.

2.1.2.4. Universal Joint Task List (UJTL)

The Universal Joint Task List (UJTL) provides the standardization required to plan, conduct, evaluate, and assess joint and multinational training. It dictates what specific functions must be accomplished by the joint force. When combined with the Service Task Lists, it provides a comprehensive list of tasks and measures for all levels of the DoD. The UJTL also provides the context for interoperability; however, it does not define how services are expected to interact with each other in the execution of the joint mission. The tasks are divided into Strategic National, Strategic Theater, Operational, and Tactical tasks. Each of these tasks includes lists of subtasks that fall under the major idea. Under tactical tasks, subsection six focuses specifically on force protection. The operational context for each task is defined by the joint conditions section. Joint Condition 2.7 is the section which focuses on the protection of each area of air, sea, and land. The most critical part of the UJTL to this study is the definition of the measures associated with each protection area. For example, the measures of Air

Superiority are defined as Full, General, Local, or No. The UTJL, however, only provides broad guidance and does not dictate how each service will fulfill its mission (Joint Staff, 2002).

2.1.3 Service Policies

Under the joint guidance, each individual service component must create its own force protection guidance to dictate how the principles set forth in joint and national doctrine will be accomplished. Military installations are controlled by the owning service component; however, in the case of joint bases or shared installations, a single service is chosen as the lead for force protection on that installation. This presents problems because of the different implementations of the joint guidance. Each service operates within the guidelines set forth, but executes those guidelines differently.

2.1.3.1 Air Force

The Air Force's Installation Security Program (ISP) is their primary guidance for force protection. Air Force Instruction (AFI) 31-101 provides the implementation of Air Force Policy Directive 31-1, Physical Security. The Air Force places primary responsibility for force protection within their Security Forces career field. This single career field is responsible for creating programs and regulations to ensure that the entire population of the installation is secure. Security Forces are responsible not only for the implementation of the Air Force ISP, but they are also responsible for ensuring that the installation complies with each level of guidance. They must create and maintain an ISP, as well as host the Installation Security Council (ISC) (HQ AFSFC/SFON & SFOP, 2003). A portion of the Air Force force protection responsibility falls to the Civil Engineer career field, as they are responsible for designing and building both home station and expeditionary structures which must comply with the Anti-Terrorism/Force

Protection (ATFP) guidelines as well as the doctrine set forth in joint publications and installation-specific regulations.

2.1.4.2 Army

The Army's physical security program is a component of its force protection program. The Army's program relies on the military police force, but it also makes use of all other soldiers to implement the policies and guidance. For example, physical security inspectors can be from any military Occupational Specialty (Department of the Army, 1993). This policy makes force protection a more implicit responsibility. The regulations within the Army are carried out by programs put in place at higher headquarters, but compliance is a command responsibility.

2.1.3.3 Navy/Marine Corps

The Navy and Marine Corps have an entirely different approach to force protection. Since they spend the majority of their time at sea, there is a command within the Navy known as the Force Protection Command. Its primary duty is to protect Naval forces from Naval threats. The Navy's port security program is managed either by civilians or their ship security personnel (NTTP 3-07.2.1, 2003; NWP 3-07.2 (Rev A), 2004).

2.1.4 Integrated Unit Base Installation Protection (IUBIP)

Integrated Unit Base Installation Protection (IUBIP) has three guiding documents: the IUBIP Concept of Operations (CONOPs), the IUBIP Functional Area Analysis (FAA), and the IUBIP Joint Capability Document (JCD). The IUBIP CONOPs "conceptualizes the integration of protection capabilities for agile, decisive, and integrated force employment in all phases of combat and supporting operations" (IUBIP, 2006). The IUBIP FAA defines the tasks required of the joint force to accomplish the goal of protecting personnel, information, and assets (Joint Chiefs of Staff, 2007). The IUBIP JCD discusses the Joint Functional Areas, as well as the required capabilities, capability gaps, and threat environment (Joint Requirements Oversight Council, 2007).

These documents provide the context for the specific project. The IUBIP CONOPs, which builds upon the FAA and JCD, defines the military problem for which the Joint Force Protection Advanced Security System (JFPASS) is being created. Specifically, as the joint force is reduced due to budgetary constraints, it will require more efficiency to continue its current level of operations. The IUBIP states that the joint force has a great deal to gain from integration and explains how this may be accomplished. The CONOPs discuss the benefit that net-centricity will have on a newer, integrated joint force and how net-centricity is required as the joint force matures (IUBIP, 2006). Net-centricity is typically defined as the operation of a group of nodes in communication with each other.

2.2 Systems Architecture

With the complexity of force protection, a system of analysis is required to gain an understanding of how the individual services interrelate. The systems engineering field is an interdisciplinary approach to enable the realization of successful systems (Blanchard & Fabrycky, 2006). The creation and design of these systems is accomplished through graphical representations, design tools, and process analysis. Through the use of these tools and system analysis, system designers and managers can better understand and therefore manage their systems.

One of the tools within the systems engineering field that has gained wide use and acceptance within the DoD is systems architecture. The DoD Architecture Framework (DoDAF) was written as the authoritative source on DoD's use and implementation of architecture. The DoDAF describes architecture as "the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time" (DoD Architecture Framework Working Group, 2007). Maier and Rechtin (2002) refer to architecture simply as "the art and science of designing and building systems." The DoDAF prescribes a systematic process of architecture by providing the standards by which architecture "views" or products (discussed in Section 2.2.1) are created, while Maier and Rechtin (2002) tend to believe that architecture is a more abstract concept which requires a "process of insights, vision, intuitions, judgment calls, and even taste."

2.2.1 DoDAF

The DoDAF is the result of at least 12 years of evolution of DoD policy and procedures (DoD Architecture Framework Working Group, 2007). It began with the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Architecture Framework v1.0 in 1996 followed by v2.0 in 1997. The DoDAF v1.0 was subsequently released in 2003. The current version of DoDAF is 1.5 and was released in 2007. DoDAF v2.0 has been released in draft form and is being coordinated for an official release expected by the middle of 2009. All of these efforts are the result of the move toward joint and multinational operations (DoD Architecture Framework Working Group, 2007). The DoD has ensured the use of DoDAF through the use of policies and directives which require its use in acquisition processes. Table 2.1 displays the evolution of the policy documents that have directed the use of DoDAF.

Table 2.1. Federal Policy for Architectures (DoD Architecture Framework Working Group, 2007)

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.

There are several types of architecture in systems engineering resources. DoDAF discusses Integrated Architectures, Composite Architectures, and Federated Architectures. Integrated architectures are those in which there is concordance between all products and entities. They use a standard nomenclature throughout the operational views (OV), systems and services views (SV), all views (AV), and technical views (TV). In this case, operational views are those which describe the general tasks, activities, and major information exchanges. Systems and services views capture specific interconnection information further specifying the information found in OVs. Technical views contain the minimum set of rules which govern the functions of the system or system elements. All-views are the overarching informational views. They provide information about the architecture, but do not actually show an architectural view. Table 2.2 shows all views included within DoDAF. Integrated architectures facilitate ease of use and communication, as well as aggregation of information. Composite architectures are those composed of separate parts. Generally, several integrated architectures are pulled together to form composite architectures which support a more broad set of goals. Finally, federated architectures are distributed information bases compiling information of use to decision-makers at higher levels. All architectures increase the net-centricity of a system by encouraging the process of examining links between nodes and modeling the composition of the system.

The DoDAF's use has become commonplace within several areas of the DoD, particularly within the acquisition process. The Joint Capabilities Integration and Development System (JCIDS) formally defines the acquisition process and directs the use of certain architecture products for milestone decision points (CJCS, 2007). For example, Milestone Decision Point A requires an OV-1 view for consideration of the project (CJCS, 2007).

Table 2.2 DoDAF Views (DoD Architecture Framework Working Group, 2007)

Applicable View	Framework Product	Framework Product Name
All View	AV-1	Overview and Summary Information
All View	AV-2	Integrated Dictionary
Operational	OV-1	High-Level Operational Concept Graphic
Operational	OV-2	Operational Node Connectivity Description
Operational	OV-3	Operational Information Exchange Matrix
Operational	OV-4	Organizational Relationships Chart
Operational	OV-5	Operational Activity Model
Operational	OV-6a	Operational Rules Model
Operational	OV-6b	Operational State Transition Description
Operational	OV-6c	Operational Event-Trace Description
Operational	OV-7	Logical Data Model
Systems and Services	SV-1	Systems/Services Interface Description
Systems and Services	SV-2	Systems/Services Communications Description
Systems and Services	SV-3	Systems/Services-Systems/Services Matrix
Systems and Services	SV-4a	Systems Functionality Description
Systems and Services	SV-4b	Services Functionality Description
Systems and Services	SV-5a	Operational Activity to System Function Traceability Matrix
Systems and Services	SV-5b	Operational Activity to System Traceability Matrix
Systems and Services	SV-5c	Operational Activity to Services Traceability Matrix
Systems and Services	SV-6	Systems/Services Data Exchange Matrix
Systems and Services	SV-7	Systems/Services Performance Parameters Matrix
Systems and Services	SV-8	Systems/Services Evolution Description
Systems and Services	SV-9	Systems/Services Technology Forecast
Systems and Services	SV-10a	Systems/Services Rules Model
Systems and Services	SV-10b	Systems/Services State Transition Description
Systems and Services	SV-10c	Systems/Services Event-Trace Description
Systems and Services	SV-11	Physical Schema
Technical Standards	TV-1	Technical Standards Profile
Technical Standards	TV-2	Technical Standards Forecast

2.2.2 Architecture Evaluation

Architecture evaluation has taken many forms from quantitative scoring measures to simple heuristics. It is of great value to not only the model builder, but to the project sponsor as well, to be able to determine the quality of a set of architectural products and the associated instantiated system. Since architectures are intended to represent a system, it is important to rate not only the architectural products themselves, but also how they accomplish the goal of representing the needs of the system itself.

One such evaluation method is Ford's i-Score (Ford, Graham, Colombi, & Jacques, 2008), which measures the interoperability of the architecture. To do so, it uses the DoDAF OV-5, OV-2, and SV-3. It is similar to Value-Focused Thinking (VFT) in that it yields a single quantitative score that represents how the architecture is performing in terms of interoperability (Ford, Graham, Colombi, & Jacques, 2008). Levis, Shin, and Bienvenu (2000) discusses the concept of executable architectures, which relies on modeling and simulation to determine the effectiveness of a system. There have been other tools as well, such as the Architecture Based Evaluation Process (Dietrichs, Griffin, Schuettke, & Slocum, 2006) and the Architecture Tradeoff Analysis Method^{SM} (Kazman, Klein, & Clements, 2000), which is intended to evaluate software architectures. Of the architecture evaluation methods in existence, none attempt to grade an architecture based on "-illities," nor do they provide a comprehensive generalized approach in line with the stakeholder's values.

2.2.3 "Ilities"

"Ilities" have grown in popularity across the quality management field. Particularly in the areas of software development and systems engineering, they have become standards for describing system attributes. The INCOSE Systems Engineering Handbook version 3.0 defines ilities as "the operational and support requirements a program must address (e.g. availability, maintainability, vulnerability, reliability, supportability, etc.)" (International Council on Systems Engineering, 2007). Within the systems engineering field, ilities tend to describe the quality attributes of a system through their descriptive nature. This makes ilities useful for describing the quality of both the instantiated system as well as the architectural products. Although a single authoritative source for a list of ilities does not exist, they are often created based on the quality needs of the system. Several studies and articles refer to individual use of ilities. Ross

(2006) discusses ilities (flexibility, adaptability, scalability, robustness) which describe the "traditional system design concerns." McManus et al. (2007) created a quantitative measure for describing certain system ilities. Their work defines and describes six ilities (robustness, versatility, changeability, flexibility, scalability, and survivability) which share some of the same attributes as other studies. These studies begin to provide a framework for the evaluation and quantification of ilities, although much more work is required in this area. It is possible to "create" ilities by simply adjusting the tense of a system attribute. A web search yields one list of 63 ilities, with many others scattered throughout various sources.

2.3 Decision Analysis

Evaluating the protection status at a United States military installation is currently a very subjective process. Each service has inspection methods in place to ensure compliance with regulations and security procedures, but there is no quantitative, objective method for achieving this goal. Inspection procedures consist of checklists that are accomplished by subject matter experts appointed by higher headquarters, but their evaluations are still based on their own subjective understanding of the regulations. In addition, these evaluations may not match fundamental joint force protection values.

The Decision Analysis (DA) field provides decision-makers a set of tools for making decisions that are more objective. In this case, DA provides a quantitative, more objective approach to accomplishing the goal of force protection evaluations. The methods provided within the decision analysis discipline give the decision-maker more insight to the problem and ensure all data is being examined, thereby facilitating better decisions. DA is particularly useful when several objectives exist and affect different groups of stakeholders. In the case of architecture, a set of products exist, which serve to document a collection of design decisions.

Decision analysis provides a tool to evaluate the previously made design decisions as they relate to stakeholder values, as well as a method to evaluate decision opportunities.

Decision analysis provides a systematic, iterative approach (shown in Figure 2.2) to solving a problem (Clemen & Reilly, 2001). It begins with the most basic step of any analysis, to identify the decision situation and understand its objectives. In this case, the design of a force protection system is being evaluated. The system being designed will be subjected to the evaluations of the DoD acquisition process. The evaluations for system acquisition are largely subjective and depend on the opinions of the sponsor and acquisition officer.

2.4 Value-Focused Thinking

Value-Focused Thinking (VFT) is a decision making tool developed by Keeney (1992); it enables decision-makers to look beyond the list of available alternatives and focus on the values or objectives that are actually important to them in the outcome of the situation. The VFT method is intended to get decision-makers closer to solutions that they actually want (Keeney, 1992). In a joint force protection system situation, this facilitates the system sponsors getting the product they need as opposed to choosing between presented alternative systems.

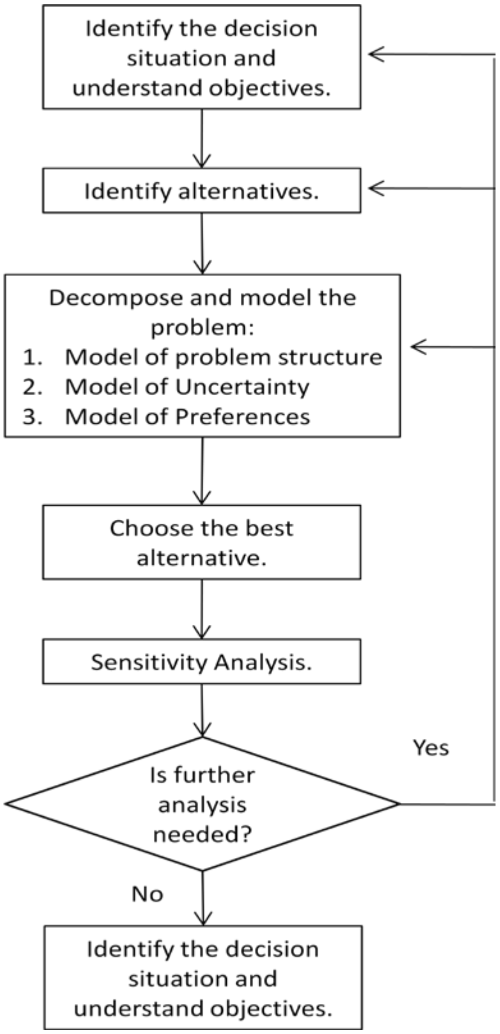


Figure 2.2. Decision-Analysis Process Flowchart (Clemen & Reilly, 2001, p. 6)

2.4.1 Alternative-Focused Thinking versus Value-Focused Thinking

The second step of the process shown in Figure 2.2, "Identify Alternatives," is the issue that defines any decision-making problem. A decision problem generally occurs when a decision-maker is presented with at least two alternatives (Keeney, 1992). They must decide among the best of the presented alternatives. This approach has been called "Alternative-Focused Thinking" (AFT) since the decision approach is based on choosing from a finite set of alternatives. Because AFT happens after a decision problem has been framed and the solution is chosen from a finite set of alternatives, it is a reactive procedure (Keeney, 1994). VFT, however, is a proactive approach in which decision-makers examine a problem before the decision is forced upon them. It enables the decision-makers to determine what is important to them in advance of making the decision and generate alternatives rather than choosing from existing alternatives. This approach also ensures that all possible alternatives are considered instead of only a limited set.

In Alternative-Focused Thinking methodologies, the decision-maker begins the process with a set of existing alternatives. Alternatives though, are only the means to achieve the values of the decision-maker in this method. For this reason, the values should be determined before alternatives are created (Keeney, 1994). The Alternative-Focused Thinking approach leads to less understanding of what is important in the end goal.

VFT is intended to lead decision-makers to better decisions. The process set forth in previous studies and literature allows for many other advantages as well. Among these are uncovering hidden objectives, guiding information collection, improving collection, facilitating involvement in multiple-stakeholder decision, avoiding conflicting decisions, evaluating alternatives, creating alternatives, and identifying decision opportunities (Keeney, 1992)

When VFT is used early enough in a process, many alternatives and opportunities for improvement are presented to the decision-maker. In many cases, a decision situation is forced and does not leave decision-makers time to evaluate values and create an exhaustive list of alternatives. Instead, they are presented a finite list of alternatives and must choose the best of those available. By applying VFT early, it is possible to guide information collection and identify decision opportunities prior to the decision situation. During the design phase of an acquisition project, there are several opportunities for improvement over the long process.

Focusing on values throughout the entire process will allow the designer to achieve a more robust and useful product for the sponsor, instead of simply fulfilling the requirements. Kirkwood (1997) discusses several of the same advantages, including that the VFT process is helpful in facilitating communications between stakeholders. VFT seeks to create a hierarchical representation of what is important to the decision-maker. This hierarchy includes tiers of value, which become more specific as the tiers progress. The value hierarchy gives stakeholders a common frame of reference for what is important in the project and gives all stakeholders input into the importance of each value. In projects with a large number of objects, complex issues, and many stakeholders, communication is essential to achieving the objectives of the project.

2.4.2 Discussion of Value

Throughout the literature regarding Value-Focused Thinking and Decision Analysis, the terms “Value” and “Objective” are often used interchangeably. “Values are what we care about” (Keeney, 1992). They are the fundamental part of any decision that dictates in what the decision-maker is truly interested. Keeney (1992) uses two distinct terms, value and objective, when discussing what is important. The term “value” refers to an idea that the decision-maker is trying to describe. The term “objective” is typically used to describe the evaluation measure of the value included in the hierarchy. Kirkwood (1997) defines the connection between a value and an objective by his definition of the term “objective.” He defines it as “the preferred direction of movement with respect to an evaluation consideration.” Several previous research efforts have used either term to describe the actual elements of the hierarchy. Shoviak (2001) uses the term “objective” almost exclusively, while Katzer (2002) uses “value” in the same way, in the same contexts. An examination of several other VFT-focused research efforts has yielded similar differences in the use of the terms. Clemen and Reilly’s (2001) discussion of objectives and values distinguishes the two terms based on their relation to the user. They refer to value as anything that matters to the decision-maker. Objectives are defined as the specific things that the decision-maker wants to achieve. Based on these definitions, the combination of the objectives gives the decision-maker their overall values. The objectives are the specific things that will influence the final decision and the values are characteristics of the preferred outcome.

2.4.3 Value-Focused Thinking Methodology

VFT was initially laid out by Keeney (1992) and refined by Kirkwood (1997). Over the years, this methodology has been applied and adapted for several purposes. Keeney (1992) discussed three “situation based” five-step processes. These processes refer to situations in which a decision problem or decision opportunity exists. The decision opportunities are then broken down into two processes. One for a situation before strategic objectives have been specified and one for situations after strategic objectives have been specified. Each of these situations have a five step process for completing the VFT process. These processes, in combination with Kirkwood (1996) can be extended to a ten-step process (Chambal, 2001). The ten-step process expands on Keeney’s by adding individual steps for measures, value functions, and hierarchy as well as expanding the analysis of the VFT process by including Kirkwood’s methods. These methods are shown in Table 2.3.

As demonstrated by the selected methodologies in Table 2.3, there are several different ways to apply Value-Focused Thinking to a decision. Each of the steps laid out in these processes share some similar features, which can be combined into a single, ten-step process, accounting for all major activities and milestones. The ten-step version guides the evaluator through the Keeney and Kirkwood methodologies in a straightforward fashion, ensuring that each iterative step accomplishes the necessary activities. The ten-step process effectively combines the previous methodologies and accounts for all of their ideas. This process has been refined and applied in several research projects. These projects include an examination of advanced academic degree profiles (Gentil, 2007), a Force Protection Battlelab project evaluation initiative (Jurk, 2002), and strategic airlift (Tharaldson, 2006). Chambal's (2008) process follows a path of distinct activities, separating Value Hierarchy creation, Measure Creation, Weighting, Scoring, and Analysis in a unique way. Figure 2.3 shows a graphical representation of the ten-step process. In the following pages, the VFT process will be discussed in depth.

Table 2.3. VFT Methodologies (Keeney, 1992; Kirkwood, 1997; Chambal, 2001)

Author	Keeney	Keeney	Keeney	Kirkwood	10-Step Process
Situation	Decision Problems	Decision Opportunities before specifying objectives	Decision Opportunities after specifying objectives	All	All
Steps	Recognize a decision problem	Indentify a decision opportunity	Specify Values	Identify Decision	Problem Identification
	Specify Values	Specify Values	Create a Decision Opportunity	Structure Objectives	Create Value Hierarchy
	Create Alternatives	Create Alternatives	Create Alternatives	Develop Evaluation Measures	Develop Evaluation Measures
	Evaluate Alternatives	Evaluate Alternatives	Evaluate Alternatives	Develop Alternatives	Create Value Functions
	Select an Alternative	Select an Alternative	Select an Alternative	Determine Single Dimensional Value Function	Weight Hierarchy
				Develop Weights	Alternative Generation
				Determine Overall Values for Alternatives	Alternative Scoring
				Select Alternative	Deterministic Analysis
					Sensitivity Analysis
					Recommendations Presentation

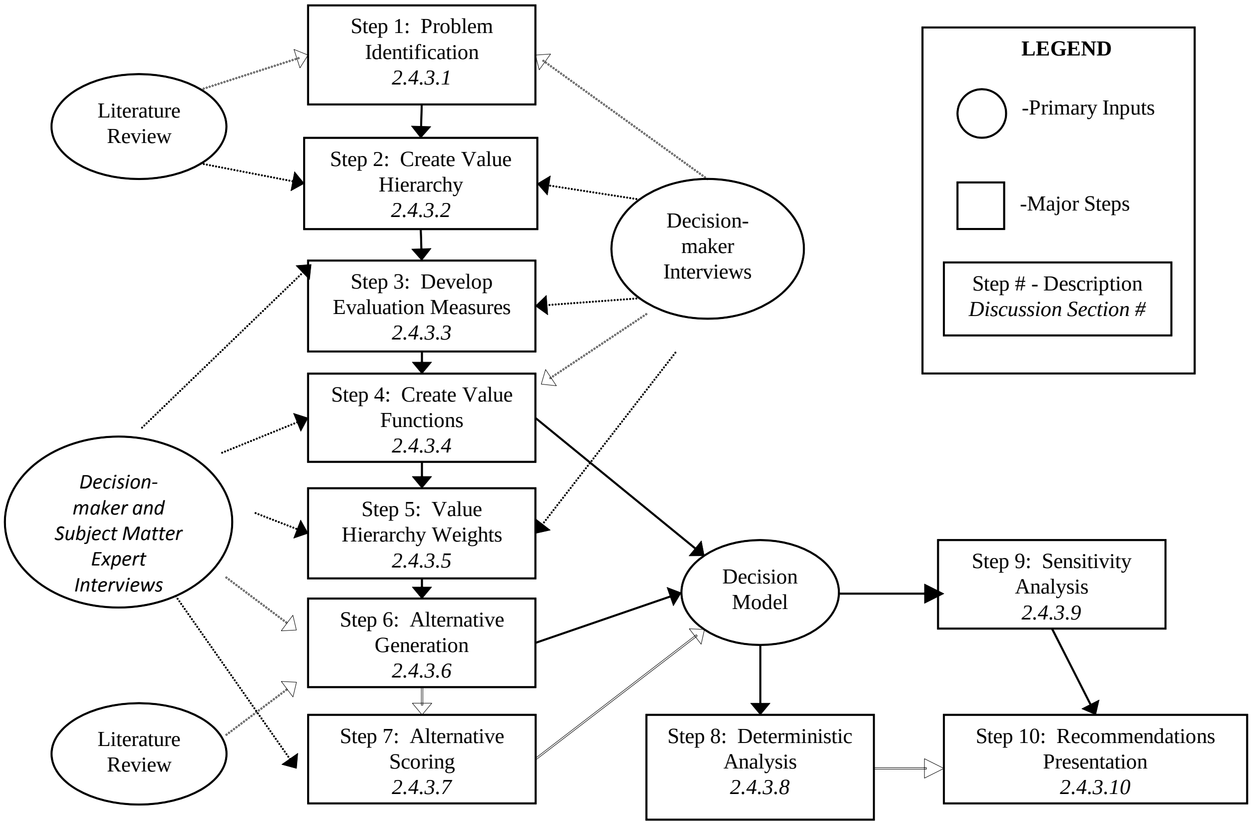


Figure 2.3. Ten-Step Process Graphical Representation (Chambal, 2001)

Parnell describes three "levels" of VFT models as the Silver, Gold, and Platinum standards (Parnell, 2007). These standards are used throughout the process as methods of communicating and building the model. The framework decided upon is descriptive of how the process is completed. Several aspects of the VFT process are impacted, such as how the hierarchy is built, description of the problem, construction of measures, and perhaps of most importance, the development of value weights. The Silver standard is the least preferable of the standards (Dawley, Marentette, & Long, 2008). It incorporates the opinions of a large number of stakeholders and uses various idea-generation techniques to determine inductively the values of the organization (Chambal, 2001). The Gold standard bases the model construction on existing documents and guidance. Through an examination of documents, such as vision statements, mission statements, rules, regulations, etc., the model builder is able to gain an appreciation for what is important to the organization, which allows deductive development of the model. The organization's senior leaders must then validate gold standard models (Chambal, 2001). Through examinations of documentation as well as validation, this standard is most easily defendable (Jurk, 2002). The Gold standard also allows the model builder to create a "strawman" hierarchy from which to begin and base discussion. Strawman hierarchies tend to facilitate discussions with the decision-maker and make effective and efficient use of time (Katzer, 2002). Finally, the Platinum standard relies on interviews regarding the values of the key decision-maker as well as technical experts and stakeholders. This method gives not only the Subject Matter Experts (SMEs) buy-in to the hierarchy, but also facilitates direct involvement of the final decision authority. The platinum standard often begins with an examination of strategic objectives, organizational plans, and visions (Chambal, 2001), but moves on to capture the values of the final decision-maker. This final decision authority's opinions and views on the system lead to a more accurate depiction of what is important in the model. These models tend to capture most accurately the intended hierarchy structure due to the direct involvement of the stakeholders and final decision authority (Braziel, 2004).

2.4.3.1 Step 1 – Problem Identification

Problem identification is the cornerstone of any scientific process and is consistently referenced as the first step to solving problems. In many cases, an undesirable solution to a problem is based on a decision-maker's failure to identify and understand the problem itself. In addition to the model builders and decision-maker understanding the objectives of the process, all stakeholders should have a clear understanding of the goal. Everyone involved in the process must have a common idea of the problem itself, so that wasted effort can be avoided.

2.4.3.2 Step 2 – Create Value Hierarchy

A value hierarchy is a graphical representation of the values or objectives most essential to the decision-maker. Keeney (1994) defines values as “Principles for evaluating the desirability of any possible alternatives or consequences.” The hierarchical structure allows the model builder to represent values from a top-down perspective, showing not only what the overarching value is, but also going into the level of detail required for the problem. The resulting hierarchy must be defendable. A defendable architecture must agree with the decision-maker’s objectives as well as the organizational goals. This must also be done within the constraints of the methodology chosen.

2.4.3.2.1 – Generating Values

The generation of values depends greatly on the standard chosen for the model being constructed. The actual process of finding these values can be quite different depending on the choice between the “silver,” “gold,” or “platinum” standard. The values may come directly from an examination of documentation or from interviews with various personnel and ultimately a validation by some level of decision-making authority. If possible, the highest-level decision-maker should be chosen (Keeney, 1994).

Keeney (1994) distinguishes between two different types of objectives or values. He refers to fundamental objectives as “[objectives that] concern the ends that decision-makers value in a specific decision context” and means objectives as “methods to achieve ends.” Means objectives serve as way to identify fundamental objectives. The means objectives can be quantified by continually asking the question “Why is that important?” until a fundamental objective is reached (Keeney, 1994). Fundamental objectives can also be called “ends objectives” (Kirkwood, 1997).

Developing the list of values can be accomplished through a number of techniques. These techniques include: develop a wish list; identify alternatives; consider problems and shortcomings; predict consequences; identify goals, constraints, and guidelines; consider different perspectives; determine strategic objectives; determine generic objectives; structure objectives; and quantify objectives (Keeney, 1994). Using Keeney's (1994) suggested techniques, one will develop a list of items including fundamental objectives and means objectives. This list must then be examined to determine what each of the list items are, thereby eliminating items that are not values. The goal of this process is to end with a list of "collectively exhaustive and mutually exclusive" objectives (Kirkwood, 1997). These objectives should be characterized by three features: a decision context, an object, and a direction of preference.

2.4.3.2.2 – Structuring Values

Once values have been determined, they must be placed into a readable, understandable, graphical structure. This structure allows for easy communication to a wider range of users. Keeney (1992) notes that prior to his work, there had not been a standard format for structuring values. He therefore proposes the hierarchical method of structuring (Keeney, 1992). Kirkwood (1997) defines a value hierarchy as "a value structure with a hierarchical or "treelike" structure." This process is also known as a "top-down" structure, as it is based on the fundamental value.

The basic nature of hierarchies is both vertical and horizontal. As demonstrated in Figure 2.4, the hierarchy is made up of both tiers and branches. Tiers are the layers or levels that, collectively, specify the values on the tier above. Branches are the values that actually specify the value above. Within each branch, the values in each progressively lower tier specify a single value from the above tier of the same branch. The breadth of the hierarchy is defined by the number of branches and the depth is defined by the number of tiers.

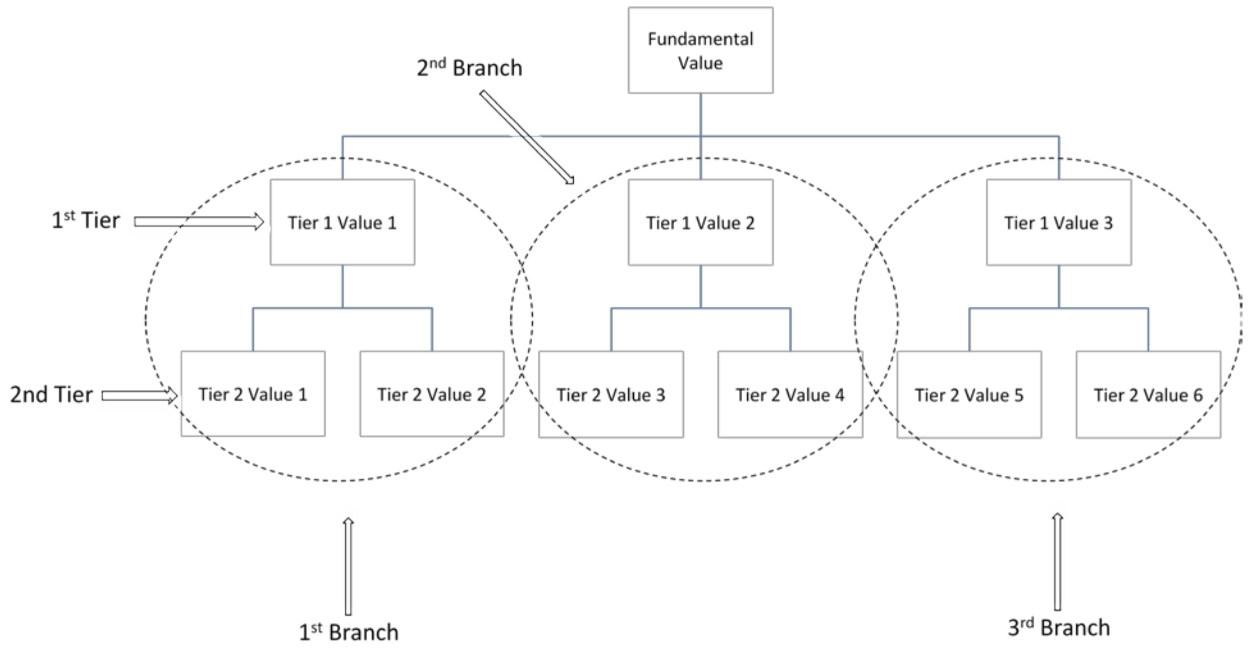


Figure 2.4. Example Hierarchy (Chambal, 2001)

Keeney's (1992) method involves three basic steps: placing the overall fundamental value at the top of the hierarchy, relating values on different levels, and stopping the structuring process. In this process, the overall value is the reason for the decision and defines the breadth of the decision problem. Choosing this overall value is therefore very important. For some decisions, it is easy to identify, but ensuring that it is the correct value will affect the entire process. Following the selection of a fundamental value, other values must be placed below it in the proper branch and tier based on their relation to the fundamental value (Keeney, 1992; Kirkwood, 1997). Each progressively lower tier specifies the values above it. In Tier 2 of Figure 2.5, Values 1 and 2 further define the value found in Value 1 of Tier 1. The combination of the two lower values makes up the higher value. The critical part of Keeney's (1992) process is stopping the structuring process. The "test of importance" is the first determination as to how many values should be included. The size of the hierarchy must be balanced with the detail necessary to capture the values. Each value must also be measurable by an attribute (Keeney, 1992). The model builder should continue moving down the hierarchy, progressively refining the values within each branch by adding more tiers, until the model builder no longer must ask "What do you mean by that?" (Katzer, 2002). Moving up the hierarchy within a branch answers the question, "of what more general objective is this an aspect?" (Katzer, 2002). When building the value hierarchy, if a value cannot be decomposed into more than one lower tier value, it should not be decomposed. As the number of tiers within a hierarchy increases, its size increases vertically.

2.4.3.2.3 – Desirable Properties of a Value Hierarchy

Kirkwood (1997) presents five properties that are desirable for any value hierarchy. These properties include completeness, nonredundancy, decomposability, operability, and small size. Completeness is considered one of the most important properties for a hierarchy to exhibit. Another way of describing completeness is if a hierarchy is "collectively exhaustive." It stands to reason that any hierarchy must contain all of the values important to the decision-maker. This includes any value that is required to evaluate the fundamental objective. For a hierarchy to show completeness, it must be possible to evaluate the objective based only on the values presented in the hierarchy. If there are other considerations required for evaluation, they must be added to the hierarchy. This includes all values, no matter how small of a part they may play in the final evaluation. Their magnitude of importance is considered during the weighting phase of the evaluation (Kirkwood, 1997).

There may also exist values that appear to be more basic to the problem than evaluation criterion. These values may be “promoted” to “screening criteria.” Screening criteria will be discussed in more depth in Section 2.4.3.6 - Alternative Generation. Determining the difference between values and screening criteria may be difficult. Screening criteria should be used for the sole purpose of reducing the number of alternatives (Kirkwood, 1997). For example, a value may be “Distance” while a screening criteria would be “Less than five miles away.” The distance value simply states that the relative distance is important in the end decision. The screening criteria “Less than five miles away” specifically eliminates certain alternatives based on their distance (Kirkwood, 1997). Each value must also pass a “test of importance.” The decision-maker must ask whether the inclusion of a specific value will alter the outcome of the decision problem. If the decision-maker feels that the exclusion of a specific value could alter the best course of action, then it must be included. If the exclusion of a value will have no effect on the outcome, then it can be left out of the hierarchy. The major caution with this “test of importance” is the possible exclusion of a collection of independently unimportant values, but which serve a major part in the decision when considered together. The collective importance of any excluded values must be continually evaluated; therefore, the excluded values should not be completely discarded, so that future iterative evaluations may be completed on them. By conducting the test of importance at different stages in the process and with the obvious groupings of these values, it is possible to ensure that none of the excluded values will have a major effect on the final decision (Keeney & Raiffa, 1993).

Nonredundancy is another very important property of a value hierarchy. Nonredundancy is also referred to as “mutually exclusivity” (Kirkwood, 1997). A hierarchy is considered mutually exclusive if no two values in the same tier overlap in any way. Every aspect of the evaluation criteria must relate to one and only one value. Each tier of the hierarchy should divide the tier above, lower levels essentially composing the values above them. The property of nonredundancy ensures that no value is double-counted and therefore receives more weight than it deserves. Based on these first two properties, every hierarchy at its very base must be “collectively exhaustive and mutually exclusive.” These are possibly the two most important properties, since they ensure that everything is included and that all values required are represented only once in the hierarchy.

Decomposability or independence refers to a value’s influence on other values (Kirkwood, 1997). The actual scoring of any value cannot have any influence on the scoring of another value. Decomposability ensures that there is not only a measurement for each value, but that the measurements themselves are also mutually exclusive. This separation of measurement ensures that the weighting of each value may be completed (Shoviak, 2001).

An operable hierarchy refers more to the utility of the tool itself. Any value hierarchy must be understandable, at a minimum to those who must use it in an evaluation (Kirkwood, 1997). This is a rather subjective property, but in communicating a hierarchy or decision analysis tool, the users must be able to understand quickly and easily the points that the model builder is trying to get across. The more technical the subject matter, the more difficult it will be to satisfy this property, although the subject matter itself does not necessarily have to have an effect on the understandability of the hierarchy itself. If the reader is able to understand the tool, then it is considered operable.

The last desirable characteristic of a value hierarchy is small size. In comparison, a smaller hierarchy is generally preferable to a larger one (Kirkwood, 1997). The key tradeoff is that it must also be collectively exhaustive. Therefore, the small size property is directly dictated by the minimum amount of information necessary to properly evaluate the decision problem. Small size also has an influence on the operability of the hierarchy. Larger hierarchies are generally more difficult to communicate to stakeholders than a compact hierarchy. The size also becomes an issue in the employment and analysis of the tool. A larger, more complex tool will be not only more difficult to use, but more difficult to evaluate.

The size issue must be considered in two dimensions. The nature of hierarchies is both horizontal and vertical. Therefore, the model builder must be sure to include not only the necessary breadth, but depth as well. Breadth of the model is determined by the number of values to which the fundamental value can be decomposed. As the level of tiers increases, the number of values generally increases exponentially. Therefore, an increase in depth has a direct effect on the breadth of the hierarchy. To keep these two issues under control, the “test of importance” and guidance by the model builder must be used to ensure that each tier and value are directly influential to the fundamental value.

2.4.3.3 Step 3 - Develop Evaluation Measures

Evaluation measures or attributes exist for determining how well an alternative performs with respect to a particular value. This can be accomplished qualitatively or quantitatively, but each lowest-tier value must be measurable. The evaluation measures should provide the mechanism for turning a subjective decision into an objective decision (Kirkwood, 1997). Graphically, the measures appear below the lowest level of decomposition in the value hierarchy. The model builder should use as many measures as necessary to properly quantify the attributes of the value.

2.4.3.3.1 – Types of Evaluation Measures

Evaluation measures may be classified as either natural or constructed and direct or proxy. The type of measure depends upon the availability of data regarding the value as well as whether the measure is qualitative or quantitative. A natural scale is one with a common interpretation to any audience. Constructed scales are developed specifically for measuring the value (Kirkwood, 1997). Generally, constructed scales are used when no natural scale is evident or they may also be used when there is not enough data to measure the value exactly (Kirkwood, 1997).

In addition to being either natural or constructed, a measure will also be either direct or proxy. Direct scales measure the degree of attainment of the value explicitly. A proxy measure still measures the value, but does so indirectly. Proxy measurement may use some other piece of data or a collection of data that represents the degree of attainment of the value. It is possible for any measure to be categorized as any combination of natural/constructed and direct/proxy (Kirkwood, 1997). A Natural-Direct measure is the most preferable, as it measures the value most accurately. Natural-Proxy and Constructed-Direct are next in terms of desirability, and a Constructed-Proxy scale is the least desirable since it requires interpolation between the measure and the value (Table 2.4) (Dawley, Marentette, & Long, 2008).

2.4.3.3.2 – Desirable Properties of Evaluation Measures

Just as with values, several properties are desirable for evaluation measures. In the case of the measures, model builders should consider measurability, operationality, and understandability. Measurability “defines the associated value in more detail than that provided by the value alone” (Keeney, 1992). Each measure must define the value as intended by the decision-maker. Operationality refers to a measure’s ability to “express relative preferences for different levels of achievement of an objective" (Keeney, 1992). Finally, a measure is considered understandable if any audience can easily understand its purpose as was originally intended by the model builder.

2.4.3.4 Step 4 – Value Function Creation

Value functions exist for the purpose of converting the measurement of an objective into value units. Converting the measurements into value solves the problem of the values being measured with different scales and different units. A Single Dimension Value Function (SDVF) plots the measurement of the value (x-axis) versus a related value unit from zero to one (y-axis) (Kirkwood, 1997). The least preferred score of a measurement will relate to zero, while the best possible score earns a full value of one. An alternative's degree of attainment of the value in question will be plotted on the x-axis of the measure. SDVFs are built using inputs from the decision-makers, stakeholders, or available data on the values.

SDVFs are defined by their shape and monotonicity; they may also be either continuous or discrete. Continuous SDVFs are either monotonically increasing or monotonically decreasing. Figure 2.5 is an example of a linear, monotonically increasing SDVF, meaning that the difference in value between 10 and 20 on the x-axis is the same as the difference between 70 and 80. Figures 2.6 and 2.7 are examples of exponential monotonically increasing SDVFs. In the case of Figure 2.6, the difference in value between 10 and 20 on the x-axis is considerably smaller than the difference between 70 and 80. This is referred to as a "convex" exponential curve. Figure 2.7 is referred to as "concave," and exhibits similar properties as a concave SDVF. Therefore, in this case, as more of the score is attained, the value gained gets smaller (more value is earned early), whereas in Figure 2.6, as more of the score is attained, the value gets exponentially larger (Kirkwood, 1997). Figures 2.8, 2.9, and 2.10 are all examples of monotonically decreasing SDVFs; measure 5 is a linear decreasing SDVF while measures 5 and 6 are exponentially decreasing SDVFs.   (Kirkwood, 1997). The decreasing SDVFs are interpreted the same way as increasing SDVFs.

Figure 2.11 is an example of a piecewise linear SDVF. Piecewise linear curves may also be monotonically increasing or decreasing. They are composed of multiple linear sections that are broken by inflection points. In the example measure, value is earned more quickly between x-axis values of 25 to 70, value is earned more slowly when the x-axis values are smaller than 25 or greater than 70 (Kirkwood, 1997).

Figures 2.12, 2.13, 2.14, and 2.15 are examples of “S-Curve” SDVFs. “S-Curve” SDVFs are a type of exponential curve which may also be either monotonically increasing or decreasing, but take on the properties of a piecewise curve while retaining the exponential shape. The four example measures shown are the four possible general configurations of S-Curves. They account for both monotonically increasing and decreasing curves as well as concave and convex shapes.

Figure 2.5. Monotonically Increasing

Figure 2.6. Monotonically Increasing

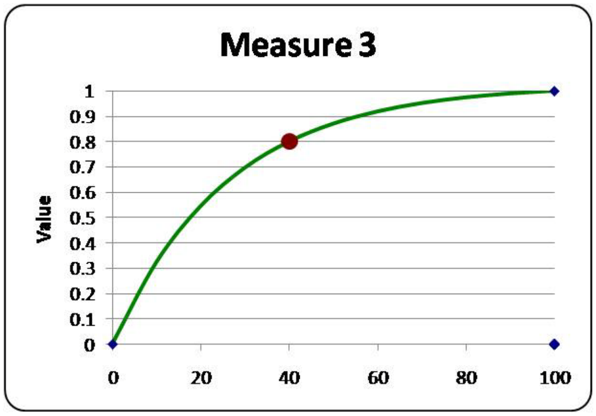
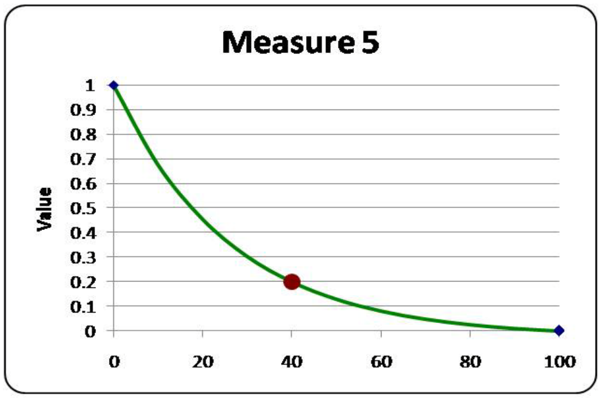


Figure 2.7. Monotonically Increasing

Figure 2.8. Monotonically Decreasing



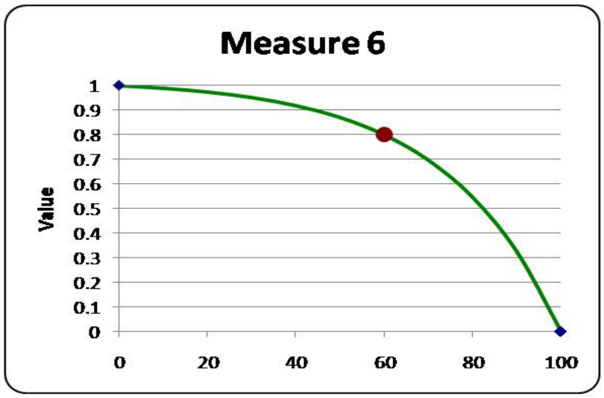


Figure 2.9. Monotonically Decreasing

Figure 2.10. Monotonically Decreasing

Figure 2.11 – Piecewise Linear

Figure 2.12. Monotonically Increasing

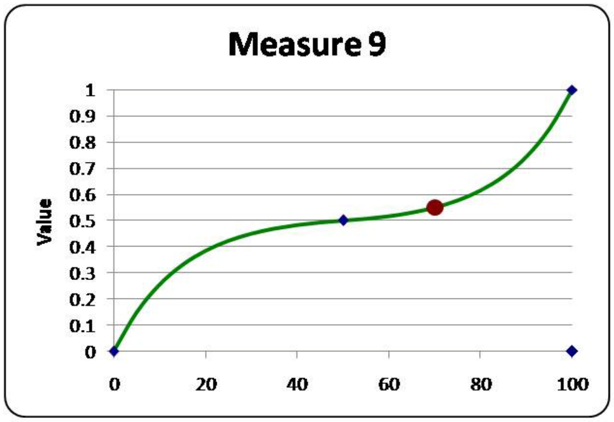


Figure 2.13. Monotonically Increasing

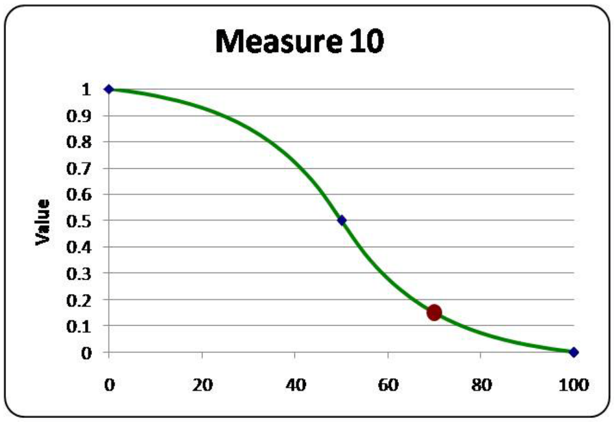


Figure 2.14. Monotonically Decreasing

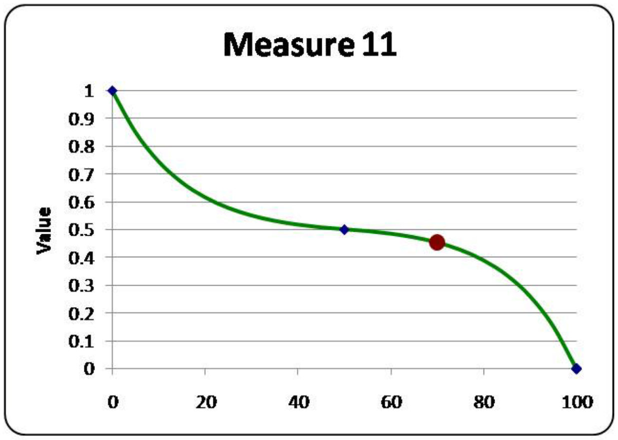


Figure 2.15. Monotonically Decreasing

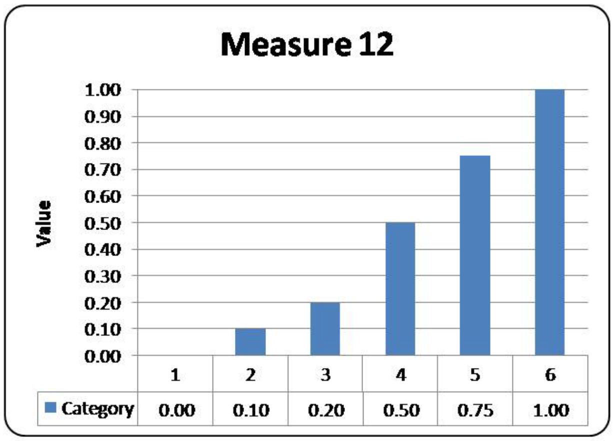


Figure 2.16. Discrete

The final possible type of SDVF is discrete. In this style of value function, the possible scores are grouped into categories or bins. The value, therefore, increases incrementally to account for the changes in categories. This type of SDVF is particularly useful for qualitative or binary measures. The categories must be well defined so that there is no question as to which category an alternative belongs. Figure 2.16 shows an example of a discrete measure.

2.4.3.5 Step 5 – Value Hierarchy Weights

With the value hierarchy and SDVFs created, the decision-maker has a solid frame of reference for what is important, as well as a basis for the values implicit in the decision. Each value must then be weighted to show its relative importance to the decision-maker. There are two primary methods for determining the weight of each value, the direct weighting method and the swing weighting method. Both of the methods give rise to local weights and global weights (Shoviak, 2001).

Local weight refers to the relative importance of a single value in relation to other values in the same branch and tier. Therefore, the values in each branch and tier must sum to one. In the case of Figure 2.5, all values in Tier 1 must total 1. Therefore, Tier 1 Value 1 may have a weight of 0.6, while Tier 1 Value 2 has a weight of 0.3 and Tier 1 Value 3 has a weight of 0.1. This means that Tier 1 Value 1 is twice as important as Tier 1 Value 2, and Tier 1 Value 2 is 3 times as important as Tier 1 Value 3. This method is applied to each tier and branch of the hierarchy. Therefore, the weight of Tier 2 Value 1 and Tier 2 Value 2 must also sum to 1 to make up the total value of Tier 1 Value 1. Measures are also weighted in the same way. As the process moves, the model builder and decision-maker may weight the hierarchy moving from the lowest tier to the highest or from the highest to the lowest.

One method for leading the decision-maker to a conclusion of the weights is the use of the "100 Coin" method (Jurk, 2002). In this situation, the decision-maker is asked to distribute 100 "coins" between the values; i.e. if the decision-maker had 100 coins to distribute between the different values, where would they be placed? In this method, the number of "coins" placed on any value becomes the percentage of importance or the percentage of emphasis placed on one value when compared to others in the same tier and branch. Decision-makers may also be asked to rate each value relative to the others. For example, the decision-maker may say that "Tier 1 Value 1 is twice as important as Tier 1 Value 2 and Tier 1 Value 2 is 3 times as important as Tier 1 Value 3." In this case, the weights become 0.6, 0.3, and 0.1, respectively. Ratios may also be used to determine the weights.

Local weights determine the relative importance of values in relation to the other values on the same tier, but values must also be rated in terms of "Global" importance. These weights are referred to as "Global Weights." The global weight may be found through direct weighting or it may be found after local weighting by their multiplicative functions in relation to the overall fundamental value in the hierarchy. Global weights must sum to 1 across an entire tier as opposed to local weights, whose sum must be one for a tier in any given branch. Consider a case in which Tier 2 Value 1's local weight is 0.75 and Tier 2 Value 2's local weight is 0.25 locally. In this case, the weights are multiplied up the hierarchy to determine their global importance. If Tier 1 Value 1's weight is 0.6, then the global weights for Tier 2 Value 1 and Tier 2 Value 2 become 0.45 ($x = 0.75*0.6$) and 0.15 ($x = 0.25*0.6$), respectively. Figure 2.17 shows the example hierarchy with local weights displayed and Figure 2.18 shows the hierarchy with global weights displayed. As is evident here, all values in a tier total 1 and the measures are then weighted according to the value that they measure.

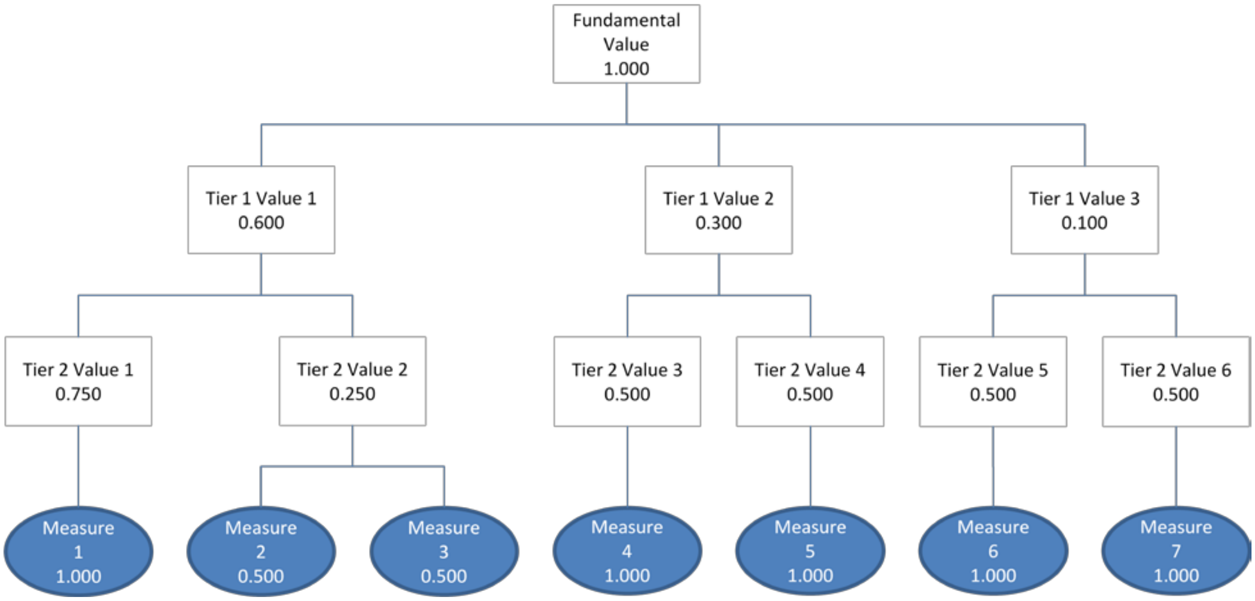


Figure 2.17. Example Hierarchy with Local Weights

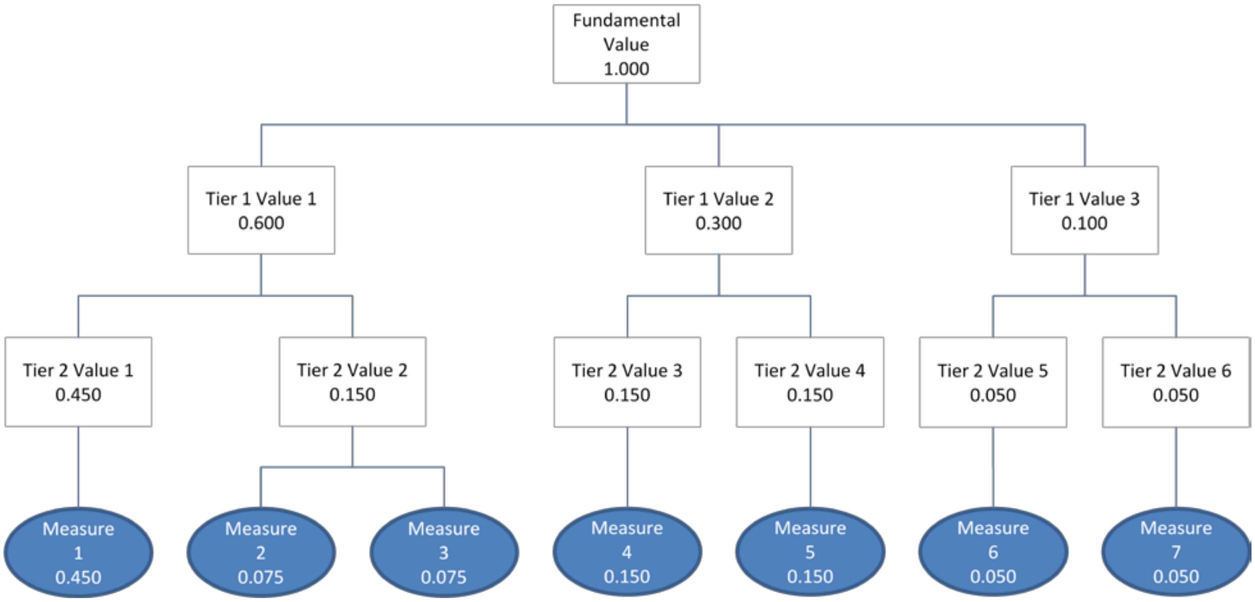


Figure 2.18. Example Hierarchy with Global Weights

Another method of weighting a hierarchy is known as "Swing Weighting." This method is a local weighting technique and was compiled from procedures set forth by Chambal (2008) and Kirkwood (1997). This technique examines the possible outcomes that may be reached based on the weights of the values. The decision-maker is asked to examine each tier of values and determine the change in increments of value that would be reached by varying the weight of each value from its least preferred state to its most preferred state. These increments are then placed in increasing order and assigned a factor of importance in relation to the smallest value. These increments, which should sum to one, are then solved as a system of equations to determine the local weight within the given tier (Jurk, 2002).

2.4.3.6 Step 6 – Alternative Generation

One of the advantages of using VFT is the ability to generate alternatives as opposed to simply choosing from given alternatives. Once the hierarchy has been weighted, this is possible. In the initial stages of alternative generation, experience gained by simply creating the hierarchy will often yield a great number of possible alternatives. Building the hierarchy often gives the decision-maker new ideas and insights into the importance of the outcome and new ideas for alternatives. "Either the alternatives are somewhere in the mind waiting to be found, or they can be created from what is in the mind" (Keeney, 1992, p. 198).

If too many alternatives are found, the list must be reduced to a manageable number. In this case, additional screening criteria may be added to eliminate some of the less desirable options. Screening criteria are based on values that serve to eliminate some alternatives prior to scoring. A screening criteria may be established if some alternative scores zero on a particular measure. Screening criteria may also be something that is required by the decision-maker; i.e., if some value or condition is not true, the alternative is eliminated completely from consideration.

Some values may be so important that an alternative will not be considered without their inclusion. Alternatives may also be eliminated based on known values. If there are not enough alternatives, this usually suggests a gap in the value hierarchy, i.e., there is something important which is not being considered and that would give the decision-maker more alternatives. Strategy generation tables may also be used to generate alternatives (Kirkwood, 1997). The most important thing to remember during this process is that the alternatives must satisfy the values in the hierarchy. In some cases, alternative generation may not be necessary if the field of alternatives is given or if some outside factor limits the alternatives.

2.4.3.7 Step 7 – Alternative Scoring

Following alternative generation, each alternative must be individually scored. Data is collected regarding each alternative and its attainment of each lowest-tier value (based on the measures of those values). Scores are then assigned to each measure within each alternative. During this process, the y-axis or value units are hidden from the scorers, so that the value does not impact the scoring of the alternatives. Each score must be well documented, clearly defined, and repeatable by anyone who scores the alternative.

2.4.3.8 Step 8 – Deterministic Analysis

The deterministic analysis step combines all data collected to this point. Through the use of an additive value function, the scores given to each alternative (step 7) are converted to value units (step 4), and then multiplied by their weights (step 5) to yield a single aggregate score. The additive value function is the way in which the decision-maker may perform detailed analysis of the alternatives (Shoviak, 2001). The general additive value is described in equation 2.1 (Kirkwood, 1997):

$$v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i) \tag{2.1}$$

Where $v(x)$ is the overall score of the alternative, $v_i(x_i)$ is the value of the score on the i^{th} measure, λ_i is weight of the i^{th} measure, n is the total number of measure, and the sum or all λ_i must equal one.

2.4.3.9 Step 9 – Sensitivity Analysis

Sensitivity analysis is performed on the hierarchy to provide additional insight into the weighting of the values and how they affect the scores of the alternatives. Typically, sensitivity analysis is performed on the higher tiers of the hierarchy, since altering the weights of values on lower tiers will have less effect on the total score. Sensitivity analysis is performed by systematically altering the weight (local or global) of one value, while keeping the other weights on that tier proportional. The weights must continue to sum to one across a tier. Sensitivity analysis serves to answer the question, “How would this decision change if another interested party had weighted the hierarchy or provided data for the SDVFs?” (Katzer, 2002, p. 46).

2.4.3.10 Step 10 – Recommendations Presentation

The final step in the process requires the model builder to present recommendations to the decision-maker. Parnell suggests that one-third of decision analysis efforts should be placed in the recommendations presentation. The recommendations must be easy to understand for all audiences. They must also explain the decision made and why it was made. It is important to remember that the final decision still lies in the hands of the final decision authority. The VFT process serves to assist the decision-making process and provide objective data and an analysis of alternatives. There may be cases where the recommended alternative may not be chosen.

2.5. Management and Planning Tools

As a part of the value determination process, it may be necessary to organize information found during the document review phase. Several tools exist for managing ideas and concepts. Tague (2004) identified seven management and planning tools; these consist of affinity diagrams, interrelationship diagrams, tree diagrams, prioritization matrices, matrix diagrams, process decision program charts, and activity network diagrams. These tools were organized in 1976 in an effort to collect quality control techniques (Tague, 2004). All of them were not created at this point, but were put together in a single work for managers to easily locate. The tools allow managers to organize ideas and concepts to make better, more efficient decisions, which take into account all known information.

2.5.1 Affinity Diagrams

The affinity diagram, developed by Jiro Kawakita in the 1960s, was created to expound on the brainstorming group creativity technique. In brainstorming, groups of people come together and generate as many ideas as possible related to a single concept. This method focuses on the power of the group to generate a larger quantity of ideas than any individual can (Osborn, 1953). Affinity diagramming takes this more generalized approach and improves upon it. The brainstorming process is used to initially generate ideas, but through a process of organization and idea mapping, combined with subsequent discussion, the ideas are eventually sorted into descriptive groups. Affinity diagrams are used in situations when there are a great many ideas or issues, which are in no apparent order and complex in nature (Tague, 2004).

The decision-maker benefits from the large quantity of ideas generated by the team by using the affinity diagramming technique. The process begins by describing the problem and ensuring that all team members are familiar with the issues. The brainstorming technique is then used to gather as many ideas as possible. These ideas are then written on individual note cards or “sticky notes.” The members of the affinity diagramming team then physically begin to silently organize the notes into groups. Each person in the process may have their own ideas, so some notes are moved several times, but no discussion is allowed during this process. Once all notes are placed in groups or set aside for discussion, the resulting groups are discussed and examined by the team. Finally, any “super groups” that have emerged are created by defining the individual groups and further organizing the cards. The end result of this process is a number of groups and possibly hierarchies which describe ideas (Tague, 2004).

The Value-Focused Thinking process involves a top-down analysis approach, but at times, it is difficult to determine the lowest-level tier values. Affinity diagramming provides a method for combining a bottom-up approach to the existing process to ensure accurate definition of the lowest tier (Pruitt, 2003). Affinity diagramming is an appropriate technique, due to its ability to organize large amounts of complex information into groups with sub-categories being built into the technique.

2.5.2 Other tools

In addition to affinity diagramming, there are several other tools commonly used in the management and planning industry (Tague, 2004). Each of these tools is used for a very specific purpose. Interrelationship diagrams, for example, describe the links and interfaces between ideas. They serve to identify any cause and effect relationships that exist. They are also used for complex issues, but are generally used as a follow-on to affinity diagramming when cause and effect relationships must be defined (Tague, 2004). Tree diagrams may also be used to breakdown more general ideas into their components. Tree diagrams often depend on affinity diagrams to first identify the issues upon which to expand (Tague, 2004). Matrix diagrams are another way of showing relationships between ideas, but they organize the relationships differently than an interrelationship diagram. Matrix diagrams can also show relationships between multiple groups of information, while including specific information regarding the relationship. They can be categorized into six different "shapes," which can be used for different numbers of groups and different types of relationships (Tague, 2004). Matrix data analysis then allows the decision-maker to perform complex mathematical analyses on the resulting matrices (Tague, 2004). "L-Shaped" matrices are often used to prioritize ideas (Tague, 2004). An arrow diagram; also known as program evaluation and review technique (PERT) chart, network diagram, activity chart, critical path method (CPM), or node diagram; is used to describe the order of tasks. Arrow diagrams are very useful in showing chronological order of ideas. They can describe when tasks precede others as well as durations (Tague, 2004).

2.6 Net-Centricity

Net-centricity refers to the process by which several nodes in communication with each other operate. In the evolving technological world, it is increasingly important that the complex network of personnel, devices, services, and information be connected. The speed of communication and efficiency of passing information between this complex system of nodes has a major part in the decision-making process. The information age has given society access to a large amount of previously unavailable information; it is now a matter of ensuring that the technology and infrastructure exists to move the information to the correct person at the correct time.

Net-centricity has given way to Net-Centric Warfare (NCW) within the U.S. military. NCW is defined by Albert et al. (2000) as,

> an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision-makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization.

The concept of NCW is the idea of linking nodes to transfer information, thereby ensuring information superiority for the warfighter (Alberts, Garstka, & Stein, 2000).

2.6.1 Net-Centric Enterprise Architecture

As systems architecture grows, the importance of capturing the communication between nodes in a relevant manner is becoming increasingly important. To emphasize this idea, Net-Centric Enterprise Architectures are becoming the standard in the systems engineering field. A net-centric enterprise architecture is formally defined by Nzuwah (2003) as,

> a light-weight, massively distributed, horizontally-applied client/server architecture, that distributes components and/or services across an enterprise's information value chain using internet technologies and other network protocols as the principal mechanism for supporting the distribution and processing of information services.

The concept of a net-centric architecture, therefore, is any architecture that makes use of technology to ensure the proper communication of all nodes in the system. In the case of systems architecture, this can refer to not only the products themselves, but to the development of the products and the net-centricity of the instantiated system. The system being represented by the architecture must also hold to the principles of net-centricity.

2.6.2 Net-Centric Enterprise Solutions for Interoperability (NESI)

Currently, the DoD does not explicitly require the implementation of net-centricity; however, it has made the intended direction to move toward it obvious. The DoD's Chief Information Officer (CIO) has stated a goal to integrate data into a central network and change the paradigm from data “push” to “pull” (Department of Defense Chief Information Officer, 2003). To this end, the U.S. Navy Program Executive Office for Command, Control, Communications, Computers, and Intelligence, in cooperation with the U.S. Air Force Electronic Systems Center and the Defense Information Systems Agency has produced the Net-Centric Enterprise Solutions for Interoperability (NESI) as a series of guidance documents. NESI provides cradle-to-grave actionable guidance for the implementation of net-centric systems that meets the goals set forth by the DoD CIO. NESI pulls together several sources to provide a body of knowledge encompassing architectural and engineering information for each step of the acquisition process. In addition to the general guidance, NESI contains checklists for the project manager to ensure compliance with the guidelines set forth in NESI (US Navy Program Executive Office for Command, Control, Communications, Computers, and Intelligence, 2008). Unfortunately, at this point, compliance with NESI is not required by the Navy or any DoD agency (Eitelberg, 2008).

Chapter 3. Methodology

The Joint Force Protection Advanced Security System (JFPASS) has the unique challenge of creating a single, joint architecture to represent force protection across the services. This architecture must be understood by various stakeholders as well as represent an effective system, which will be the groundwork for all future force protection acquisition efforts. This led the architecture developers to seek out a tool for evaluating and gaining insight into their product.

Drawing upon Value-Focused Thinking (VFT), this research presents a Value-Driven Enterprise Architecture score for mapping architectural products to stakeholder acquisition values. The generalized VFT methodology laid out in Chapter 2 is built upon in this section to extend to enterprise architecture evaluation with a value focus in application to the JFPASS architecture. Each step of the process is examined in depth to build the final hierarchy. This includes all steps up to and including step 7.

3.1 Problem Identification

The JFPASS project grew out of the DoD's need to be both more net-centric and more joint. A series of architectural products were developed to meet this requirement. This architecture has similar problems to other architectures in the lack of effective evaluation tools, but a new element for this problem is the extreme complexity of the architecture and the desire to examine both the architectural quality and the *System Effectiveness* with a single tool.

To solve the problem of evaluating the architecture, the research question was framed as: "How should common Joint Force Protection values be used to evaluate a "To-Be" architecture for net-centric force protection" (Havlicek, 2008). In this case, the system is the JFPASS architecture. To further define the problem, the context was first researched and defined.

Several documents refer to the protection of personnel, assets, and information as the three key areas to be protected in the context of joint force protection (IUBIP, 2006; JCS, 2004; Office of the CJCS, 2008; Office of the CJCS, 2007). Figure 3.1 shows a hierarchy of the documentation and guidance that guides force protection. Figures 3.2 through 3.4 specialize this idea to show the mediums from which each area must be protected.

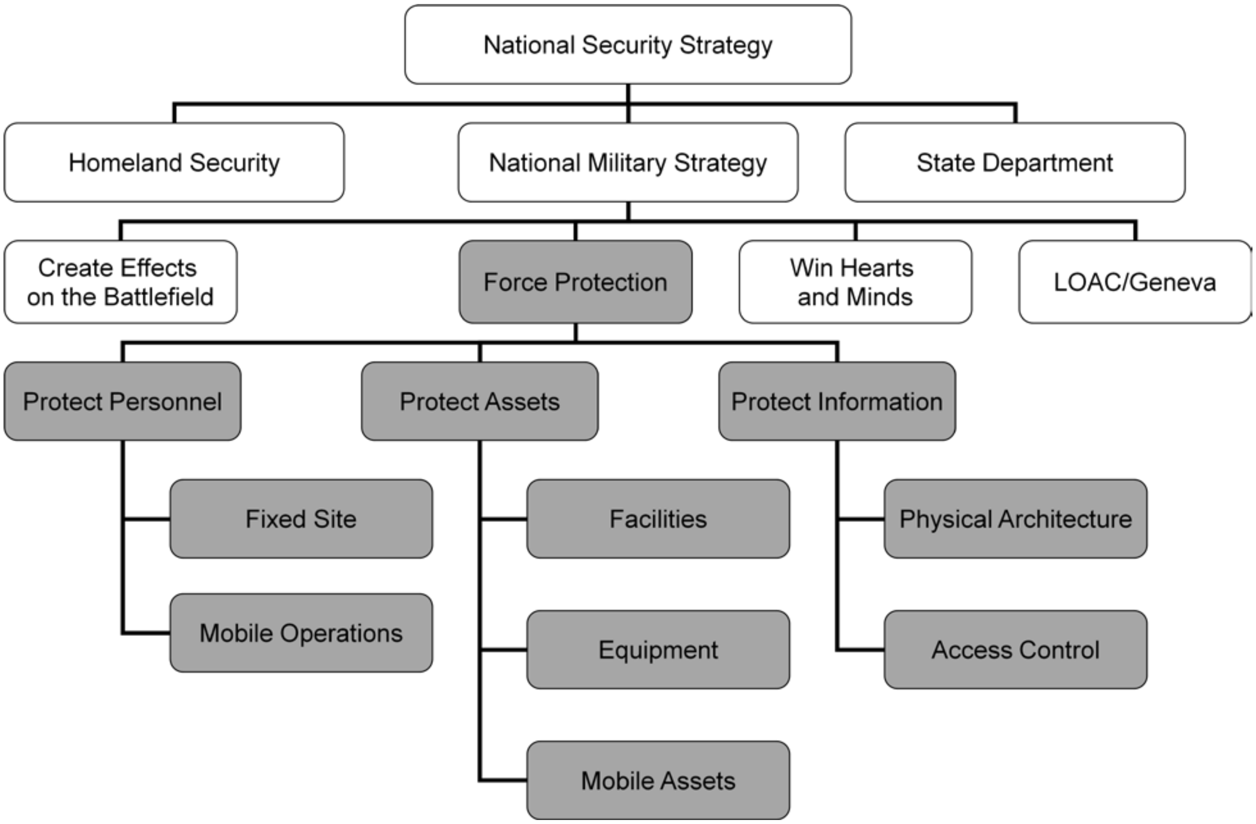


Figure 3.1. Documentation Hierarchy for Force Protection

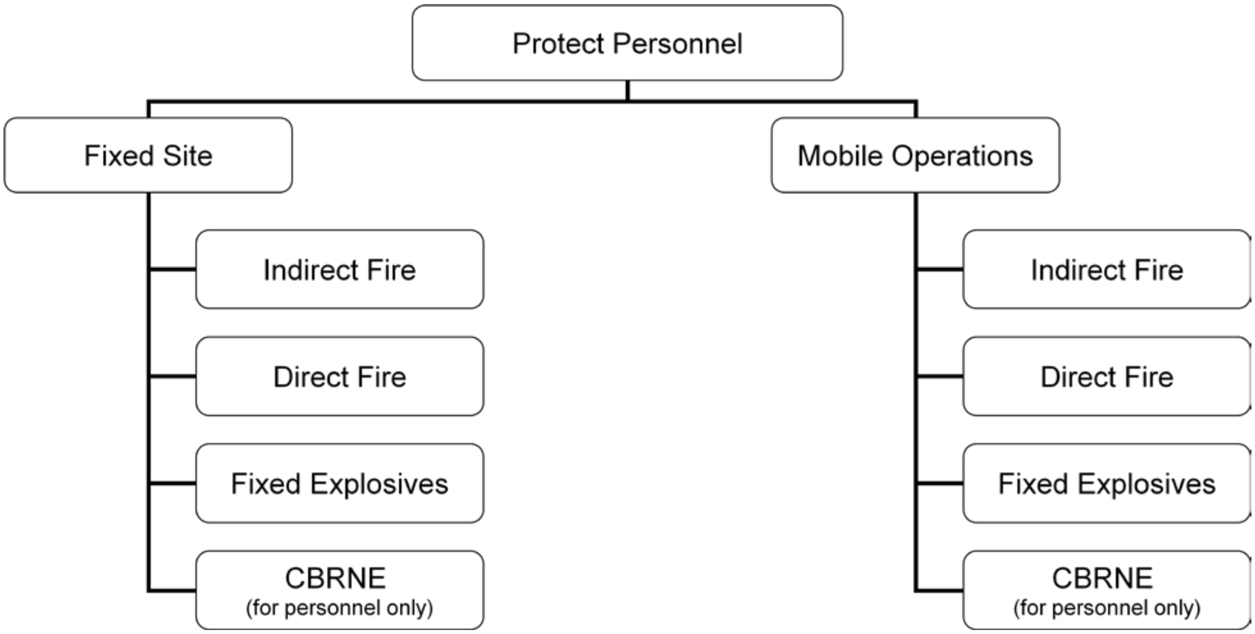


Figure 3.2. Protect Personnel Specialization

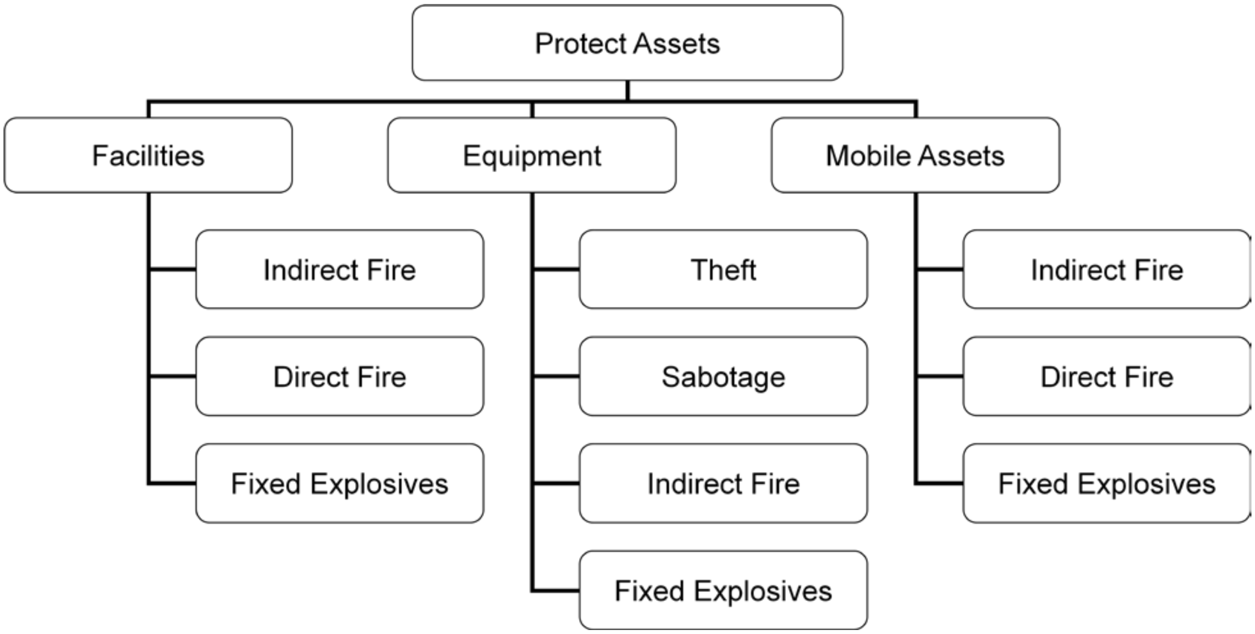


Figure 3.3. Protect Assets Specialization

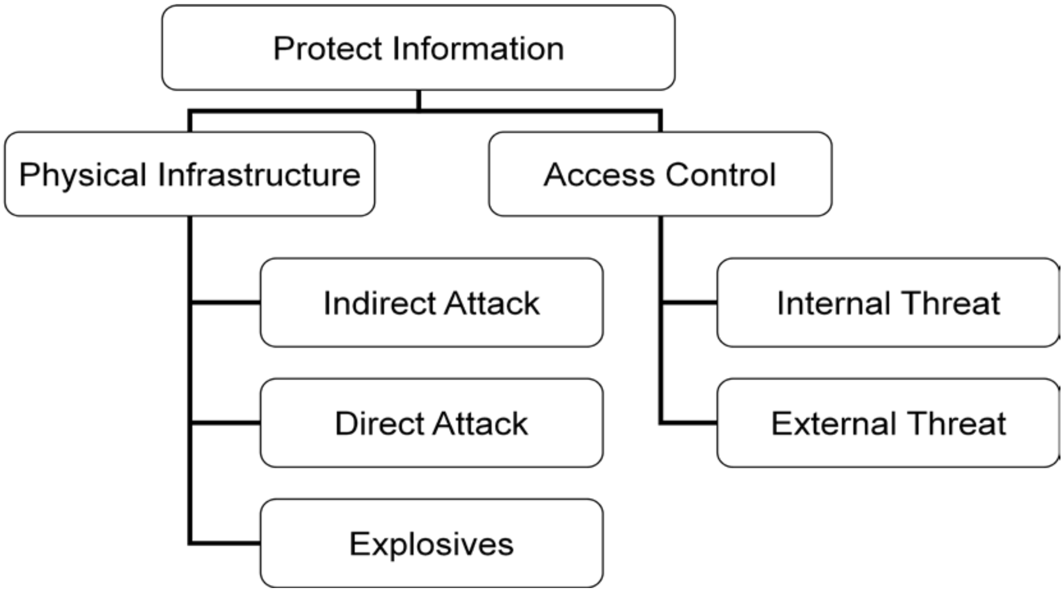


Figure 3.4. Protect Information Specialization

The National Security Strategy (NSS) provides the highest-level guidance for military operations (Office of the President of the United States of America, 2002). The National Military Strategy (NMS) specifies the military portion of the NSS (Joint Chiefs of Staff, 2004). One of the four tenets of the NMS is force protection, which is divided into the protection of personnel, assets, and information. The IUBIP specifies that the scope of force protection be across fixed, semi-fixed, and mobile sites. Fixed sites are defined as those facilities in either the Continental United States (CONUS) or Outside the Continental United States (OCONUS) where Mutual Security Agreements or Status of Forces Agreements exist. Semi-fixed sites are any locations established for a temporary purpose, which includes expeditionary locations or locations in the CONUS or OCONUS that are no intended to be occupied for more than one year at construction. Finally, mobile sites are those where a unit is performing its mission, including convoys, logistics patrols, or other movements between sites.

At each of the three types of sites, personnel and assets must be protected in the same basic ways, as the personnel generally depend on the assets (vehicles and buildings) for shelter and movement. Often attacking an asset will have a direct affect on the security of the associated personnel. Chemical, Biological, Radiological, Nuclear, and High-Yield Explosives (CBRNE) risks, however, are only considered for personnel, since CBRNE threats do not have an effect on the assets, aside from denial of their use. The CBRNE threat is intended to impact the personnel occupying the asset. Protecting information is a slightly different concept. Information must be protected in two contexts: the infrastructure that carries information and the access that individuals have to that information. Access control involves not only electronic access control such as ensuring that only authorized personnel have access to the information, but also ensuring that access is not granted from person to person-to-mission critical information.

Within the context of protecting personnel, assets, and information, force protection must accomplish all of the DAWDR (Detect, Assess, Warn, Defend, Recover) activities. For the JFPASS project, the focus of the architecture is only on the Detect, Assess, and Warn activities, although mechanisms exist in the architecture for the Defense and Recovery of a location.

3.2 Create Value Hierarchy

The first decision to be made regarding the value hierarchy was the basic split of how to evaluate the system. Two divisions of quality must be addressed: the quality and accuracy of the architectural views or products and the effectiveness of the instantiated system that the architectural products attempt to represent. Due to the complexity of the system, the divisions were separated into separate branches. This decision leads to better decomposability and easier operability (Kirkwood, 1997). Splitting the architecture from the system also ensures independence and mutual exclusivity of each value, as some ideas apply to each side, but in a different context. Furthermore, the operability of the hierarchy is improved by making the hierarchy not only easier to read, but also extendable to other situations. With the architecture and system aspects separate, both branches may be used independently in other projects. Either of the two branches may also be replaced by another branch to increase accuracy for use on another system, thus making the hierarchy modular. However, making this separation violates the desirable property "small size" of a hierarchy. By separating the two values, the hierarchy would potentially be larger in terms of total branches, although the number of measures would stay the same due to the requirement to measure the same information, regardless of the outcome of this decision.

3.2.1 Hierarchy Background

The initial value hierarchy created to address the problem presented in Section 3.1 was developed using "ilities" and the affinity diagramming process. A representative list of ilities was gathered from various sources, including Ross (2006); McManus, Richards, Ross, and Hastings (2007); and INCOSE (International Council on Systems Engineering, 2007). The internet website "Wikipedia" also contains a list of ilities, which was used to ensure that as many ilities as possible were gathered. Since Wikipedia is a user-edited site, this gives a wider pool of quality attributes from which to pull at the risk of getting inaccurate information. Since this data pull was intended only to gather terms, not definitions or uses, inaccurate information was not an issue (Wikipedia, 2006). This search for ilities was done in place of an on-site brainstorming process, to ensure that previous research and uses of the quality attributes were represented in the list. The full list of 98 ilities is shown in Appendix A. Ilities were chosen for this exercise for their historical use in describing the quality attributes of various systems. By finding all of the applicable ilities related to the project, it was possible to capture all of the necessary quality attributes to describe both the architectural quality of the products and the effectiveness of the instantiated system.

In accordance with the affinity diagramming process, each of these ilities was written on individual note cards. The affinity-diagramming team was then sequestered in silence to physically arrange the note cards into groups of similar qualities. At the conclusion of the process, 30 subgroups were found. This led to an interactive discussion of the groupings and further refinement of the subgroups. This discussion first identified quality attributes and subgroups that did not apply to the JFPASS project. The eliminated ilities were: composability, demonstrability, learnability, nomadicity, portability, predictability, seamlessness, testability, timeliness, trainability, and transactionality. Composability refers to creating some new form by combining components. While the construction of the system will be created through the combination of its components, the ability to do so was not considered a measurable quality attribute. The actual combination of components is a design consideration that must be considered before any architectural products are produced. Demonstrability and testability refer to the ability of the system to be demonstrated. These ilities were eliminated because the JFPASS Joint Capabilities Technology Demonstration is already in progress; therefore, the demonstrability of the system is assumed and is not required as a quality attribute. Learnability and trainability were considered too vague due to the confusion as to whether the learning referred to the system or the system users. Trainability is an attribute that will be considered at some point in the creation of the system, but as JFPASS is a "system of systems" still in the design phase, there is no way to definitively measure the ability of the system to be taught to others. Nomadicity and portability were eliminated because the JFPASS is not considered a "mobile" system. Predictability and seamlessness were also vague in definition in terms of the

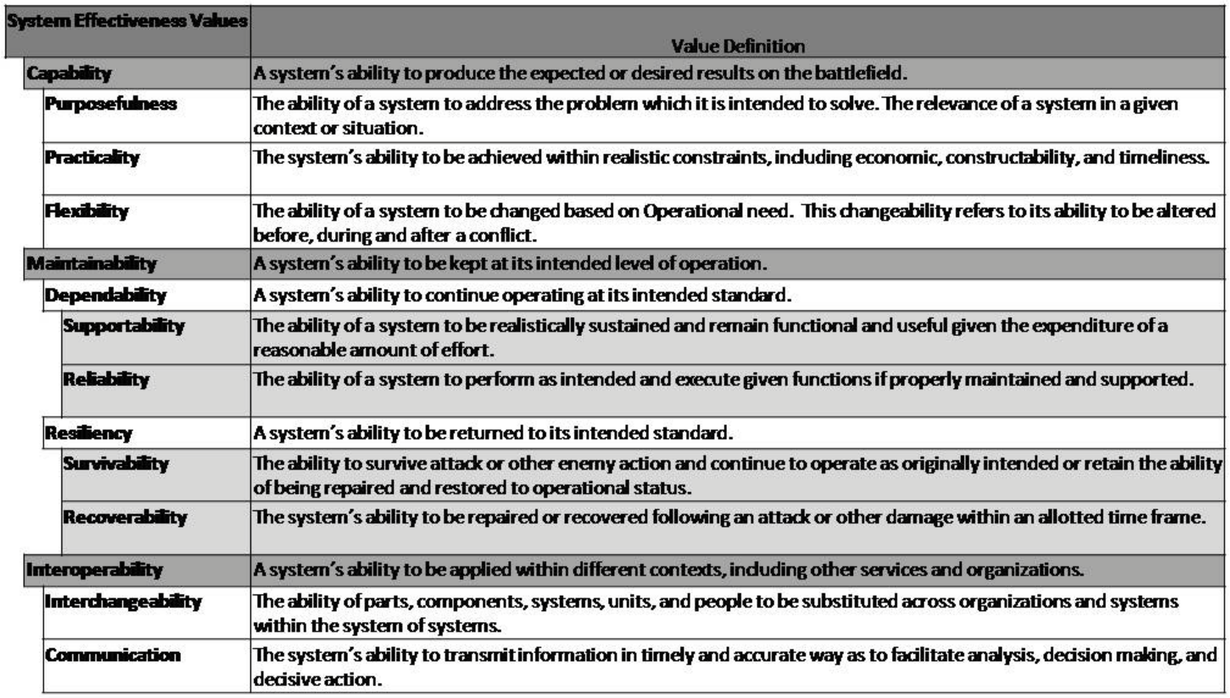
JFPASS system. Timeliness refers to the time required to create the system. While timeliness could be defined to show when the system will be fielded and implemented, there are currently no time estimates or requirements for the fielding of the system. Finally, transactionality was eliminated due to the connotation of its root word, "transaction." There will be no monetary transactions taking place as a function of this system; therefore, the ility was eliminated.

The resulting 22 subgroups were then examined for agreement and accuracy. After minor alterations to the locations of certain words based on definition, super groups were formed. The two primary supergroups were based on the decision to split the architecture and system qualities. The groups related to the quality of the system being represented were placed in a supergroup called "*System Effectiveness*," while the groups related to the quality of the architectural products were placed in a supergroup called "*Architecture Quality*." *Architecture Quality* is addressed by Cotton and Haase (2009). The *System Effectiveness* supergroup is addressed here. The group names shown in the following discussion and tables are based on the final decisions, following sponsor discussion.

The *System Effectiveness* value was subsequently decomposed into three second-tier values: *Capability, Maintainability, and Interoperability*. *Maintainability* was comprised of two third-tier values called *Dependability* and *Resiliency*. *Dependability* was further decomposed into *Supportability* and *Reliability*, while *Resiliency* was decomposed into *Survivability* and *Recoverability*. Appendix B shows the final *System Effectiveness* quality attributes grouped according to value, along with their synonyms.

Prior to creating the hierarchy itself, each value group name was defined to ensure that the synonyms that compose the group were accounted for in the final consideration of the group. Each of the value definitions are listed in Table 3.2. These definitions incorporated the definition of the quality attribute itself and the synonyms for the particular group name, as well as the value to the decision-maker. Following sponsor discussion, the defined and grouped ilities were converted into a value hierarchy. The resulting hierarchy is shown in Figure 3.5

Table 3.2 System Effectiveness Value Definitions



System Effectiveness Values	Value Definition
Capability	A system's ability to produce the expected or desired results on the battlefield.
Purposefulness	The ability of a system to address the problem which it is intended to solve. The relevance of a system in a given context or situation.
Practicality	The system's ability to be achieved within realistic constraints, including economic, constructability, and timeliness.
Flexibility	The ability of a system to be changed based on Operational need. This changeability refers to its ability to be altered before, during and after a conflict.
Maintainability	A system's ability to be kept at its intended level of operation.
Dependability	A system's ability to continue operating at its intended standard.
Supportability	The ability of a system to be realistically sustained and remain functional and useful given the expenditure of a reasonable amount of effort.
Reliability	The ability of a system to perform as intended and execute given functions if properly maintained and supported.
Resiliency	A system's ability to be returned to its intended standard.
Survivability	The ability to survive attack or other enemy action and continue to operate as originally intended or retain the ability of being repaired and restored to operational status.
Recoverability	The system's ability to be repaired or recovered following an attack or other damage within an allotted time frame.
Interoperability	A system's ability to be applied within different contexts, including other services and organizations.
Interchangeability	The ability of parts, components, systems, units, and people to be substituted across organizations and systems within the system of systems.
Communication	The system's ability to transmit information in timely and accurate way as to facilitate analysis, decision making, and decisive action.

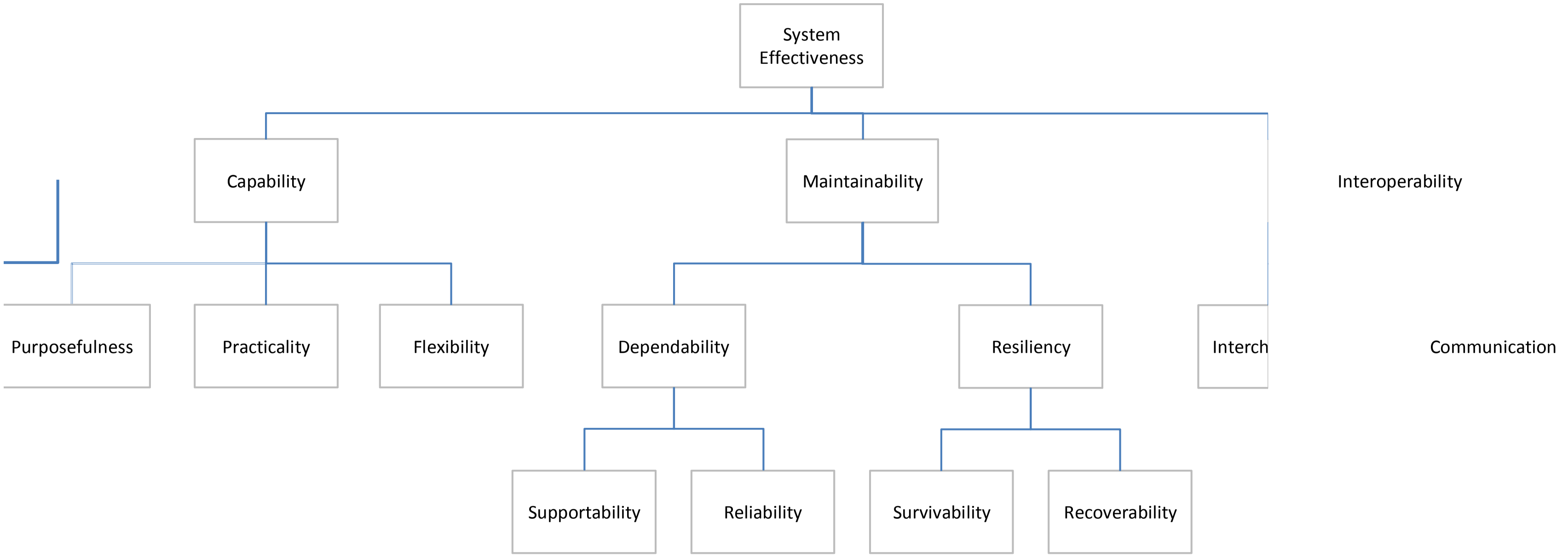


Figure 3.5. System Effectiveness Value Hierarchy

3.2.2 *System Effectiveness* Hierarchy

In the creation of the value hierarchy, several naming changes, definition changes, and alterations to structure were required to create a representative hierarchy. These changes were accomplished through further literature review and during meetings with the decision-maker and sponsoring organization. The value hierarchy was created using the resulting groups of the affinity diagramming process, based on quality attributes. This section describes the values found on each level of the hierarchy in more depth. The initial draft hierarchy was presented during these meetings, resulting is discussion and ultimately validation by a panel of Subject Matter Experts (SMEs) and the decision-maker.

In the initial iteration of the value tree, the *System Effectiveness* branch was called System Value. During a discussion regarding the naming and definition of the *Capability* value (which was initially named Effectiveness), it was decided that the term Effectiveness better described the entire System branch as opposed to a single value under the system branch; therefore, Effectiveness was promoted to the branch name to better describe all of the values under the branch. Each of the values in the branch (*Capability*, *Maintainability*, and *Interoperability*) relate to the overall effectiveness of the instantiated system.

3.2.2.1 *Capability* Branch

Capability was originally known as Effectiveness. However, Effectiveness was decided to be too broad of a term to describe the purpose of the *Capability* branch. The *Capability* branch was defined as, "A System's ability to produce the expected or desired results on the battlefield." Subsequently, it is intended to represent the operational ability of the system to accomplish its intended purpose. In other words, a system must have the ability to meet the objectives for which it was designed. On the third tier of the hierarchy, *Capability* is decomposed into *Purposefulness*, *Practicality*, and *Flexibility*. These lower tier values serve to specify the ideas that make up *Capability*.

Within the context of *Capability*, the "the ability of a system to address the problem which it is intended to solve or the relevance of a system in a given context or situation" was called the *Purposefulness* of the system. This value actually defines whether the system does what it is intended to do in the proper situations. The value of *Purposefulness* is used to account for a major idea of *System Effectiveness*. This value accounts for a great deal of the *Capability* of a system.

The *Practicality* of the system defines whether it can actually be realized. *Practicality* is officially defined as, "The system's ability to be achieved within realistic constraints, including economic, constructability, and timeliness." This value was considered important due to the inability of the system to accomplish its intended objectives if it cannot be constructed or implemented within realistic constraints. Without a practical system, the goals of the system designer will not be achieved.

The *Flexibility* value was initially placed under the *Interoperability* branch due to a connotation involving its ability to change to operate with other systems. However, a system's ability to change in relation to other systems is primarily determined by its initial design once it is implemented. Therefore, *Flexibility* was moved to better capture the system's ability to change to meet changing and evolving operational objectives. This allowed a more strict definition, which eliminated the problem of broad connotations for the word *Flexibility*. The official definition of *Flexibility* is "the ability of a system to be changed based on operational need. This changeability refers to its ability to be altered before, during, and after a conflict."

3.2.2.2 *Maintainability* Branch

The entire *Maintainability* branch was validated by the decision-maker as being acceptable as initially presented. Definitions of values were altered slightly to ensure maximum achievement of the decision-maker's values. *Maintainability* itself is defined as, "A system's ability to be kept at its intended level of operation." Any system requires some type of regular action to ensure that its intended operation continues uninterrupted.

Below *Maintainability*, the first branch was called *Dependability*. *Dependability* is officially defined as, "A system's ability to continue operating at its intended standard." The *Dependability* branch refers to the maintenance of the system under normal operating conditions. *Dependability* deals with the "peacetime" operations and maintenance of a system. On the next tier, *Supportability* is one of the values under *Dependability*. This value deals with a system's ability to operate as normal, given a standard maintenance schedule. *Dependability*'s definition is "the ability of a system to be realistically sustained and remain functional and useful given the expenditure of a reasonable amount of effort." A reasonable amount of effort refers to operations performed in accordance with a standard maintenance schedule. This value does not incorporate major alterations or repairs, only a normal recurring work program type of maintenance. The second value under *Dependability* is *Reliability*. The *Reliability* value deals with the ability of the system to continue its operation if maintained properly. *Reliability* is the relationship between *Supportability* and the operation of the system. Its definition is "the ability of a system to perform as intended and execute given functions if properly maintained and supported."

Resiliency is the second branch falling directly under *Maintainability*. *Resiliency* is "a system's ability to be returned to its intended standard." If the *Dependability* branch deals with a system's operation during normal peacetime or uninterrupted operations, *Resiliency* refers to the system's operation following some type of interruption. In the context of Joint Force Protection, this interruption is some type of hostile action. *Resiliency* measures how easily a system may be repaired following such an action. Under *Resiliency*, the first of two values is *Survivability*. *Survivability* is the part of *Resiliency* dealing with a component's ability to withstand some hostile action. It is defined as "the ability to survive attack or other enemy action and continue to operate as originally intended or retain the ability of being repaired and restored to operational status." *Survivability* measures how a system operates once it has been affected by some hostile action. The second *Resiliency* sub-value is *Recoverability*. *Recoverability* is another portion of *Resiliency* referring to a system's ability to be returned to full operational status following an interruption of operations due to hostile action. It is defined as "the system's ability to be repaired or recovered following an attack or other damage within an allotted time frame." The definition refers to repair and recovery, both of which are intended to allude to the returning of the system to its original intended operation or the state that it was at prior to the hostile interruption. "An allotted time frame" is a time period at the decision-maker or user's discretion. Any system or system component must be designed to be returned to its original level of operation within a specified time frame.

3.2.2.3 *Interoperability*

Interoperability is the value which measures the ability of the system to operate in conjunction with other systems and nodes. *Interoperability* covers both the net-centricity of a system and its ability to be used in different contexts. *Interoperability* is defined as "a system's ability to be applied within different contexts, including other services and organizations."

Interchangeability is the portion of *Interoperability* that accounts for the system and components to be useful across different contexts. The decision-maker and subject matter experts felt that it was very important for components to be interchangeable. Each system and component should be able to be changed out for another seamlessly. This concept includes personnel as well as components. Soldiers, Airmen, Sailors, and Marines must all have the same basic knowledge on the systems in question and be trained to the same level in force protection awareness. JOINT OPERATIONS are extremely important and to accomplish a truly Joint environment, all personnel must have a similar training base. *Interchangeability* is defined as "a system's ability to be applied within different contexts, including other services and organizations."

Communication refers to the ability of the nodes within the system to communicate with each other. Both infrastructure and common languages are important for this value to be achieved. *Communication* is "the system's ability to transmit information in timely and accurate way as to facilitate analysis, decision making, and decisive action." An interoperable system must send information between nodes quickly and with complete data integrity.

3.3 Develop Evaluation Measures

With the full value hierarchy built, each lowest-tier value must be measured. Therefore, the lowest-tier values were assigned one or multiple evaluation measures. The goal of an evaluation measure is to determine the level of attainment of each value. Table 3.3 lists all evaluation measures, including their important characteristics. Although weights are not discussed until section 3.3, Table 3.3 also shows the global weights (λ) for each measure. The source for each measure suggests where a scorer should start investigating the architecture to find the information. Table 3.4 presents the definitions for each measure. Given the vast range

Table 3.3. *System Effectiveness* Evaluation Measures

	Measure Name	λ	Type	Source[1]	Lower Bound	Upper Bound
1	OPERATIONAL NEEDS	0.041	Constructed - Direct	SV-5	0%	100%
2	THREAT DETECTION	0.041	Constructed - Proxy	OV-5	No	Yes
3	THREAT ASSESSMENT	0.041	Constructed - Proxy	OV-5	No	Yes
4	WARNING PLAN	0.041	Constructed - Proxy	OV-5	No	Yes
5	TECHNOLOGICAL AVAILABILITY	0.02	Natural - Direct	SV-7,8,9	TRL 1	TRL 9
6	ENVIRONMENTAL IMPACT	0.02	Constructed - Proxy	AV-1	Cannot be built	Within all constraints
7	MONETARY PRACTICALITY – INITIAL	0.02	Natural - Direct	AV-1	Over budget	Under budget
8	MONETARY PRACTICALITY – MAINTENANCE	0.02	Natural - Direct	AV-1	Over budget	Under budget
9	ADAPTATION	0.027	Constructed - Proxy	SV-8	Static	Easy, On-Site
10	SUPPORTABILITY REQUIREMENTS	0.035	Constructed - Direct	SV-7	No	Yes
11	RELIABILITY REQUIREMENTS	0.064	Constructed - Proxy	SV-7	No	Yes
12	SYSTEM REDUNDANCY	0.04	Constructed - Direct	OV-6	None	All/Multiple
13	RECOVERABILITY REQUIREMENTS	0.026	Constructed - Direct	SV-7	No	Yes
14	JOINT OPERATIONS	0.033	Constructed - Proxy	AV-1	No	Yes
15	NESI DEVELOPMENT	0.066	Constructed - Direct	TV-1	No	Yes
16	NESI EVALUATION	0.066	Constructed - Proxy	TV-1	No	Yes
Total of *System Effectiveness* Global Weights		0.600				

1. Primary source of information; other views may be required

Table 3.4. Measure Definitions

***System Effectiveness* Branch**		
Value	**Measure**	**Measure Definition**
Purposefulness	OPERATIONAL NEEDS	What percentage of operational needs are addressed by the system?
Purposefulness	THREAT DETECTION	Has a Threat Detection Plan been established?
Purposefulness	THREAT ASSESSMENT	Has a Threat Assessment Plan been established?
Purposefulness	WARNING PLAN	Has a base warning plan been established?
Practicality	TECHNOLOGICAL AVAILABILITY	What is the Technological Availability of the system?
Practicality	ENVIRONMENTAL IMPACT	Can the system be realized within Environmental Constraints?
Practicality	MONETARY PRACTICALITY - INITIAL	Can the system's initial cost be realized within current budgetary constraints?
Practicality	MONETARY PRACTICALITY - MAINTENANCE	Can the system be maintained within current budgetary constraints?
Flexibility	ADAPTATION	How well does the system adapt to changing threats?
Supportability	SUPPORTABILITY REQUIREMENTS	Have supportability requirements been accounted for?
Reliability	RELIABILITY REQUIREMENTS	Have reliability requirements been accounted for?
Survivability	SYSTEM REDUNDANCY	The degree to which critical systems are redundant?
Recoverability	RECOVERABILITY REQUIREMENTS	Have recoverability requirements been accounted for?
Interchangeability	JOINT OPERATIONS	Have CONOPs been constructed to account for all organizations?
Communication	NESI DEVELOPMENT	Was NESI Guidance taken into account when constructing architecture?
Communication	NESI EVALUATION	Has a NESI evaluation been completed on the architecture?

of available products and latitude for which architects may use the products, it may be necessary to examine other products or views to find the information necessary for each measure. In cases where a specific view has been created for the sole purpose of representing a certain type of information, that view will be considered essential in the measurement of the value at hand. This accounts for information that may be extrapolated by the user examining several other products, but was not explicitly stated by the architect, when it is possible.

3.3.1 *Capability* Measures

The goals of the measures under *Capability* are to collectively measure the attainment of the *Capability* value. *Capability* is meant to determine if the system is able to produce the sponsor's desired effects on the battlefield. Through use of the *Purposefulness, Practicality*, and *Flexibility* values, the three major aspects of *Capability* are captured. Each of these lower tier values must be measured to determine their effect on the *Capability* value.

3.3.1.1 Evaluation Measures for *Purposefulness*

Purposefulness requires more than one measure to completely determine its level of attainment. Four total measures score four separate aspects of *Purposefulness* as determined by the sponsor. Each of these measures serves to determine a particular portion of the *Purposefulness* value. This is where the Detect, Assess, Warn, Defend, Recover (DAWDR) construct was considered.

3.3.1.1.1 OPERATIONAL NEEDS

The first evaluation measure under the *Purposefulness* value determines whether the system designers have accounted for the sponsor's initial requirements. The measure asks: "What percentage of the Operational Needs is addressed by the system?" It is possible to trace each operational need to a requirement, to a capability, and ultimately down to a function or system capability. The DoDAF facilitates this primarily through the SV-5 product. The SV-5 alone is not capable of accomplishing this measurement, due to its lack of an explicit list of OPERATIONAL NEEDS. The AV-1 product must be used in coordination with the SV-5 to find this association. This measure is Constructed-Direct. The SV-5 is a constructed product, through which the scorer may determine if OPERATIONAL NEEDS have been met by system components. The measurement scale is not a common way of determining whether OPERATIONAL NEEDS have been met, as SV-5s require some architecture knowledge to read. It directly measures the value due to the fact that determining if all operational needs have been accounted for determines the exact level of attainment of the value.

3.3.1.1.2 THREAT DETECTION

The THREAT DETECTION measure grew out of the DAWDR (Detect, Assess, Warn, Defend, Recover) construct. For the system to meet its purpose and accomplish its goals on the battlefield, it must account for at least the first three aspects of the DAWDR construct. THREAT DETECTION measures whether a Threat Detection Plan has been developed. At this stage of development, it is impossible to measure the actual quality of the Threat Detection Plan; it is only possible to measure its existence. At a later time in system development, it may be possible to alter this measure to account for the quality of the Threat Detection Plan. The activities associated with the Threat Detection Plan will be located in the OV-5 if it is available. By tracing the system's activities, it will be possible to determine if there are system activities that account for threat detection. If a Threat Detection Plan exists, the activities that accomplish it must also be present in the OV-5. If the OV-5 is not available, the OV-1 and OV-3 will be examined for a detection plan. This measure is a Constructed-Proxy measure. It will be obvious to any reader if the plan exists, making the scoring scale binary. The measurement question, however, was constructed for the purpose of this evaluation. By using the activities associated with the plan as opposed to the plan itself, the scorer must make an inference that if there are activities, then the plan has been created; therefore, it is a proxy measure.

3.3.1.1.3 THREAT ASSESSMENT

THREAT ASSESSMENT is similar in all ways to THREAT DETECTION, except it measures whether a plan exists to assess the threat once it has been detected. This accounts for the second aspect of the DAWDR construct. This measure will also examine the OV-5 to look for activities related to Assessment (with OV-1 and OV-3 as secondary views). THREAT ASSESSMENT is a Constructed-Proxy measure.

3.3.1.1.4 WARNING PLAN

WARNING PLAN is the third aspect of the DAWDR construct measured by this model. It is also very similar to THREAT DETECTION and THREAT ASSESSMENT. In this case though, the OV-5 is examined for any mentions of the activities related to warning the base population. A warning plan should warn not only the base population, but also specific organizations as required. Warnings may also be "tiered," so that only certain people are warned depending on the purpose for the warning. Warning plans may be very prevalent in the OV-1 and OV-3 in this case, as the warning of people relates directly to both the system boundary and node communication. It is also Constructed-Proxy.

3.3.1.2 Evaluation Measures for *Practicality*

The value of *Practicality* must also be measured using more than one aspect. Since it is also a very complex issue and the definition calls for several layers of *practicality*, each of those layers must be measured. Each of the measures of *Practicality* measures an idea that was declared to be an important measure by the decision-maker.

3.3.1.2.1 TECHNOLOGICAL AVAILABILITY

Technology Readiness Levels (TRLs) are described in the Defense Acquisition Guidebook (Department of Defense, 2004). The nine Technology Readiness Levels (TRL) were created by the U.S. government to "assess the maturity of evolving technologies." They allow the decision-maker to determine the level of development of certain systems during the acquisition process. TRLs are being used in this case to measure the overall Technological Availability of the system of systems. The TRL of each component will be averaged to determine an overall TRL for the entire system. TRLs measure *Practicality* by determining how easy it will be to actually construct the system. They are capable of showing whether a technology is still in the very early development stages or available immediately off the shelf. This is a Natural-Direct measure since TRLs are widely used within the DoD and are intended to measure the Technological Availability of systems prior to acquisition. Each of the nine levels is detailed in Section 3.4. The SV-9 is the most likely location for TRL information. The system developers have latitude in determining exactly which view will provide the TRLs for each component. It is possible for the AV-1 to also have a more direct assessment of the TRL of the entire system.

3.3.1.2.2 ENVIRONMENTAL IMPACT

The ENVIRONMENTAL IMPACT measure determines if the system can be realized within the environmental constraints of a given location. Since the system is not in any specific location during the design phase, it is examined prior to construction to determine if it will fit into the environmental constraints of a given area. For example, to protect the perimeter of an installation, the base could build a 20-foot high, 10-foot thick concrete wall around the installation and cover the entire installation with netting to create a protective "bubble," however, this method would be cost, time, and environmentally restrictive. Since many environmental laws would be broken in order to accomplish this feat, it is considered impractical. Most projects require some sort of Environmental Impact Statement (EIS) before implementation, but at this level of development, an EIS may not be available. It would be expected that language regarding the environmental practicality would be included in the AV-1 of a systems architecture, but any environmental specification being adhered to will be located in the TV-1; therefore, the TV-1 is the primary location for this measurement. This measure is a Constructed-Proxy measure. This information is typically included in an EIS, but it is time restrictive for an architecture evaluator to do this. Environmental Practicality is found by examining the technical standards for environmental wording. At a later stage of development, this measure will no longer be Constructed-Proxy, once an EIS is available for review.

3.3.1.2.3 MONETARY PRACTICALITY – INITIAL

In the previous example of perimeter detection, the large concrete wall could not be constructed due to its impact on the environment. For this measure, the same concept applies, but to the cost of the wall. The MONETARY PRACTICALITY - INITIAL measure determines if the program can afford the initial implementation cost of a project. In order for the project to be completed within the DoD, funds must be realistic and available. The Defense Acquisition Guidebook includes specific guidelines on funding and affordability (Department of Defense, 2004). There are several places within the architecture where costs may be incorporated. For this evaluation, the AV-1 will first be examined as it contains overall system information and more broad concepts such as cost. If information is not found there, other views, such as the OV-5, which has an optional “cost overlay” function, will be examined. This is a Natural-Direct measure since dollars are a common unit of measurement and the estimate directly measures the cost of the project.

3.3.1.2.4 MONETARY PRACTICALITY – MAINTENANCE

This measure examines the "life-cycle cost" of the system. Within the DoD acquisition system, both initial costs and life-cycle costs are required for a project to reach milestones within the process (Department of Defense, 2004). Life-cycle costs provide an estimate of how much a system will cost to maintain throughout the entire effective life of the system, including disposal at the end of its effective life. While it is difficult to determine monetary constraints in the future, it is possible to examine future budgets and multi-year plans to see if the gaining office can work the additional cost into their projected budgets. This measure will also be located primarily in the AV-1 product. MONETARY PRACTICALITY – MAINTENANCE is also a Natural-Direct measure for the same reasons as MONETARY PRACTICALITY – INITIAL.

3.3.1.3 Evaluation Measure for *Flexibility*

Measuring a system's *Flexibility* is a difficult concept and requires very strict definition of the value. *Flexibility* is defined based on its ability to adapt to changes on the battlefield; therefore, the measurement seeks to determine its ability to do that. The *Flexibility* value has only one measure of effectiveness.

A system's *Flexibility* is directly dependent on how easy or possible it is to change the system configuration quickly and effectively. ADAPTION measures if it is possible to change the system and the considerations taken to do so. The location of information such as this is not explicitly stated anywhere in the DoDAF views. The first candidate view for finding this information is the SV-8, Systems Evolution Description. The SV-8 tells the reader of any planned future improvements to the system or whether adaptations are possible. This view should provide information as to how easy it will be to alter the system as well. ADAPTION is a Constructed-Proxy measure. Since there is no standard system for measuring a system's flexibility, a scale must be constructed to measure this concept. Since the value is abstract, though well defined, no direct measurement will be possible; it is a proxy measurement of things that would make a system flexible.

3.3.2 *Maintainability* Measures

In discussions with the decision-maker, it was determined that the *Maintainability* of a system is often absent from an architecture. Although there are no DoDAF views that specifically require explicit information regarding how easy a system is to maintain, the DoDAF does provide a good vehicle for doing this. The SV-7 product provides the performance characteristics for the components in the system. Therefore, the evaluator must extrapolate this information from the SV-7. There are obviously certain parameters to which the system is designed. Such systems engineering concepts as "Mean Time-Between-Failures (MTBF)," "System Availability," "Mean Time-To-Repair," "Mean Uptime," "Mean Downtime," and "Reliability" have actual equations and methods for evaluation. These things are normally specified in the project requirements, i.e., the system must be designed to meet certain reliability standards. For these things to be designed into the system, design calculations must be done at some point and the standard must be included in the architecture. The SV-7 is the view normally associated with such performance standards, but these characteristics are typically not included in the SV-7. The measures for *Maintainability* are SUPPORTABILITY REQUIREMENTS, RELIABILITY REQUIREMENTS, SYSTEM REDUNDANCY, and RECOVERABILITY REQUIREMENTS.

3.3.2.1 Evaluation Measure for *Supportability*

Supportability relates to a system's ability to be maintained in its operational environment. The SV-7 must be altered to include this information. The measure for *Supportability* is simply named "SUPPORTABILITY REQUIREMENTS." If the system designers have incorporated supportability requirements into the design, they should be included in the SV-7. The official measure simply asks, "Have supportability requirements been accounted for?" The term Supportability Requirement refers to specific systems engineering concepts. Mean Time-Between-Maintenance (MTBM) and Mean Time-Between-Replacement (MTBR) measure the time that the system is active between scheduled maintenance. The longer this time is, the more maintenance is required; therefore, more man-hours are required. The concepts of $\bar{M}$ (Mean active maintenance time), M_{max} (Maximum maintenance time), and $\bar{M}_{PT}$ (Mean active-preventative-maintenance-time) measure how much time is actually spent in the maintenance of the system. These *Supportability* concepts basically measure the "down-time" and time between scheduled maintenance. At this point of design, it is important only to determine if these things have been considered in the design and ensure that they are explicitly stated in the architecture. At a later time, it will be important to ensure that the times are acceptable (although the system must meet the basic requirements to be considered a viable alternative). Through the use of these "career-field standard" equations (Blanchard & Fabrycky, 2006), the concept of *Supportability* may be measured, as these are the ideas that are intended to be measured. It can be assumed that a system is supportable if it exhibits these qualities. The question of *Supportability* is a constructed idea for this evaluation, thus, the measure is Constructed-Proxy.

3.3.2.2 Evaluation Measure for *Reliability*

The *Reliability* value has characteristics similar to *Supportability*. Thought it measures a separate value, the way in which they are measured is similar. The measure "RELIABILITY REQUIREMENTS" specifically asks, "Have reliability requirements been accounted for?" It also looks in the SV-7 for similar equations. *Reliability* seeks to measure the "up-time" of the system or the length of time that it is operational prior to disruption. This measure assumes that proper preventive maintenance has been accomplished. The evaluator should look for such equations as the Availability family (achieved: A_a, inherent: A_i, operational: A_0) and MTBF (Blanchard & Fabrycky, 2006). This measure is also a Constructed-Proxy measure as it uses the same type of standard equations to measure the concepts involved in this value.

3.3.2.3 Evaluation Measure for *Survivability*

Survivability departs slightly from the method used to determine the other *Maintainability* values. *Survivability* measures how susceptible a system is to hostile action and how that action will affect the system. Redundant systems tend to remain operational through more hostile actions than systems with no redundancies. SYSTEM REDUNDANCY allows a back-up system to take the place of the primary in the case of failure or attack, thereby allowing the system to remain operational. The "SYSTEM REDUNDANCY" measure determines the degree to which systems are redundant. The OV-6, Operational Event Trace Description, will provide some insight as to whether there are intentional system redundancies present. Through the OV-6's use of chronological event depiction, it is possible to see which systems are performing similar actions simultaneously and whether back-up systems exist or not. The measure in this case is Constructed-Proxy. There is no standard way to measure redundancy; however, looking in the OV-6, the scorer may be able to get an impression as to whether a system will remain operational after attack.

3.3.2.4 Evaluation Measure for *Recoverability*

Recoverability returns to the construct in place for the *Supportability* and *Reliability* values. *Recoverability*, however, measures "RECOVERABILITY REQUIREMENTS" through the use of Mean-Time-to-Repair (MTTR) and $\bar{M}_{CT}$ (Mean active-corrective-maintenance-time). These ideas measure the length of time that it takes to actually repair the system after some failure. Whether the failure is through enemy attack or through some other type of system failure, these equations will account for how long a component takes to repair. The SV-7 is also the source for these concepts. *Recoverability* is also a Constructed-Proxy measure, as it uses standard equations and directly measures the concept of recoverability.

3.3.3 *Interoperability* Measures

The final branch of *System Effectiveness* determines how well the system operates with other systems and between its own nodes. *Interoperability* was one of the major focuses for the sponsors of the JFPASS; therefore, its measurement was important to the value of the architecture. The two *Interoperability* values are measured through the use of three total evaluation measures.

3.3.3.1 Evaluation Measure for *Interchangeability*

Interchangeability deals with the ability of the system components and nodes to be interchanged between service components. In the Joint environment, being able to operate smoothly in any service context is vital. The measure "JOINT OPERATIONS" is the sole *Interchangeability* measure, and it determines how many services have been involved in the development of the system. The existing CONOPs for each service must be considered so that no critical functions are ignored, thereby ensuring a fully interoperable system. The matter of ensuring that each service component can operate within the context of the new system is a matter of training, but ensuring that their existing CONOPs and critical operations have been accounted for will speed the process. The AV-1 document will outline how other services were incorporated in the design process, but the OV-2, OV-3, and OV-4 may also contain information regarding the other services' CONOPs which were incorporated. This measure is a Natural-Proxy type. The number of services is a constructed way of measuring this concept, and its way of measuring *Interoperability* is only a proxy for how the system will actually allow the *Interchangeability* of different services.

3.3.3.2 Evaluation Measures for *Communication*

The ability of the system to communicate is essential to its basic operation. Since this is a largely automated system, the nodes must communicate with one another. In addition, the system must be able to communicate its processes with the users. The Net-Centric Enterprise Solutions for Interoperability (NESI) guidance was used to determine the system's ability to communicate. The two *Communication* measures are NESI CONSIDERATION and NESI EVALUATION.

3.3.3.2.1 NESI CONSIDERATION

"Was NESI guidance taken into account when constructing the architecture?" The system designers should make use of this detailed guidance for net-centric systems. Since the JFPASS is required to be net-centric and with the DoD's shift to net-centric warfare, some standard of net-centricity is required. Currently, NESI is the only set of consolidated guidance for determining how a net-centric system should look. At this early stage of development, the consideration of the NESI guidance in the design is the best way to measure the design component of *Communication*. At a later time, it will be possible to measure how net-centric a system is, but components must be in operation in the field to actually see how they will communicate. The primary source for NESI DEVELOPMENT is the TV-1. If the NESI documentation is not listed in the TV-1, it may not have been considered. AV-1 is a possible back-up as well. NESI DEVELOPMENT is a Constructed-Direct measurement. NESI is becoming the DoD standard for net-centric designs and if a system is constructed to the specifications contained within, then it is generally a communicable system.

3.3.3.2.2 NESI EVALUATION

The NESI documentation includes many evaluation measures of its own. This allows the system developers to perform an initial evaluation to ensure that their system is net-centric. Through the use of the checklists included in NESI, the NESI EVALUATION measure can determine how the system developers have done. Again, at this stage of development, it is important only that the evaluation has been completed. The actual results of the evaluation should be included as an appendix to the architecture, but the quality of the results will not have as heavy of an influence until the system reaches a Milestone B approval authority. The NESI EVALUATION may either be found in the TV-1 or as an appendix to the architecture. This is a Constructed-Proxy measure. Although NESI is becoming a standard tool, the evaluation is not a direct measure for this model. It is a way to determine if the evaluation was done through another system.

3.4 Create Value Functions

Following the creation of the full hierarchy including values and measures, Single Dimension Value Functions (SDVFs) were assigned to each measure. The SDVFs served to convert the measure's score to a value, based on the range of the measure. These SDVFs converted the individual scales to value units ranging from zero to one. These value scores may then be summed using the general additive value function. All SDVFs were developed in coordination with the decision-maker.

3.4.1 *Capability* Measures Functions

The OPERATIONAL NEEDS measure, under the *Purposefulness* value was scored on a scale of 0 to 1. These scores represent the percentage of OPERATIONAL NEEDS addressed by functions. The SDVF is a monotonically increasing type; therefore, as more of the OPERATIONAL NEEDS of the system are met, more value is gained. The value is gained in an exponentially increasing fashion, so that the difference between 0.1 and 0.2 is the same as the difference between 0.7 and 0.8. Figure 3.6 displays the SDVF for OPERATIONAL NEEDS. This SDVF was validated by the decision-maker on 12 February 2009.

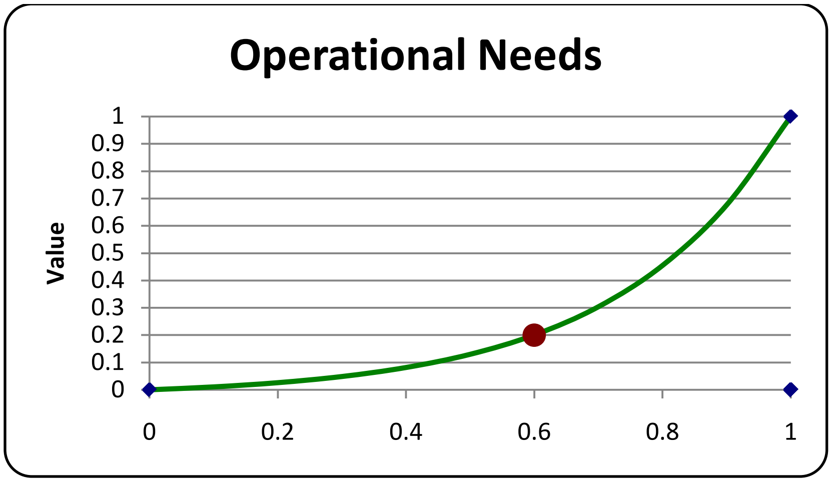


Figure 3.6. OPERATIONAL NEEDS Single Dimension Value Function

The second measure of *Purposefulness*, THREAT DETECTION, is a binary measure. The acceptable range of scores for THREAT DETECTION is either "no" or "yes." This measure determines if a Threat Detection plan exists. The SDVF for THREAT DETECTION is discrete, with two bins. All possible value is earned if the score is "yes" and no value is earned if the score is "no." Figure 3.7 shows a generic binary SDVF, which may be applied to any binary measure. All subsequent binary measures, of which there are a total of nine, use the SDVF in Figure 3.7. The SDVF was validated by the decision-maker on 20 November 2008.

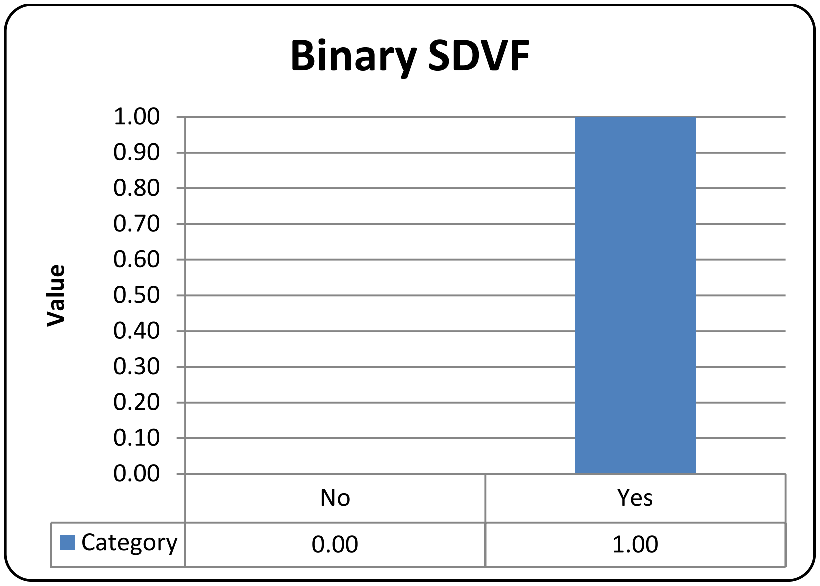


Figure 3.7. Generic Binary Single Dimension Value Function

The last two measures of *Purposefulness*, THREAT ASSESSMENT and WARNING PLAN, are also binary measures. These measures determine if either a Threat Assessment or Warning Plan exists. The SDVF for both is discrete, binary as well. All possible value is earned if the score is "yes" and no value is earned if the score is "no." Figure 3.7 shows the binary SDVF, which was validated for this measure by the decision-maker on 20 November 2008.

The first measure of *Practicality*, TECHNOLOGICAL AVAILABILITY, is based on a widely used scale called Technology Readiness Levels. This is a 9-level scale; therefore, the SDVF is discrete with nine bins. TECHNOLOGICAL AVAILABILITY determines the level at which technology is available for this project. Table 3.5 shows all TRLs with their definitions. As TRLs increase, more value is gained. Though this Value Function is discrete, the bins take on an exponentially increasing value curve. Therefore, the difference between TRL 1 and TRL 2 is much smaller than the difference between TRL 7 and TRL 8. Figure 3.8 demonstrates this concept. The SDVF was validated by the decision-maker on 11 January 2009.

Table 3.5. Technology Readiness Levels

TRL 1	Basic Principles observed and reported – Lowest level of technology readiness
TRL 2	Technology concept and/or application formulated invention begins
TRL 3	Analytical and experimental critical function and/or characteristic proof of concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment
TRL 7	System prototype demonstration in an operational environment
TRL 8	Actual system completed and 'flight qualified' through test and demonstration
TRL 9	Actual system 'flight proven' through successful mission operations

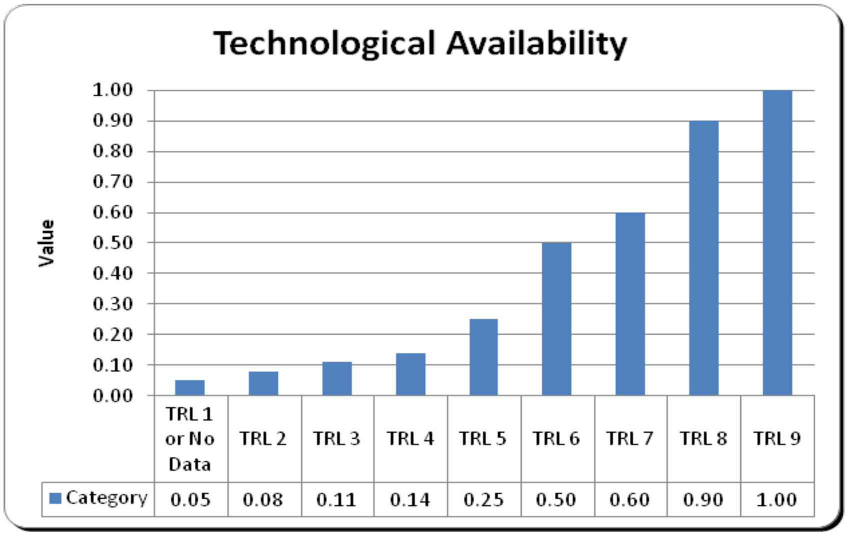


Figure 3.8. TECHNOLOGICAL AVAILABILITY Single Dimension Value Function

The second measure of *Practicality* is ENVIRONMENTAL IMPACT. ENVIRONMENTAL IMPACT is a discrete value function with four bins. It is intended to measure the level of impact that a given system has on its environment. For this measure, the bins were designed to capture increasing stringency of environmental laws and restrictions. In this case, the lowest value is that a system cannot be built within any environmental restrictions, i.e., it will have a vast detrimental effect on the environment. Contingency Operations environmental constraints are next in level of restrictiveness. Following that, the CONUS or Contingency constraints provide a higher level of restriction. Finally, since a system would have to comply with three separate levels of restriction; CONUS, Contingency, or Host Nation constraints is the most restrictive level of ENVIRONMENTAL IMPACT. It is assumed that it is easier to design for CONUS constraints than it is to design for Host Nation constraints, since the corporations and designers are familiar with the CONUS laws. There is a jump in value between having a system that can be built in Contingency and CONUS constraints. Figure 3.9 displays the SDVF for ENVIRONMENTAL IMPACT. This SDVF was validated on 20 November 2009.

Figure 3.9. ENVIRONMENTAL IMPACT Single Dimension Value Function

The third measure of *Practicality* is MONETARY PRACTICALITY - INITIAL. This measure is a discrete SDVF with three bins. It is intended to measure the attainment of the ability to construct a system within budgetary constraints. To this end, the three bins were constructed to capture situations in which the system estimates fall above, within, and below budget. The "Within Budget" bin refers specifically to estimates which fall within +/-5% of the given program budget. Therefore, any estimate falling above 5% of budget qualifies as "Above Budget," while any estimate falling below 5% of budget is considered to "Save Money." Figure 3.10 displays the SDVF for this MONETARY PRACTICALITY measures. It was validated by the decision-maker on 12 February 2009.

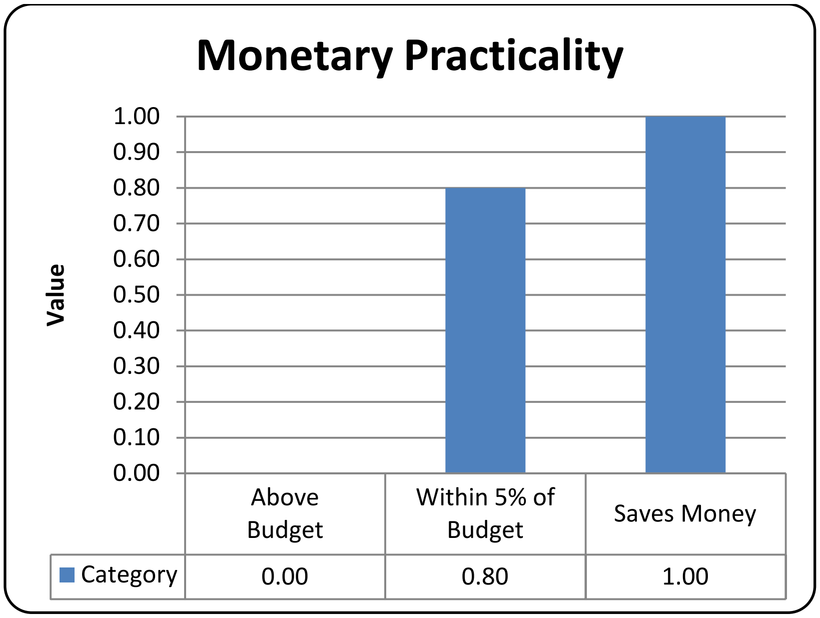


Figure 3.10. MONETARY PRACTICALITY Single Dimension Value Function

The last measure of *Practicality*, MONETARY PRACTICALITY – MAINTENANCE, is very similar to the previous measure, except that it refers to the life-cycle cost of the project. The SDVF converts value in the same way, with the same levels. This is demonstrated in Figure 3.10. This SDVF was also validated on 12 February 2009.

ADAPTION is the single measure of *Flexibility*. ADAPTION measures the degree to which the system is able to adapt to changing operational requirements. This is measured on a discrete scale with five bins. Each bin measures an increasingly easier method of changing the system configuration. The lowest bins and therefore of lowest value is “Static,” meaning that the system is not capable of being changed once it is implemented. The next level is “Unacceptable Effort,” which refers to a system which can be changed, but is cost and/or time restrictive to actually make the change to meet the mission at hand. “3rd Party Acceptable Effort” refers to a situation in which the system can be changed within cost and time constraints, but a 3rd party must be “imported” to make the change. In this case, users are not capable of changing the system as needed. The next level is “On-Site Acceptable effort.” In this case, the users are capable of making the change within cost and time constraints, though it may require such considerations and consultation from system designers, system downtime, or added cost. The final bin and of most value to the decision-maker is “Minimal Effort.” This refers to a system that is flexible by its very nature. Any changes to meet operations requirements are quickly and easily made with little to no additional time or cost. As the system gets easier to change, more value is added, with a significant jump in value, 0.4 value units, between “Unacceptable Effort” and “3rd Party Acceptable Effort.” This value jump represents the value to the decision-maker of having a system that is capable of being changed. Figure 3.11 shows the SDVF for ADAPTION, which was validated by the decision-maker on 20 November 2008.

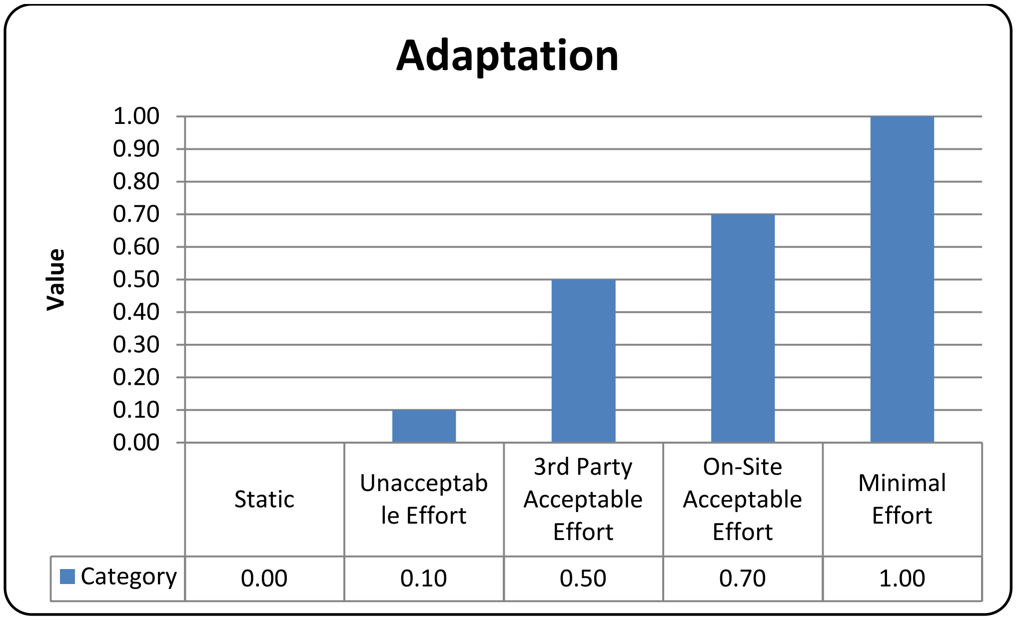


Figure 3.11. ADAPTION Single Dimension Value Function

3.4.2 *Maintainability* Measures Value Functions

SUPPORTABILITY REQUIREMENTS is the first of the *Maintainability* measures. Specifically, SUPPORTABILITY REQUIREMENTS measures the *Supportability* value by determining if the system designers have considered supportability issues. This is a discrete, binary SDVF; with its range being either "no" or "yes." If the equations related to supportability were mentioned, then the system gains full credit ("yes"); if these equations were not considered, the system earns a "no." If the SV-7 product does not exist, the system will also score "no," since the SV-7 is required to determine the design tolerances used for the component systems. Figure 3.7 shows the SDVF for SUPPORTABILITY REQUIREMENTS, which was validated on 20 November 2008.

The RELIABILITY REQUIREMENTS measure is similar to *Supportability*, in that it is also binary and seeks to measure the use of reliability style equations in the design of the system. RELIABILITY REQUIREMENTS is the second of the *Maintainability* values and specifically measures the *Reliability* value. *Reliability* considerations are a different set of design criteria, but are also found in the SV-7. Value is earned in the same way as SUPPORTABILITY REQUIREMENTS. Figure 3.7 demonstrates this in the SDVF. This SDVF was validated on 20 November 2008.

SYSTEM REDUNDANCY measures the degree of attainment of the *Survivability* value. If a system has redundancies, then it is more likely to survive an attack. To accomplish this measurement, a discrete value function with four bins was created. As the redundancies on systems increase, more value is earned. The bins represent a value "jump" when multiple redundancies are considered for systems. The lowest bin is "No redundancy," meaning that all systems are stand-alone and would constitute a loss of mission effectiveness if they were destroyed. The next bin, "Some Systems have Single Redundancies," captures the idea that some systems are given a single back-up to ensure their operation. The decision-maker felt that it was important for systems to have more than a single redundancy in a force protection scenario; therefore, the next bin, "Some Systems have Multiple Redundancies," captures the next level, which adds a great deal of value to the measure. Finally, "All Systems have Multiple Redundancies" is the highest bin and level of value. Figure 3.12 displays the SDVF for SYSTEM REDUNDANCY. This SDVF was validated on 20 November 2008.

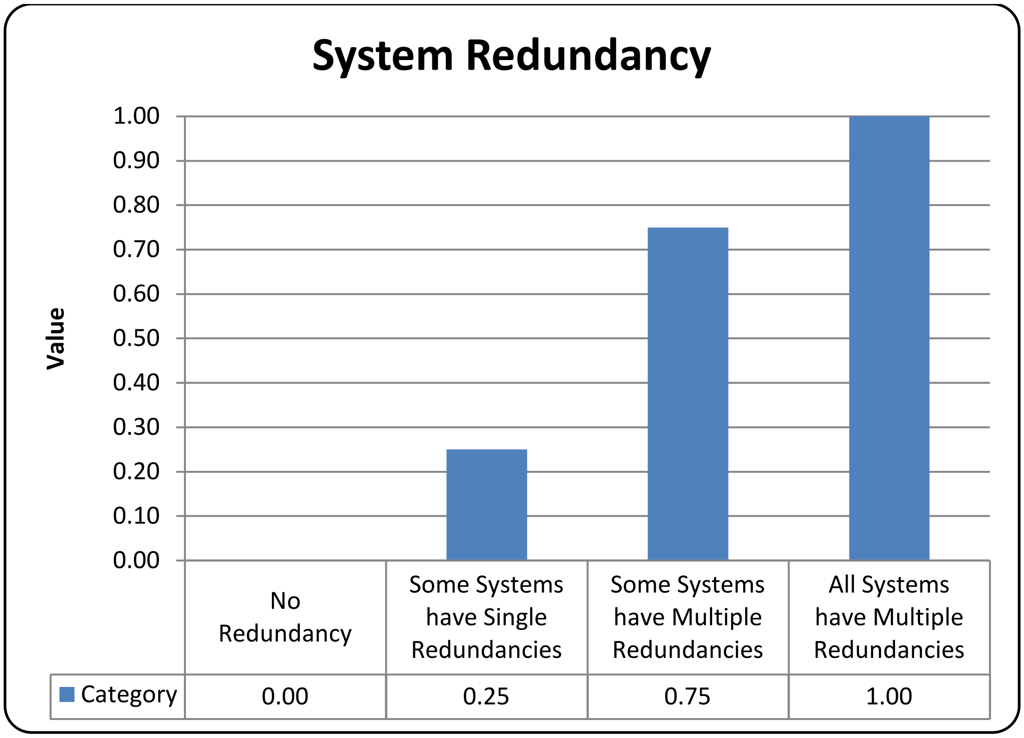


Figure 3.12. SYSTEM REDUNDANCY Single Dimension Value Function

The RECOVERABILITY REQUIREMENTS measure is the last of the *Maintainability* measures, which specifically measures the value of *Recoverability*. This measure's SDVF follows the same example as both SUPPORTABILITY REQUIREMENTS and RELIABILITY REQUIREMENTS. It is a discrete, binary SDVF. In this case, the equations generally associated with recoverability are looked for in the SV-7 product. Figure 3.7 shows the SDVF for RECOVERABILITY REQUIREMENTS. It was validated on 20 November 2008.

3.4.3 *Interoperability* Measures Value Functions

JOINT OPERATIONS is the single measure associated with the *Interchangeability* value. This measure determines whether multiple service components' CONOPs have been considered in the design of the system. This is a binary, discrete SDVF. In order to receive value for this measure, the system must incorporate all services' CONOPs. No credit is given unless all four service components have been considered. The SDVF was constructed in this manner to ensure that the importance of having all service components is captured. Without all four services, the interchangeability of the system is of no value. The range for this SDVF is also "yes" or "no." The only way to score 100% value or a "yes," is to have all service components' CONOPs considered in the design. Figure 3.7 displays the validated (on 20 November 2008) SDVF.

NESI DEVELOPMENT is the measure created to determine the degree of attainment of the *Communication* Value. This measure seeks to determine if the Net-Centric Enterprise Solutions for Inoperability guidance has been taken into account for the design of the system. This is a binary, discrete SDVF, measuring either "yes" or "no" as to whether NESI has been used. Figure 3.7 shows the binary SDVF used for NESI DEVELOPMENT. This SDVF was validated on 20 November 2008.

NESI EVALUATION measures the same value in the same way as NESI DEVELOPMENT. NESI EVALUATION, however, seeks to determine if the system designers have completed an evaluation on the system. Supplied in the NESI documentation are several checklists and measures for determining the net-centricity of a system. The system designers must have completed these evaluations to gain credit for NESI EVALUATION. Figure 3.7 shows the SDVF for NESI EVALUATION. This SDVF was validated on 20 November 2008.

3.5 Value Hierarchy Weights

To determine the importance of each measure, values must first be individually weighted. By determining local weights, the global weights are easily found. This study uses primarily the direct weighting procedure, although an additional procedure using "Tornado Charts" was used for validation and final weight determination. Table 3.6 shows each *System Effectiveness* tier's values with their global and local weights. The global weights for at each tier sum to 0.6 to represent the 60% of the fundamental value accounted for by the *System Effectiveness* branch. All weights in sections discussed in section 3.5 represent the final weights following validation.

Table 3.6. Value Weights

Value	**Tier**	**Local Weight**	**Global Weight**
System Effectiveness	1	0.6	0.6
Capability	2	0.45	0.27
Maintainability	2	0.275	0.165
Interoperability	2	0.275	0.165
Purposefulness	3	0.6	0.162
Practicality	3	0.3	0.081
Flexibility	3	0.1	0.027
Dependability	3	0.6	0.099
Resiliency	3	0.4	0.066
Interchangeability	3	0.3	0.05
Communication	3	0.7	0.116
Supportability	4	0.35	0.035
Reliability	4	0.65	0.064
Survivability	4	0.6	0.04
Recoverability	4	0.4	0.026

3.5.1 Tier 1 Weights

A top-down approach was used for the majority of the weighting, although validation was completed in a bottom-up fashion. Tier one was the first tier to be weighted (top-down). With the split between *System Effectiveness* and *Architecture Quality*, relative weights had to be determined to find how important each of the two branches would be. The local weights were found to be 0.6 and 0.4, respectively. These weights account for the importance of the instantiated system versus the architectural products. While the architectural products are very important, particularly in the acquisition realm, the value of the system being represented is of more importance.

3.5.2 Tier 2 Weights

The three values considered on Tier 2 of the Hierarchy were *Capability*, *Maintainability*, and *Interoperability*. A direct weighting scheme ("100 coin method") was used for these values. Initially, *Capability* was weighted at 0.40, with *Maintainability* and *Interoperability* both being 0.30 of the value of *System Effectiveness*. The decision-maker agreed that *Maintainability* and *Interoperability* were in fact of equal weight, but the importance of *Maintainability* and *Interoperability* in relation to *Capability* was adjusted. The final value of *Capability* was found to be 0.45 of *System Effectiveness*, while *Maintainability* and *Interoperability* were 0.275 each. These final values incorporate the changes made during weighting validation. *Capability* has the highest weighting due to the importance that the system is capable of performing its intended operations. If a system cannot do what it is intended to do, it is little value to the user; therefore, the 0.45 weighting accounts for this major importance in terms of the system's ability to do its job. *Maintainability* and *Interoperability* are both important to the decision-maker, but are overshadowed by *Capability*.

3.5.3 Tier 3 Weights

Tier three was weighted next using the local weighting method. These values were examined branch-by-branch to ensure that each value was accounted for and no areas were left unconsidered. Following the weighting, each value on Tier 3 was validated.

3.5.3.1 Tier 3 *Capability* Branch Weights

The three values under *Capability* are *Purposefulness*, *Practicality*, and *Flexibility*. It was unanimously agreed among the decision-maker and subject matter experts that *Purposefulness* was by far the most important value – possibly in the entire hierarchy. With that knowledge, *Practicality* and *Flexibility* were weighted using a swing-weight style approach.

Practicality was agreed to be less important than *Purposefulness* and *Flexibility* less important than *Practicality*. Next, relative weights were examined. It was determined that *Practicality* is approximately three times as important as *Flexibility*. This decision was made, because if a system cannot be practically constructed, then its flexibility does not matter. *Purposefulness* was then agreed to be twice as important as *Practicality*. This decision was made because a system may be practical, but if it does not accomplish its goals, there is no need to construct the system in the first place. This process yielded weights of 0.60 for *Purposefulness*, 0.30 for *Practicality*, and 0.10 for *Flexibility*.

3.5.3.2 Tier 3 *Maintainability* Branch Weights

The *Maintainability* branch is the only branch within *System Effectiveness* that contains a fourth tier of decomposition. The first step for weighting this branch was to determine the weights of the tier-three values. The tier-four values were examined after all tier-three values were weighted. *Maintainability* has sub-values of *Dependability* and *Resiliency*. *Dependability* refers to a system's maintainability during peace-time operations, and *Resiliency* refers to its maintainability during hostile actions. The weighting for these values was based on the frequency of occurrence. Since the U.S. military has more assets that are operating in peace-time operations, *Dependability* was determined to be more important. While the military has more operations engaged in peaceful actions, the operations vulnerable to hostile actions are considered to be of more importance to the completion of the National Security and National Military strategies. This idea was confirmed by Subject Matter Experts. Therefore, *Resiliency* was weighted at 0.40 and *Dependability* was weighted at 0.60. *Dependability* being only slightly more important accounts for the mission impact of contingency operations, but the overall importance of the military's peace-time operations.

3.5.3.3 Tier 3 *Interoperability* Branch Weights

The *Interoperability* branch was the last branch of *System Effectiveness* to be weighted. This branch accounts for *Interchangeability* and *Communication*. The swing weighting method was used for this weighting. It was determined first the *Communication* was more important to the decision-maker; meaning that the nodes communicating effectively is more important than the components having the ability to be interchanged. With *Interchangeability* being the less important value, the discussion led to a determination that *Communication* was four times more important than *Interchangeability*. This order of magnitude captures the extreme importance of the initial nodes performing their communication function first. Their *Interchangeability* falls behind, since without communication, there would be no need to interchange.

3.5.4 Tier 4 Weights

Following the completion of tier-three weighting, tier-four weights were examined. Only three values of the hierarchy have tier-four values. These values were examined individually to find their local weights. Under the *Maintainability* branch, the values of *Dependability* and *Resiliency* were decomposed by one additional level, giving four tier-four values under *Maintainability*.

Dependability was examined first. The sub-values of *Supportability* and *Reliability* compose the idea of peace-time dependability. *Supportability* represents the ability to maintain the system and *Reliability* represents the system’s ability to continue standard operations if maintained properly. *Supportability* was found to be less important than *Reliability*, based on the need for system “up-time.” If a system is difficult to maintain, the system will be offline more often. The most important thing about standard peace-time operations is that the system is operational more often than it is not. Therefore, the decision-maker was willing to sacrifice maintainability for more operational time. Initially, *Reliability* was found to be twice as important as *Supportability*, but the validation phase found that *Reliability* was actually 0.65 of the value of *Dependability* and *Supportability* was 0.35 of the value. This determination was made using the "100 coin method" during validation.

The second aspect of *Maintainability*, *Resiliency*, was weighted next. A similar consideration was made for this value. It is of more importance that the system remains operational during an attack than it is easily repaired after the attack. Generally, more time is available following an attack and repair is not as critical; therefore, ensuring that the system never goes down is important. The direct weighting method was used for the values of *Survivability* and *Recoverability*. *Survivability* was found to be 0.60 of the value of *Resiliency* and *Recoverability* 0.40.

3.5.5 Weight Validation

Following the initial value weighting, the entire Hierarchy was reviewed to ensure weights were accurate. The weights were validated using the "tornado chart" weighting method. Each level of the hierarchy was examined from a "bottom-up" method. The bottom-up method was chosen, so that as measures were re-weighted and adjusted, the weights of the higher levels could immediately reflect the changes. A major advantage of the tornado weighting method is that it allows the decision-maker to see the relative importance of values in different branches and ensure that their relative placement is correct; therefore, global weights were used during the validation process. Global weights are the weights of the value relative to all other values on the same tier of the hierarchy.

3.5.5.1 Tier 3 Validation

Tier three was the first level to be validated using a “stacked” tornado chart. Since there is not a full fourth tier, it was not possible to start on the fourth level. By stacking Tier 4 values and displaying on a single bar chart, the decision-maker was able to see both the tier-three values and the tier-four values at the same time. Weighting was first done using separate Tier 1 branches (*System Effectiveness* and *Architecture Quality*) and then combined into a single chart. In each chart, the relative placement of each value was individually examined to ensure its placement in the overall hierarchy. Figure 3.13 shows the tier-three global weights for each value in the system branch. When local weights are multiplied up through the hierarchy to be converted to global weights, their order of importance is found.

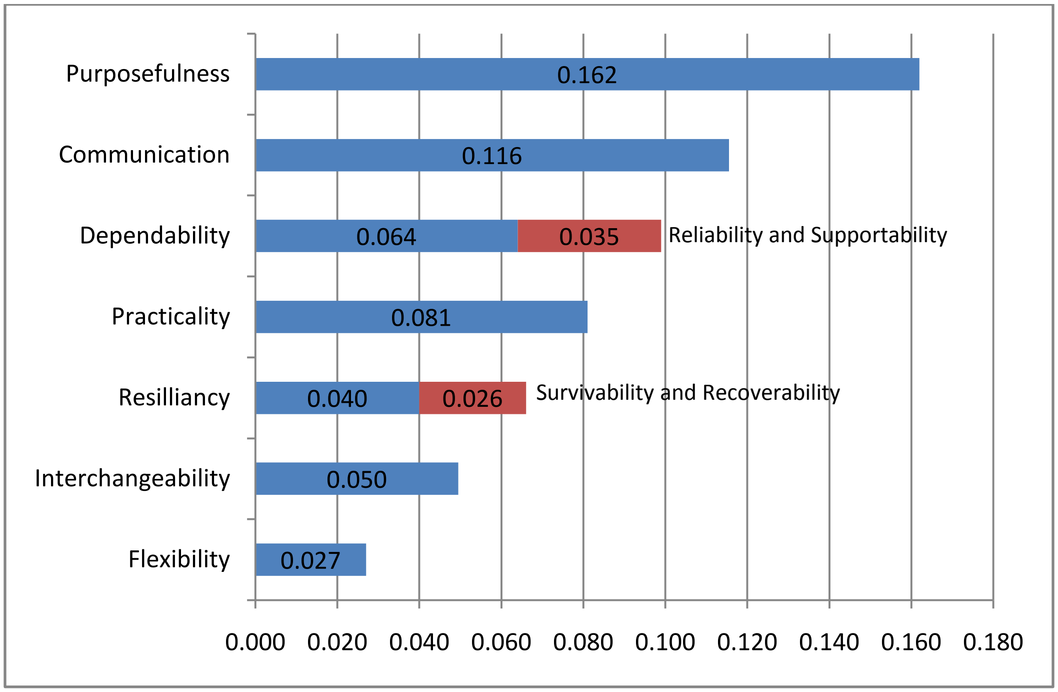


Figure 3.13. Tier 3 *System Effectiveness* Global Weights Stacked

In the initial presentation of the value weights, *Purposefulness* was weighted similarly, but shared the *Capability* value with only one other value. Once *Flexibility* was moved to the *Capability* branch, each of the three values under *Capability* were re-weighted. *Purposefulness* maintained its original weight of 0.60 locally, giving it a global value of 0.162. It was unanimously agreed that *Purposefulness* should be the most important value globally. *Practicality* was discussed next. Its original weight was 0.40, but with the addition of *Flexibility*, was re-weighted to be 0.30 of the value of *Capability* and 0.081 global value. *Practicality* was important enough to be in the top of values of importance, therefore its weight was monitored to ensure that it remained within the top five values. Its final global importance was fifth overall. *Flexibility* was weighted at 0.10 as discussed in section 3.5.3.1. Its global value was 0.027. *Flexibility*'s final importance was fourteenth of importance globally.

The tier three *Maintainability* values were examined next. *Dependability* and *Resiliency*, with their sub values of *Reliability*, *Supportability*, *Survivability*, and *Recoverability* were validated by adjusting the weight of the subvalues to determine what effect it had on the overall values of *Dependability* and *Resiliency*. *Reliability* and *Supportability*, the *Dependability* subvalues on tier four, were originally weighted at 0.60 and 0.40 locally. These weights were adjusted to 0.65 for *Reliability* and 0.45 for *Supportability*. This change was made to account for the fact that *Reliability*, being the system's "up-time" is more important than the ease of maintenance for a system. The 5% change to each value was made to adjust their standings in the tornado chart. When examined together, these values make up 100% of the *Dependability* value. Their global values were equal to 0.064 for *Reliability* and 0.035 for *Supportability*. These global values were used to examine the value's standings on the Tornado chart. This change placed *Dependability* above *Understandability* in the global rankings Tornado chart

(Figure 3.46) and in the top five of all values. *Dependability* is more important than understandability, because the system's ability to continue performance (maintenance time and system up-time) is more important to the decision-maker than the ease of reading architectural products. It also assured *Dependability*'s place above *Practicality* on the *System Effectiveness* values only tornado chart (Figure 3.44). *Dependability* itself (*Reliability* plus *Supportability*) is weighted as 0.60 local and 0.099 global on tier three. *Dependability* is the third most important value globally.

Resiliency is composed of the subvalues *Survivability* and *Recoverability*. *Survivability* and *Recoverability* were both accepted by the decision-maker with the weights as presented. The *Survivability* value was presented as 0.60 local and 0.04 global. *Recoverability* was 0.40 local and 0.026 global. These weights were assigned as such to account for the importance of the system remaining operational during an attack. It is important for the system to be recovered quickly, but the more critical time period is during the attack itself. These subvalues combine to form the tier three value of Resiliency. Resiliency, on tier three is weighted as 0.40 local and 0.066 global. These weightings place Resiliency as the sixth most important value globally.

Finally, the *Interoperability* branch was examined on tier three. The two tier three *Interoperability* values were *Interchangeability* and *Communication*. Due to the movement of *Flexibility* from the *Interoperability* branch to the *Capability* branch, *Communication* was re-weighted to 0.70 from 0.60 locally. This left *Communication* at 0.116 global value, making it the second most important value globally. *Interchangeability* remained at 0.30 local weight. Its global value was set at 0.05 and was the seventh most important global value.

Figure 3.14 shows all global values on tier three of the hierarchy. This Tornado chart includes both *System Effectiveness* values and *Architecture Quality* values. As shown on this chart, six of the seven most important values are from the *System Effectiveness* branch of the hierarchy. These rankings were validated based on the importance of the system to perform as expected. The Architectural products are also important, but they only represent the instantiated system and therefore rank lower globally. The one *Architecture Quality* value in the top seven is Understandability. This value is placed in its location due to the importance of the architectural products to be understood and to effectively communicate the concepts of the future system to a wide audience.

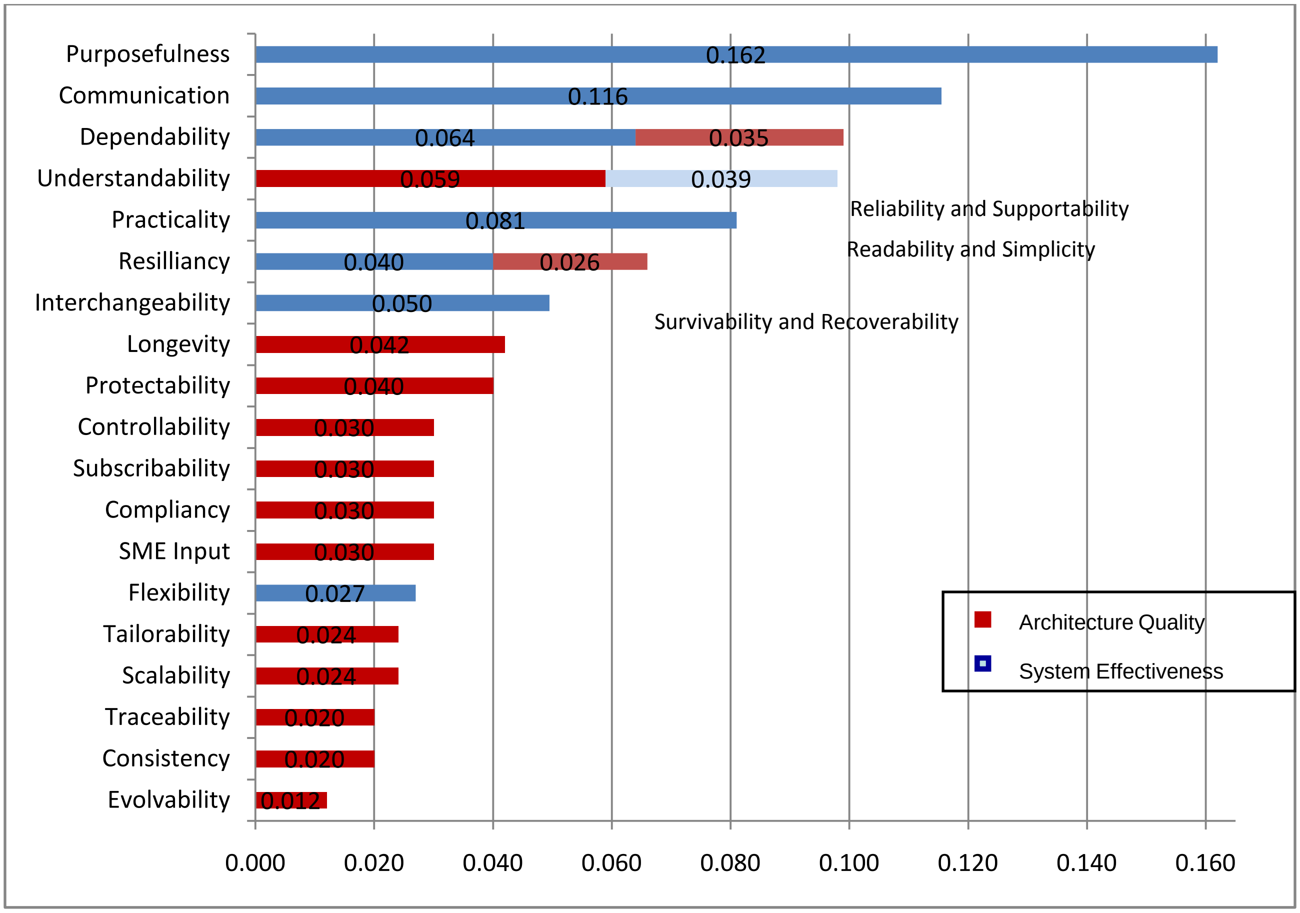


Figure 3.14. Tier 3 All Global Values

3.5.5.2 Tier 2 Validation

Tier two validation was done using the same method as tier three. Figure 3.46 shows the final global and local weights for the *System Effectiveness* values. Following the weighting of the tier three values, tier two values were simply checked for their placement among other *System Effectiveness* values and other tier 2 values. Figure 3.15 shows all values in Tier 2. *Capability* was validated at 0.45 local weight and 0.27 global weight. *Interoperability* and *Maintainability* were both validated at 0.275 local and 0.165 global weight.

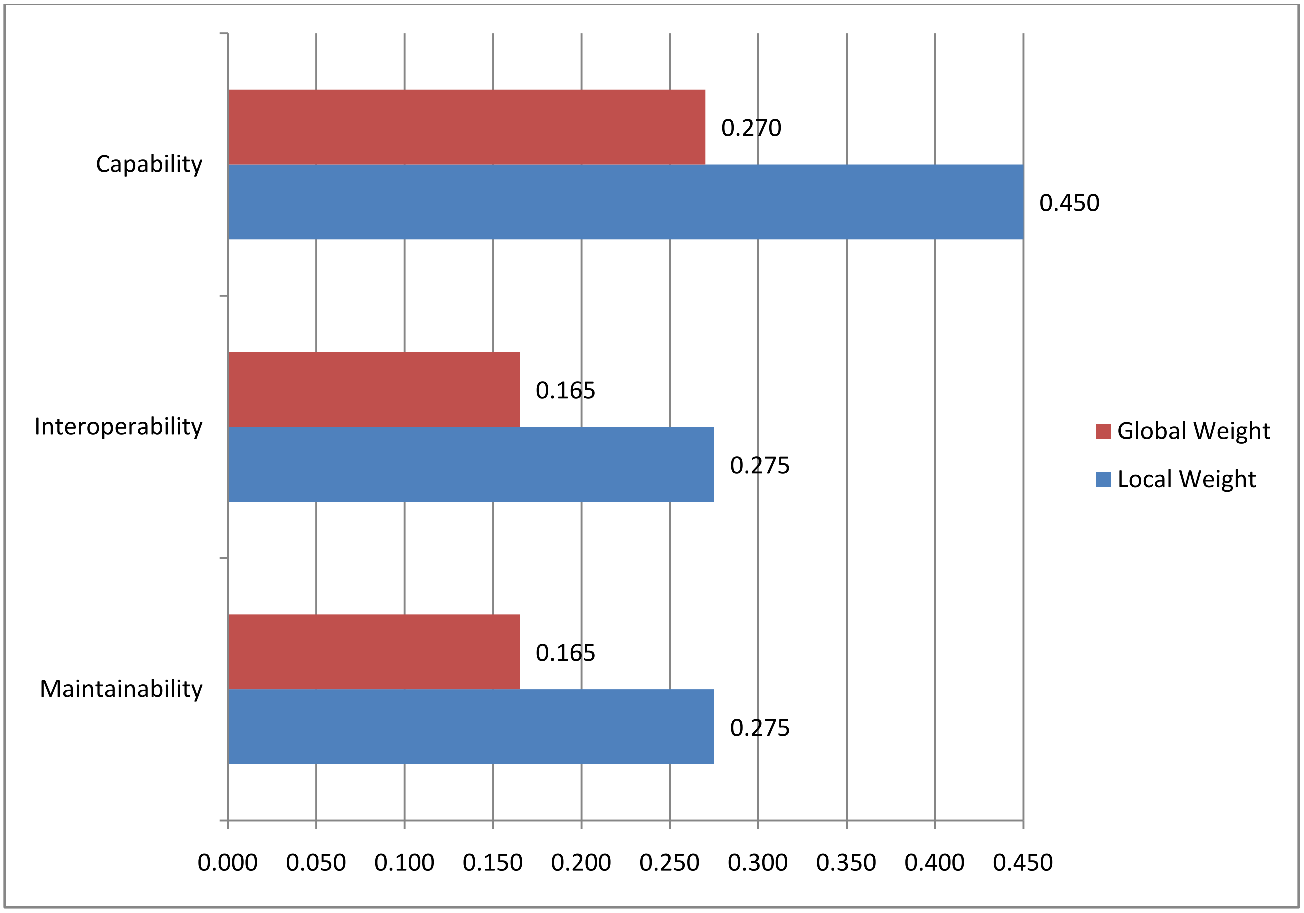


Figure 3.15. Tier 2 *System Effectiveness* Local and Global Weights

When examined among other tier 2 values, *Capability* was still the most important value with its 0.27 global value. *Interoperability* and *Maintainability* were the next most important tier two values at 0.165 global weight each. This ranking confirmed *Capability* as the highest weighted value.

3.5.5.3 Tier 1 Validation

The final validation completed was for the tier one values. The only tier one values are the two major branches of the hierarchy. *System Effectiveness* was weighted at 0.60 of the fundamental objective and *Architecture Quality* at 0.40 of the fundamental objective. This accounts for the higher importance of the instantiated system, versus the architectural products that represent the system.

Chapter 4. Analysis and Results

Following the finalization of the value hierarchy the existing architecture was scored and future alternatives were generated. For the Value-Driven Enterprise Architecture, the JFPASS system was evaluated first. Following this baseline score, the other generated alternatives were scored for comparison purposes. A sensitivity analysis was then completed to determine the effect that the weights of each value had on the final score as well as the impact of each measure to the final score.

4.1 JFPASS Architecture Scoring

The JFPASS system was examined first. Each measure in the hierarchy was examined individually and assigned a score based on the existing architecture. Since the existing architecture is at a very early stage of development, there are portions of value that have not yet been earned. The instantiated system does not yet exist; therefore, only the architectural products were used as data sources in the scoring process. Some measures may score higher based on information not yet included in architectural products, but since this information is not readily available to a third party reviewer and is therefore not verifiable, it cannot be included in the scoring of the system. Some areas of value are located in very specific architectural products; therefore, if these products do not yet exist, some measures cannot be accurately scored until those products are created. Value will be earned incrementally as new information is available during the life cycle of the project. The scoring presented here is the baseline for future improvements. The views available for scoring the JFPASS are listed in Table 4.1. Table 4.2 shows the final scores for each of the measures. To score the alternatives, the hierarchy was entered into a proprietary software package, Hierarchy Builder v1.01© (Weir, 2006). The Hierarchy Builder © package allows for all aspects of the scoring and analysis of a hierarchy.

Hierarchy Builder © also generates the Single Dimension Value Functions (SDVF) as entered by the user. To determine the equations associated with the continuous SDVFs, a trendline was fit to the curve and the equation was exported from Microsoft Excel©.

Table 4.1 Available JFPASS views

AV-1	SV-1
OV-1	SV-2
OV-2	SV-4
OV-4	SV-6
OV-5	TV-1
OV-6c	

Table 4.2 Scores and Associated Values

Alternative Name	**JFPASS 17 February 2009**		
Measure	**Score**	**Global Weight**	**Value**
OPERATIONAL NEEDS	0	0.041	0.001
THREAT DETECTION	Yes	0.041	1.000
THREAT ASSESSMENT	Yes	0.041	1.000
WARNING PLAN	Yes	0.041	1.000
TECHNOLOGICAL AVAILABILITY	TRL 1	0.02	0.050
ENVIRONMENTAL IMPACT	CONU.S. and Contingency constraints	0.02	0.800
MONETARY PRACTICALITY – INITIAL	Cost Unknown	0.02	0.000
MONETARY PRACTICALITY – MAINTENANCE	Cost unknown	0.02	0.000
ADAPTATION	Static	0.027	0.000
SUPPORTABILITY REQUIREMENTS	No	0.035	0.000
RELIABILITY REQUIREMENTS	No	0.064	0.000
REDUNDANCY	Some systems, single redundancy	0.04	0.250
RECOVERABILITY REQUIREMENTS	No	0.026	0.000
JOINT OPERATIONS	Yes	0.033	1.000
NESI DEVELOPMENT	Yes	0.066	1.000
NESI EVALUATION	No	0.066	0.000

4.1.1 *Capability* Measures Scoring

OPERATIONAL NEEDS primarily requires the use of the AV-1 and SV-5, although information may also be found in the OV-1, OV-3, OV-5, and SV-7. The AV-1 provides a list of OPERATIONAL NEEDS upon which to base the analysis. At a minimum, the AV-1 provides the system purpose and goals. The SV-5 is then used to trace those requirements down to functions or components, thereby ensuring that each Operational Need is met by some portion of the system. The AV-1 provided by the sponsoring organization had no information regarding the operational needs. In addition, there was no SV-5 from which to trace functions to components. Therefore, the OPERATIONAL NEEDS measure scores 0% in this evaluation with zero associated value.

THREAT DETECTION was scored based on the existence of a Threat Detection plan. At a later point in the development of the project, the Threat Detection plan itself may be graded, but at this point, its existence was the only important value. The OV-5 was examined in this case to determine its existence. OV-1 and OV-3 were also used for back up and additional information for the Threat Detection plan scoring. The OV-5 has an operational activity devoted to the DAWDR concept of Detect. Under this activity are many sub activities outlining exactly how the JFPASS will accomplish the Detect activity. In addition to the information in the OV-5, the OV-1 shows a system component devoted to threat detection as well. The THREAT DETECTION measure scored “Yes” with an associated value of one.

The same architectural views were used in the evaluation of THREAT ASSESSMENT as were used for THREAT DETECTION. The OV-5 included a similar activity called “Assess,” which accomplished the activities required in a Threat Assessment Plan. The OV-1 also includes an assessment component in the system scope. THREAT ASSESSMENT scored “yes” in the evaluation with an associated value of one.

The OV-5 and OV-1 were again employed in the scoring of WARNING PLAN. The OV-5 includes a Warn activity. The OV-1 also includes a “Wide Area Alert” component. There are some other aspects of the OV-1 which allude to a Warning plan, including the “Chemical Sensors,” “Lan,” and “C2,” all of which may accomplish a portion of the warning plan. WARNING PLAN scored “Yes” in the evaluation with an associated value of one.

The SV-8 view typically includes information related to the *Flexibility* of a system. Since an SV-8 does not yet exist for the JFPASS, other views were examined for information regarding ADAPTION. No information was found to score ADAPTION in the existing architecture products. ADAPTION was scored as “static” in this evaluation. A flexible system must include information regarding flexibility, as well as how the system may be altered in the architecture. A “Static” score yields zero value in this hierarchy.

The Technology Readiness Level (TRL) Scale was employed for the TECHNOLOGICAL AVAILABILITY measure. Typically, an SV-9 would include the necessary information to determine the TRL of a component. Since there was no SV-9 product, specific information on system components was searched for among the existing products. The TRL was not explicitly or implicitly stated in any of the existing products nor was there information to extrapolate the TRL for any component. Therefore, TECHNOLOGICAL AVAILABILITY was scored as “TRL 1 or No data” with an associated value of 0.05. The lowest level of TRL was assigned since this level accounts for components that have not yet entered any phase of development.

The ENVIRONMENTAL IMPACT measure was scored using the TV-1 product. Section 3.93 of the TV-1 is the Environmental section. The guidance documents listed here include Mil

Standards for Environmental Engineering, Electromagnetic Compatibility, and Interference Standard requirements. The documents included represent a cross section of some of the types of environmental guidance documents that must be considered in the design of an environmentally practical system. The inclusion of these documents in the TV-1 assumes the inclusion of these documents in the design of the system. The standards being used in this system are military and United States federal standards; therefore, the system was scored "CONUS and Contingency constraints" with an associated value of 0.8. The inclusion of military standards shows that contingency environments have been considered.

Indicators for the MONETARY PRACTICALITY – INITIAL measure may be found in the OV-5 product, although there are no specifically required views in DoDAF for estimates. Cost may be included in a layer of the OV-5 for some tools. If no cost is included in the OV-5, the OV-7 is also examined for possible cost elements. The JFPASS architecture had no cost information in any of the available views; therefore, the MONETARY PRACTICALITY measure scored "Cost Unknown" with an associated value of zero.

MONETARY PRACTICALITY – MAINTENANCE measure also scored "Cost Unknown" in this evaluation. The same views were examined for costs elements, but JFPASS did not include any cost information. The life-cycle cost for the system is an important consideration for decision-makers, but this estimate was not available in the provided views, so the value associated with MONETARY PRACTICALITY – MAINTENANCE was zero.

4.1.2 *Maintainability* Measures Scoring Score

Every system must be designed with tolerances for components to ensure that the system is within design parameters. DoDAF includes a vehicle for these requirements by way of the SV-7 product. Since the JFPASS does not currently include an SV-7; therefore, the existence of design standards for supportability cannot be verified. None of the other provided products include the information either. SUPPORTABILITY REQUIREMENTS therefore scores “No” with an associated value of zero.

Reliability Requirement considerations must also be taken into account in the design of a system. Since the SV-7 does not yet exist in the JFPASS, the equations and values required to ensure the inclusion of *Reliability* could not be located. The architecture must include some verification of these items to ensure that they are considered in the system design. RELIABILITY REQUIREMENTS scored “No” with an associated value of zero in this evaluation.

It is assumed that if redundancy exists of critical systems, these systems will be more survivable during an attack. SYSTEM REDUNDANCY ensures more system up-time during hostile action. The OV-6 event trace shows some evidence of system redundancies. The JFPASS includes one OV-6c for a single system activity. This view shows some evidence of redundancy in this activity. Additional views show some evidence of redundancy as well. Based on the data provided in these views, SYSTEM REDUNDANCY was scored as “Some Systems, Single Redundancy.” This gave the SYSTEM REDUNDANCY measure a value of 0.25.

The lack of an SV-7 product does not enable the verification of RECOVERABILITY REQUIREMENTS. These equations must be verified to ensure their inclusion in the architectural design. Since they cannot be verified, this measure scored “No” with an associated value of zero.

4.1.3 *Interoperability* Measures Scoring

The JOINT OPERATIONS measure is based on the consideration of all service components. Since it is a critical requirement that no service be left out, this measure is scored either “yes” or “no.” In this instance, JOINT OPERATIONS scored “yes” based on information drawn from a variety of views. The AV-1, OV-2, OV-3, OV-4, and SV-2 were the primary resources used for this evaluation. The AV-1 specifically contains references to all service documentation. In the available Operational Views, there is evidence of other service requirements, such as port security and convoy security which alludes to specific service requirements and operations. The associated value with this measure is one.

The TV-1 is the primary view employed in the evaluation of the NESI DEVELOPMENT measure. Section 3.1 and 3.2 of the TV-1 refer to Information Technology. Specifically, Section 3.1.2, Common Infrastructure Data Format Standards, and section 3.1.3, Network Management, relate to the concept of net-centricity. There are also documents related to wireless communications. While the Net-Centric Standards for *Interoperability* (NESI) is not referenced specifically in the TV-1, the concepts set forth in NESI are accounted for based on the documents provided in the TV-1. NESI DEVELOPMENT scored “Yes” with an associated value of one in this evaluation.

The evaluation criterion and checklists provided in the NESI Guidance were not completed for this system. There is no evidence in the provided architecture that the system was evaluated for compliance with NESI. NESI EVALUATION scored “No” in this evaluation with an associated value of zero.

4.2 Deterministic Analysis

With all measures scored, a deterministic analysis was performed to find a single, aggregate score for the entire project. Using the general additive value function, this score combines the associated values for each score as well as the weight of each measure. This score is simply a weighted average of these numbers. The Hierarchy Builder© software was used to generate graphs and do a comparative analysis of possible alternatives.

4.2.1 Additive Value Function

The general additive value function was used to create the JFPASS final score. The general additive value function is represented as (Kirkwood, 1997, p. 230):

$$v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i) \qquad \text{Eq 4.2}$$

Where $v(x)$ = the overall score of the alternative, $v_i(x_i)$ = the value of the score on the i^{th} measure, λ_i = weight of the i^{th} measure, n = the total number of measure, $\sum_{i=1}^{n} \lambda_i = 1.0$

Table 4.3 shows all measures and weights with the *Architecture Quality* measures included. To obtain a score for the full system, the measures for *Architecture Quality* must also be used. It is possible to examine the two branches separately, but this will give the decision-maker an incomplete picture of the entire system. The deterministic analysis for the *System Effectiveness* branch of JFPASS was completed using the entire system as well as the *System Effectiveness* branch alone. For all analyses, the *Architecture Quality* score was held static from Cotton and Haase's (2009) evaluation of the system.

Table 4.3 All Measures and Weights

Measure Description	**Global Weight (λ_i)**	**Value**
OPERATIONAL NEEDS	0.041	0.000
THREAT DETECTION	0.041	0.041
THREAT ASSESSMENT	0.041	0.041
WARNING PLAN	0.041	0.041
TECHNOLOGICAL AVAILABILITY	0.020	0.001
ENVIRONMENTAL IMPACT	0.020	0.016
MONETARY PRACTICALITY - INITIAL	0.020	0.000
MONETARY PRACTICALITY - MAINTENANCE	0.020	0.000
ADAPTATION	0.027	0.000
SUPPORTABILITY REQUIREMENTS	0.035	0.000
RELIABILITY REQUIREMENTS	0.064	0.000
SYSTEM REDUNDANCY	0.040	0.010
RECOVERABILITY REQUIREMENTS	0.026	0.000
JOINT OPERATIONS	0.033	0.033
NESI DEVELOPMENT	0.066	0.066
NESI EVALUATION	0.066	0.000
ACCESS	0.022	0.022
PRODUCT LOCATABILITY	0.011	0.011
DOCUMENT PROTECTION	0.033	0.033
PROTECTION	0.033	0.011
FILE MANAGEMENT	0.021	0.000
FILE FORMAT	0.021	0.021
CONNECTIONS	0.013	0.008
ARCHITECTURE REDUNDANCY	0.013	0.013
ARCHITECTURE ECONOMY	0.013	0.013
OV READABILITY	0.029	0.027
SV READABILITY	0.029	0.021
SCALE	0.024	0.014
DECOMPOSITION	0.024	0.024
TOOL FORMAT	0.012	0.012
DODAF COMPLIANCY	0.025	0.025
REQUIREMENT TRACEABILITY	0.025	0.000
INTERNAL CONSISTENCY	0.013	0.009
EXTERNAL CONSISTENCY	0.013	0.009
SME INVOLVEMENT	0.013	0.000
SME EFFECTIVENESS	0.013	0.000

4.2.2 JFPASS Analysis

The final score for the total system was found to be 0.538 out of 1.000. Figure 4.1 shows a stacked bar chart of each of the two major Tier 1 values. The *System Effectiveness* branch, though weighted higher (0.6) in the fundamental objective, received less of the overall weight.

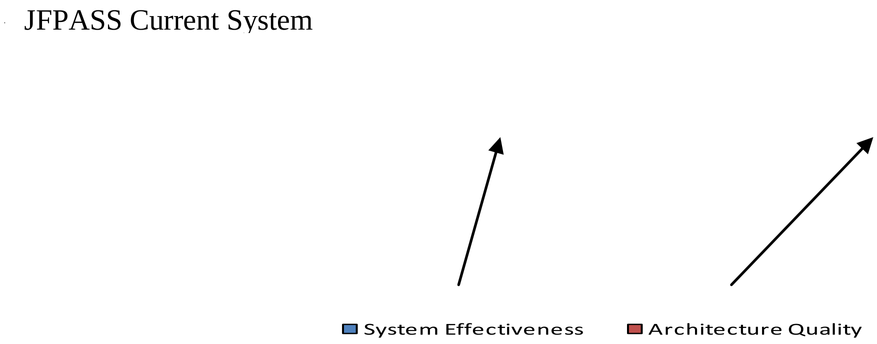


Figure 4.1 JFPASS Score Fundamental Objective - Values

Figure 4.2 shows the VDEA Score score sorted by measure. In this example, each measure’s value and global weight accounts for a portion of the bar chart. While *Purposefulness* is the highest weighted value, it has four measures intended to measure the concept. Therefore, each of those four measures have a smaller global weight. NESI DEVELOPMENT and NESI EVALUATION, however, have only one measure to determine the degree of attainment of the value; therefore, their measures’ global weights are higher. The high global weight and associated value of NESI DEVELOPMENT and NESI EVALUATION cause these measures to be among the highest weighted measures. It is evident in Figure 4.2 that a large portion of value was lost due to the lack of a performing a NESI EVALUATION and the lack of OPERATIONAL

NEEDS attainment. Three of th four *Maintainability* measures rank third, sixth, and seventh in possible global weight of the system. Some value was earned by SYSTEM REDUNDANCY, but no value was earned by Reliability or SUPPORTABILITY REQUIREMENTS.

Of the 0.60 total possible value of the fundamental objective, the *System Effectiveness* branch of the hierarchy earned 41.3% of its value. This equates to 0.248 of the 0.600 possible value units for *System Effectiveness*. Figure 4.3 shows the measures under the *System Effectiveness* branch only. This figure and score does not take into account any of the *Architecture Quality* measures or scores.

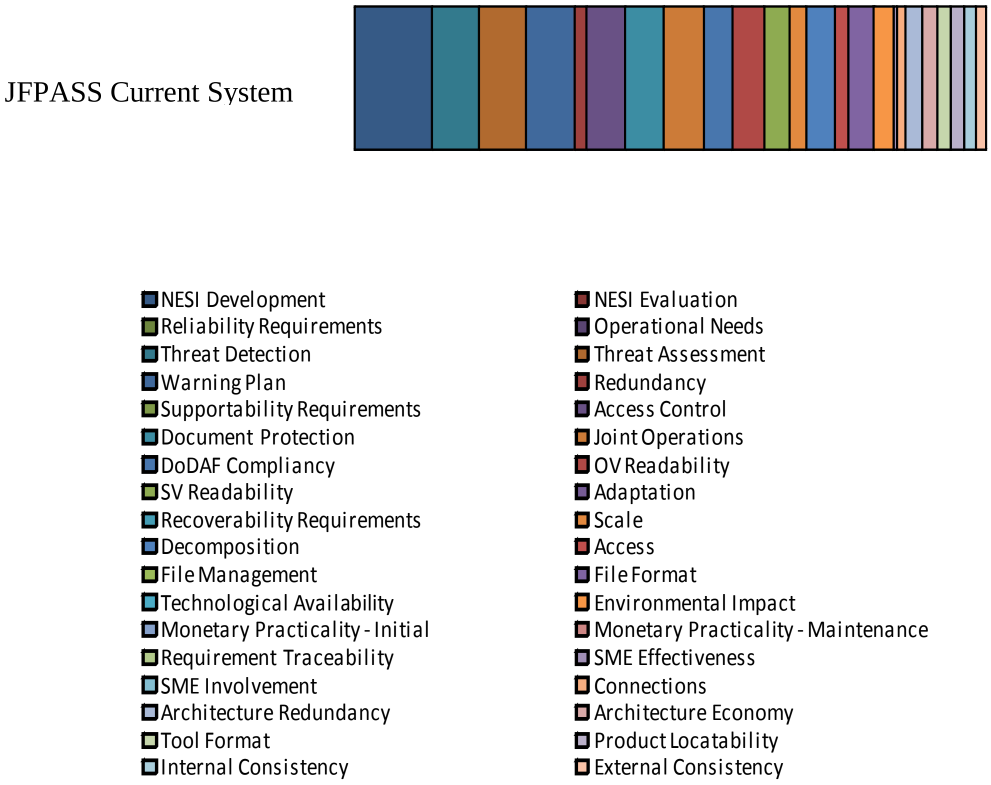


Figure 4.2 JFPASS Score Fundamental Objective - Measures

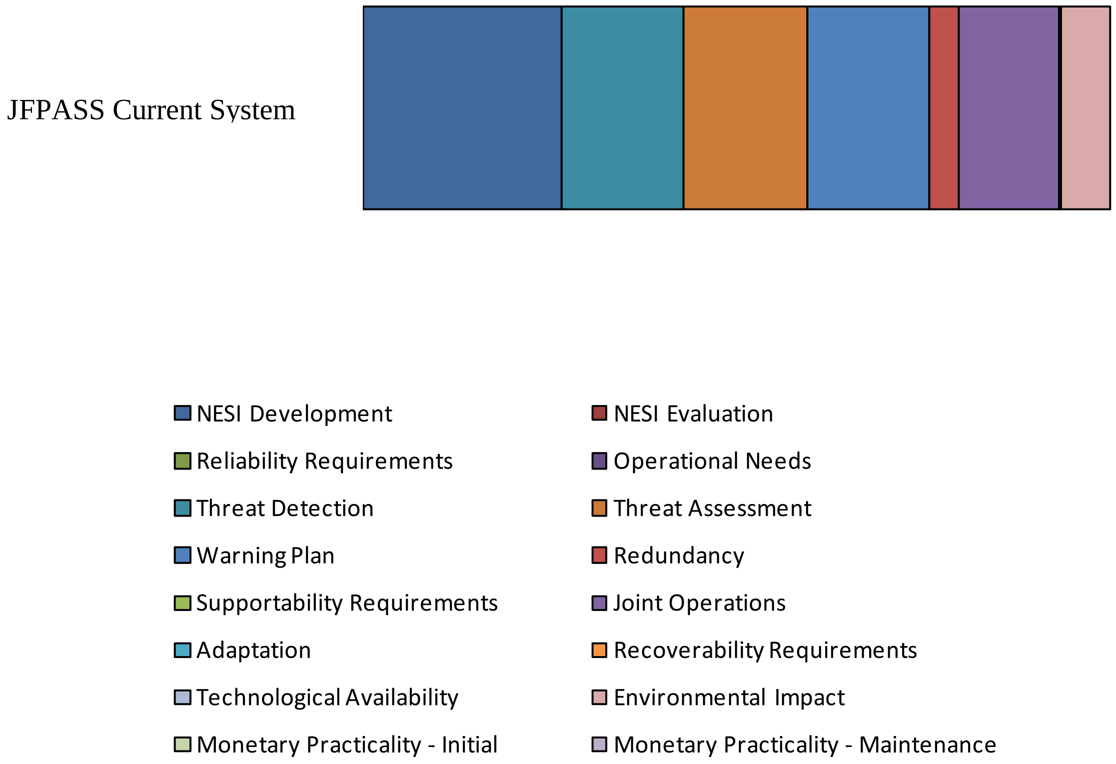


Figure 4.3 *System Effectiveness* Score – Measures

When examining the *System Effectiveness* branch alone in figure 4.3, it is evident where value was lost in the system. NESI EVALUATION, RELIABILITY REQUIREMENTS, and OPERATIONAL NEEDS are the three highest ranking measures that did not score any value. SYSTEM REDUNDANCY earned 0.25 of its total possible value, but none of the other *Maintainability* measures, SUPPORTABILITY and RECOVERABILITY REQUIREMENTS, earned any value. JOINT OPERATIONS earned full value, but ADAPTATION, TECHNOLOGICAL AVAILABILITY, MONETARY PRACTICALITY – INITIAL, and MONETARY PRACTICALITY – MAINTENANCE did not earn any value.

The next area of the hierarchy to be analyzed was the *Capability* branch of the *System Effectiveness* branch. *Capability* earned 51.4% of its total possible value (45% of *System Effectiveness*). The measures providing value to this branch are THREAT DETECTION, THREAT ASSESSMENT, WARNING PLAN, TECHNOLOGICAL AVAILABILITY, and Environmental Practicality. Figure 4.4 shows the bar chart of this branch. The *Interoperability* branch and *Maintainability* branch each only contributed one measure worth of value to the total score. Additional bar charts for the *System Effectiveness* Branch are found in Appendix C.

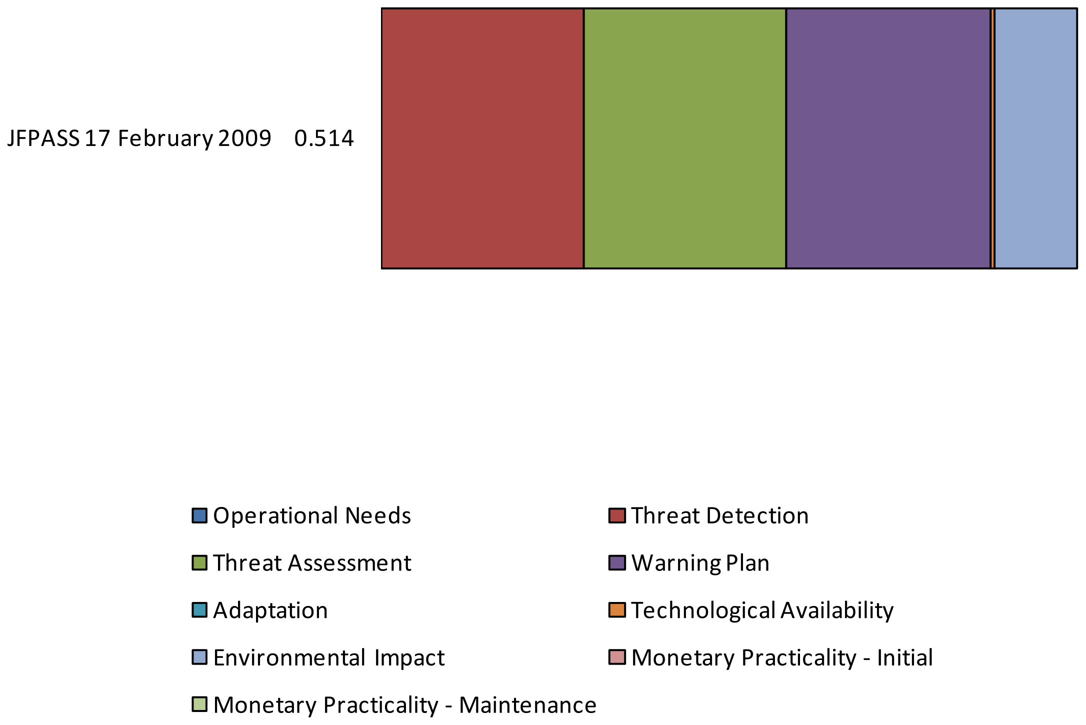


Figure 4.4 *Capability* Score – Measures

4.2.3 Gap Analysis

The actual generation of alternatives was completed via a gap analysis. This gap analysis allows the model builder to determine how much of an affect each measure has on the overall score. By adjusting the score of each measure and evaluating the total system score, the gap between the current value and highest possible (or lowest possible) value can be found. Table 4.4 shows the results of this sensitivity analysis in the range of each measure's scoring possibilities. The range is shown in the low and high columns. The "current" column shows the current overall system score, with the final column showing the gap between the current system score and the highest possible score that could be attained by maximizing the measure in question.

Table 4.4 Gap Analysis Score Ranges

	Global Value			
Measure	**Low**	**High**	**Current**	**Gap**
OPERATIONAL NEEDS	0.538	0.578	0.538	0.040
THREAT DETECTION	0.497	0.538	0.538	0.041
THREAT ASSESSMENT	0.497	0.538	0.538	0.041
WARNING	0.497	0.538	0.538	0.041
TECHNOLOGICAL AVAILABILITY	0.538	0.557	0.538	0.019
ENVIRONMENTAL IMPACT	0.521	0.542	0.538	0.021
MONETARY PRACTICALITY - INITIAL	0.538	0.558	0.538	0.020
MONETARY PRACTICALITY - MAINTENANCE	0.538	0.558	0.538	0.020
ADAPTATION	0.538	0.565	0.538	0.027
JOINT OPERATIONS	0.505	0.538	0.538	0.033
NESI DEVELOPMENT	0.472	0.538	0.538	0.066
NESI EVALUATION	0.538	0.604	0.538	0.066
SUPPORTABILITY REQUIREMENTS	0.538	0.572	0.538	0.034
RELIABILITY REQUIREMENTS	0.538	0.602	0.538	0.064
SYSTEM REDUNDANCY	0.528	0.567	0.538	0.039
RECOVERABILITY REQUIREMENTS	0.538	0.564	0.538	0.026

4.2.3.1 *Capability* Measurement Sensitivity

The OPERATIONAL NEEDS measurment was altered by increasing the score by 10% or 0.1 incrementally. Each incremental increase created a new alternative. The ten created alternatives showed a gap of 0.04 value units between the lowest score of OPERATIONAL NEEDS and the highest score.

The THREAT DETECTION measure is a binary measure; therefore, there are only two scoring possibilities. Since the current score is set to "yes," the alternative to this measurement scenario is if the measurement was scored "no." The alternative was worth less value than the current situation, with a loss of 0.041 value units. THREAT ASSESSMENT is the same in all ways to the THREAT DETECTION measurement in sensitivity. The range is also 0.041, as well as the binary nature. The WARNING PLAN measure is also similar to THREAT DETECTION and THREAT ASSESSMENT. It also has a range of 0.041 meaning that if it were to be scored "no," the maximum global system value lost would be 0.041.

TECHNOLOGICAL AVAILABILITY had a total of nine generated alternatives for sensitivity analysis. The TECHNOLOGICAL AVAILABILITY measurement was set to each TRL level for each alternative and the range for the TECHNOLOGICAL AVAILABILITY measure was found. The range was 0.019 change in value unit from the lowest score to the highest score of TECHNOLOGICAL AVAILABILITY. The current score of this measure was "Unknonwn/TRL 1," therefore any additional information or change to this measure would cause an increase to the total system score.

ENVIRONMENTAL IMPACT measurement has four possible score settings. This gives ENVIRONMENTAL IMPACT a range of 0.021, from 0.521 to 0.538 total system scores. The current system score is 0.538 with only one higher score possible. Therefore, only 0.004 value units are available for ENVIRONMENTAL IMPACT.

MONETARY PRACTICALITY – INITIAL has four possible score categories. The current score of this measure earns no value, therefore any change to the score would cause an increase to the total system score. The possible change is 0.20 globally. Figure 4.32 and 4.33 show the global and local measure sensitivity. MONETARY PRACTICALITY – MAINTENANCE has the same range and numerical value possibilities as MONETARY PRACTICALITY – INITIAL.

ADAPTION has five possible value categories. Currently the ADAPTION measure earns no value, therefore any increase in measurement will cause an increase in total system score. The range of scores for ADAPTION is 0.027 globally. While ADAPTION has a smaller effect on the total system score, any value earned helps the overall system score.

4.2.3.2 *Maintainability* Measurement Sensitivity

SUPPORTABILITY REQUIREMENTS is a binary measure, which is currently measured at its lower value possibility. If the score is set to “yes,” the possible change in value is 0.034 value units. This change in overall score indicates that this measurement will have a significant impact on the overall score.

The RELIABILITY REQUIREMENTS measure is also a binary scoring set. Since the *Reliability* value has a higher global weight, the range in score change is larger for this measure of *Maintainability*. The VDEA score range is 0.064 for RELIABILITY REQUIREMENTS.

RECOVERABILITY REQUIREMENTS is also a binary measure. It is similar to both SUPPORTABILITY REQUIREMENTS and RELIABILITY REQUIREMENTS and is currently scored as “no.” The range for this measure is 0.538 – 0.564, meaning that the highest possible value change between the lower score and higher score is 0.026.

The SYSTEM REDUNDANCY measure is rated on a scale of four possible levels. The current system is scored at the second level. The range between the lowest and highest scoring possibilities is 0.039 value units. As one of the four *Maintainability* measures, SYSTEM REDUNDANCY is an important design consideration, which is evident in its effect on the total system score.

4.2.3.3 *Interoperability* Measures Sensitivity

The JOINT OPERATIONS measurement scored "yes" in this evaluation, giving it its full possible value. If it had been scored no, the greatest change to the total system score would have been 0.033 value units, taking the system score to 0.505. This is a relatively large change for a single measure, indicating that the JOINT OPERATIONS measurement is of great importance.

The NESI DEVELOPMENT measurement is a binary measure, currently scored at its higher score of "yes." NESI DEVELOPMENT is one of the more important measures in this evaluation, with a global weight of 0.066. Therefore, its impact on the total score is higher than most other measures. The swing between its higher and lower score possibilities is 0.066 value units. This makes the lower possible range of the VDEA score to 0.472 for this measure.

The final measure on the *System Effectiveness* branch of the hierarchy was NESI EVALUATION. This measure also has a high global weight making it a relatively important measure. In this case, the system scored at the lower possibility, therefore if the score was changed to "yes," the change in VDEA score would be 0.066, taking the total score to 0.604.

4.2.4 Alternative Generation

Step six of the Value-Focused Thinking (VFT) process is the Alternative Generation step. In the standard VFT process, at this point, the hierarchy would be used to find alternatives which fit the evaluation criteria. In the case of the Joint Force Protection Advanced Security System

(JFPASS), though, a single alternative was created by the decision-maker. However, several additional alternatives were generated as comparison criteria for the decision-maker. These alternatives also demonstrated the additional insight to be gained from the VFT process.

When generating alternatives, two approaches were taken. First, a set of alternatives was generated which represented the baseline or current system with improvements. These alternatives show future iterations of the system with a product focus, in which new products are added to the architecture with the intent of improving the VDEA score. The second set of alternatives represents random scoring scenarios. These scenarios do not take into account the current or baseline architecture.

Table 4.5 shows the alternatives that were generated for the decision-maker. These alternatives represent different versions of the architecture. In Table 3.8, each measure is linked to its source views. The “Perfect Architecture” represents an architecture that scores 100% value in all currently available *System Effectiveness* areas as an upper bound. The “Current Architecture” or “Baseline” is the architecture as provided by the sponsor. Other alternatives represent possible alterations to the existing architecture, based on the addition of more views. The views used for additional alternatives were determined based on the sources for measures (Table 4.6) and the gap analysis shown in Figure 4.5. By determining where the current architecture lost value, it was possible to generate alternatives that filled those gaps by adding the necessary views. For example, the OPERATIONAL NEEDS measure requires at a minimum an AV-1 and SV-5, in addition to all existing views, to earn full value. Therefore, an alternative was created for a full AV-1 and SV-5, which assumes that these products include the minimum information necessary to assign full value to OPERATIONAL NEEDS.

Table 4.5. Generated Alternatives

Perfect Architecture
Baseline
Baseline plus OV-3
Baseline plus SV-5
Baseline plus SV-7
Baseline plus SV-8
Baseline plus SV-9
Baseline plus full AV-1
Baseline plus AV-1 and SV-7
Baseline plus AV-1, SV-7, and SV-5
Baseline plus SV-7, SV-8, and SV-9
Random VDEA Score 1
Random VDEA Score 2
Random VDEA Score 3
Random VDEA Score 4

Table 4.6. Required Views for Measures (Osgood, 2009)

	AV-1 Overview and Summary Information	OV-1 High-Level Operational Concept Graphic	OV-2 Operational Node Connectivity Description	OV-3 Operational Information Exchange Matrix	OV-4 Organizational Relationship Chart	OV-5 Operational Activity Model	OV-6 Operational Rules Model/State Transition/Event-Trace Description	SV-2 System/Services Communication Description	SV-5 Operational Activity to System Function/Systems/Services Traceability Matrix	SV-7 Systems/Services Performance Parameters Matrix	SV-8 Systems/Services Evolution Description	SV-9 Systems/Services Technology Forecast	TV-1 Technical Standards Profile
Operational Needs	x	x		x		x			x	x			
Threat Detection		x		x		x							
Threat Assessment		x		x		x							
Warning Plan		x		x		x							
Technological Availability												x	
Environmental Impact													x
Monetary Practicality - Initial						x							
Monetary Practicality - Maintenance						x							
Adaptation											x		
Supportability Requirements										x			
Reliability Requirements										x			
System Redundancy							x						
Recoverability Requirements										x			
Joint Operations	x		x	x	x			x					
NESI Development													x
NESI Evaluation													x

Figure 4.5. Gap Analysis

Baseline plus SV-7 (in addition to existing products) is an alternative created to show the difference in score if the Maintenance value measures (except SYSTEM REDUNDANCY) were assigned full values. Without an SV-7, it is very difficult to score these measures. The OV-3 alternative exists since it is a supporting view for four measures. Baseline plus SV-5 demonstrates the effect of adding only an SV-5 without a full AV-1. Baseline plus SV-8 shows the value associated with adding an SV-8 and Baseline plus SV-9 shows the value associated with adding an SV-9. The SV-8 and SV-9 products account for the TECHNOLOGICAL AVAILABILITY and ADAPTION measures. An alternative was also created that incorporates a full AV-1, SV-7, and SV-5, which allows the hierarchy to maximize the OPERATIONAL NEEDS measure, as well as three of the *Maintainability* measures. Finally, an alternative was generated that includes an SV-7, SV-8, and SV-9. This alternative represents a situation in which TECHNOLOGICAL AVAILABILITY, ADAPTATION, and three of the four *Maintainability* measures. The full scoring scheme for each of these alternatives is shown in Appendix D.

The second set of generated alternatives was produced by allowing each measure's score to take on a random value. In cases where the measurement was on a continuous interval, a random number was selected on that interval. In cases where the measure could take on discrete categorical values, each category was given equal likelihood of occurrence for selection. Once all scoring scenarios were generated, the related value was summed to obtain an cumulative score. This process was performed 500 times and four of these 500 cases are presented as alternatives. Since measurements are independent and mutually exclusive, each measurement score may take on any scoring value without an effect on the measurement of other values. These alternatives produced from Monte Carlo sampling are intended to provide additional comparison criteria for the baseline.

Monte Carlo generation of alternatives was completed using a spreadsheet. To obtain the composite random scores, the A*rchitecture Quality* scores were held static with their current values. A Monte Carlo sampling technique was used to randomize *System Effectiveness* measurements. This measurement was then transformed to a value using the SDVF and multiplied by its measure weight (λ_i). The composite score was for each alternative was calculated by summing all values for each measure. Five hundred separate scoring iterations were created. These 500 new "alternatives" represented 500 different possible alternatives with random measurements for each measure, and therefore a random score. They do not represent the current JFPASS value or measurement, only hypothetical VDEA scores. Once the set of 500 scores were produced, a random number generator was used to select four of the iterations from the set of 500. Each of the numbers selected represented a random score of the VDEA instrument. The random selector chose random alternatives 26, 207, 379, and 420l; hereafter called Random VDEA Score alternatives. Each of these situations were then entered to the Hierarchy Builder© software and analyzed alongside the other generated alternatives.

4.2.5 Alternative Analysis

As a part of the JFPASS deterministic analysis, each of the generated alternatives were also examined. Appendix D shows the scores for each of the measures in each alternative. Figure 4.6 shows the rankings and scores of all alternatives. It is important to note that though the addition of certain views may not help the overall score of the system, that does not mean that those views at not useful. Each view within DoDAF serves a specific purpose and should not be discounted if the information contained within it is helpful to the system designers or decision-maker. This analysis is based on the information that is important the scoring of the system based on the decision-maker's values. If additional views are required, they may not impact the score of the system, but this does not lessen their importance to system design.

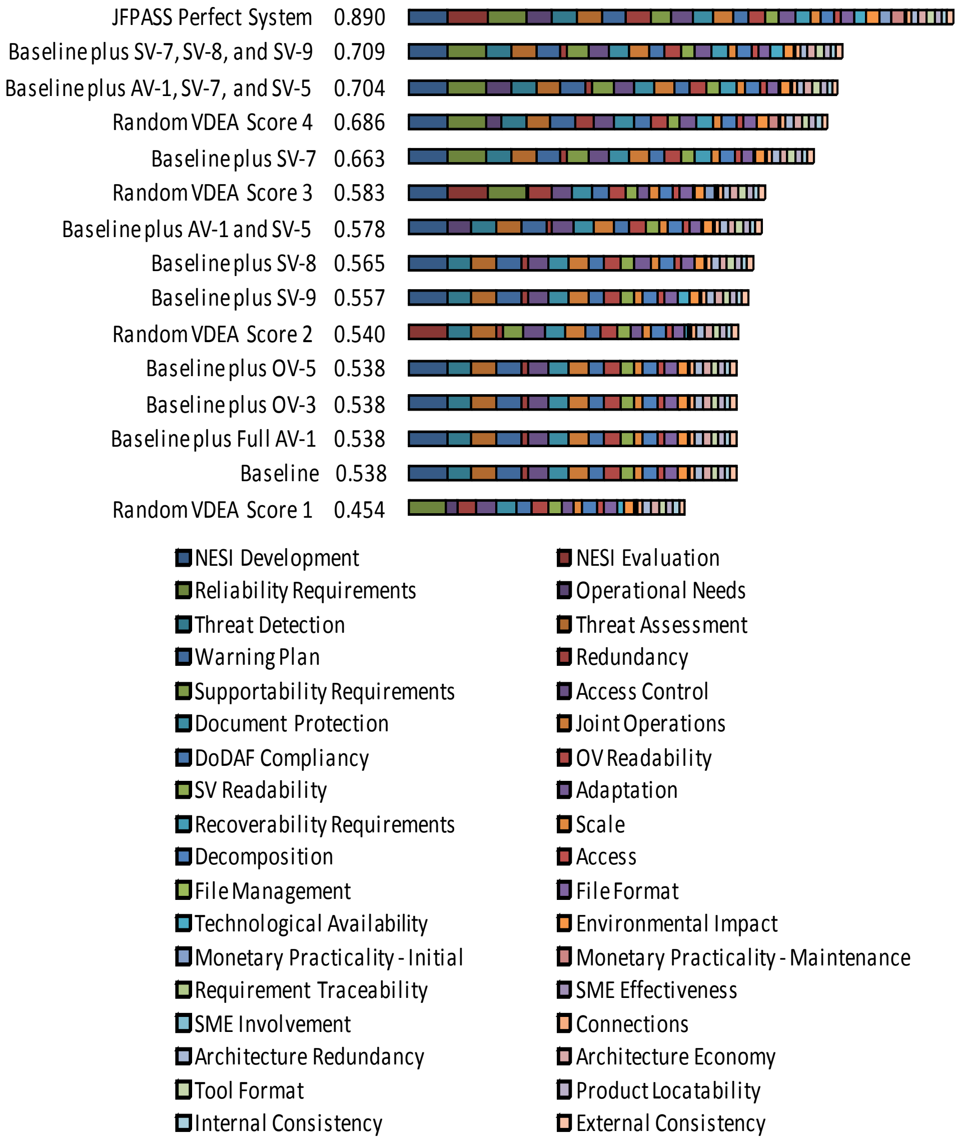


Figure 4.6 All Alternatives and Scores

The Perfect System score represents a system in which all *System Effectiveness* measures have scored their maximum value. The *Architecture Quality* scores were held constant from

Cotton and Haase's (2009) evaluation of the system. With all *System Effectiveness* scores maximized, the system scored 0.890 of 1.000 possible value units.

The highest scoring "non-perfect" alternative was a situation in which SV-7, SV-8, and SV-9 products are added. The addition of these views allows for the maximization of TECHNOLOGICAL AVAILABILITY, ADAPTATION, and three of the four *Maintainability* measures. Each of these views maximizes different areas of the hierarchy, to show the additive advantages of creating additional views. This alternative scored 0.709 of 1.000 possible value units.

The next highest scoring alternative was the current system with and AV-1, SV-7, and SV-5 added. Adding these views allows the system to maximize both the OPERATIONAL NEEDS measure as well as the *Maintainability* measures. The addition of a full AV-1 and SV-5 allows for OPERATIONAL NEEDS to be maximized, while the SV-7 allows for the *Maintainability* measures to be maximized. This alternative scored 0.704 out of 1.000 value units.

The Random VDEA Score 4 alternative represents a random scoring situation. The individual scores for each measure of Random alternative 4 are shown in Appendix D. Random alternatives were generated to demonstrate to the decision-maker additional possible scoring situations which may not have been considered in the generation of other alternatives. This allows the decision-maker other means to achieve a certain level of architecture value.

JFPASS with SV-7 was the next highest scoring alternative. This alternative is meant to demonstrate the effect that the addition of an SV-7 that includes the necessary documentation for the *Maintainability* measures would have on the system score. SV-7 is therefore the next most important view to be added to the existing architecture. This view would provide the required information to prove that the values under *Maintainability* were considered in the system design. The score for this measure was 0.663.

Random VDEA Score 3 scored the next highest value. This alternative scored 0.583. The JFPASS alternative that includes AV-1 and SV-5 allows the OPERATIONAL NEEDS measure to be maximized. By adding these views with the required information, the score of the system becomes 0.578. The SV-8 product allows the system to maximize its score for ADAPTION. If this view is created, with necessary information for an improved ADAPTION score, the total system score increases from 0.538 to 0.565.

SV-9 allows for a similar increase in value. The addition of an AV-9 view will allow for the TECHNOLOGICAL AVAILABILITY measure to be scored higher. This measure is more difficult though. There is a possibility that simply adding the SV-9 product will not increase the score. Since the TRL is based on the actual availability of technology, in order to maximize the TRL scoring, the technology used in the system must rate higher on the TRL scale. The creation of this alternative allows the decision-maker to see how much of an effect the maximization of TECHNOLOGICAL AVAILABILITY will have on the total system score.

Random VDEA Score 2 scored the next highest on the list of alternatives. This random alternative had a score of 0.540 and represents a system with very minor changes to the current configuration. In addition, this alternative shows the effects of failing to maximize or earn value on some of the views that the baseline has achieved value on.

The next three alternatives all scored the same as the current JFPASS system. The addition of an SV-5 product by itself does not add any value to the system. The SV-5 is used to trace capabilities to system functions, but without a list of OPERATIONAL NEEDS, the SV-5 does not add much value based on what is important to the decision-maker. The SV-5 is only useful when combined with a complete AV-1. Without the SV-5, though, a more complete and explicit AV- 1 is of little value as well. The system with an OV-3 added also does not earn any additional value. This was the last view that could possibly add value to the system or was useful in the determination of the scoring of some values. The OV-3 is used for the score of OPERATIONAL NEEDS, THREAT DETECTION, THREAT ASSESSMENT, WARNING PLAN, and JOINT OPERATIONS. Since the OV-3 is only a supplemental view for determining the score of these measures, its additional does not help the current system. In the case of THREAT DETECTION, THREAT ASSESSMENT, WARNING PLAN, and JOINT OPERATIONS, these measures were already scored at maximum value, therefore the OV-3 does not assist in scoring those measures.

Finally, the Random VDEA Score 1 Alternative has a VDEA-Score of 0.454. This random alternative represents a system which is more lacking than the existing system. This random alternative lacks many of the stronger valued measures and therefore scores lower. This alternative shows a contrast to the baseline in which many of the values did not earn their full values.

The scores and difference from the current system for all alternatives can be found in Table 4.7. This table illustrates exactly how much effect improvements to the current architecture will have on the total score. For example, the addition of an SV-7 can cause a maximum change of 0.125 value units to the system. Therefore, adding this one product has the highest impact on the system. Adding an SV-7, SV-5, and completing the AV-1 will have a maximum change of 0.166 value units. But making this change will require the addition of two products and alterations to an existing product. Therefore, the most cost effective value adding measure will be to add an SV-7.

Table 4.7 Alternative Scores and Maximum Value Additions

Alternative Name	Score	Maximum Value Change
JFPASS Perfect System	.890	0.352
Baseline plus SV-7, SV-8, and SV-9	.709	0.171
Baseline plus AV-1, SV-7, and SV-5	.704	0.166
Random VDEA Score 4	.686	0.148
Baseline plus SV-7	.663	0.125
Random VDEA Score 3	.583	0.045
Baseline plus AV-1 and SV-5	.578	0.040
Baseline plus SV-8	.565	0.027
Baseline plus SV-9	.557	0.019
Random VDEA Score 2	.540	0.002
Baseline	.538	0.000
Baseline plus full AV-1	.538	0.000
Baseline plus OV-3	.538	0.000
Baseline plus SV-5	.538	0.000
Random VDEA Score 1	.454	-0.084

4.3 Sensitivity Analysis

The Hierarchy Builder© software includes a sensitivity analysis tool which examines the weight of each value and measure in the hierarchy. This sensitivity analysis tool allows the user to see how the VDEA score would be changed by adjusting the weight of a particular value or measure. By examining how weights affect the scoring of alternatives, the decision-maker can gain insight as to how the weighting of a certain value affects the decision.

4.3.1 Global Weight Sensitivity Analysis

The Hierarchy Builder© software's sensitivity analysis tool is capable of performing sensitivity analyses both globally and locally. This sensitivity analysis shows the decision maker how the final decision may be affected by altering the weight of a particular value. Since the weights were chosen and validated by the decision-maker, the current weights are assumed correct. Sensitivity analysis is provided to demonstrate alternative scenarios and allow for further verification of weight.

4.3.1.1 Alternative Sensitivity Analysis

Sensitivity analysis in a multiple alternative situation is generally more useful to the decision-maker. In a multiple alternative situation, adjusting the weights of certain values or measures may lead to one alternative being chosen over another. In some cases, a small change in weight may lead to a major change in the ranking of alternatives. It is therefore important to closely examine the sensitivity curves for each of the alternatives to ensure that the weighting is correct and the proper alternative is being selected. In the case of the JFPASS, the alteration of some weights may affect which product should be included next in the architecture. With more alternatives, the complexity of the analysis and decision increases, and minor alterations may have a larger effect on the outcome. Any changes to weights must be well vetted through the decision-maker to ensure the change is being made for the proper reasons.

4.3.1.1.1 Alternatives *System Effectiveness* Sensitivity Analysis

When a sensitivity analysis is performed on all alternatives, the best performing system is, quite obviously, the Perfect system alternative. This provides a good point of comparison for the other alternatives. The analysis shows that if the local weight of *System Effectiveness* is increased to one, the perfect system is by far the best performing alternative; this is followed by the SV-7, SV-8, and SV-9 alternative. The next best performing alternative is the Current system plus AV-1, SV-7, and SV-5 included. Though this is the next best performing alternative, there is still a great deal of value not being earned. Each of the alternatives has a negative slope as the weight of *System Effectiveness* approaches one. This chart shows the decision maker that even in the case of the best generated alternative, there are value gaps. In addition, if the global weight of *System Effectiveness* is altered between zero and one, there will be no effect to the alternative preference. Figure 4.7 shows the sensitivity analysis for *System Effectiveness* with all alternatives included.

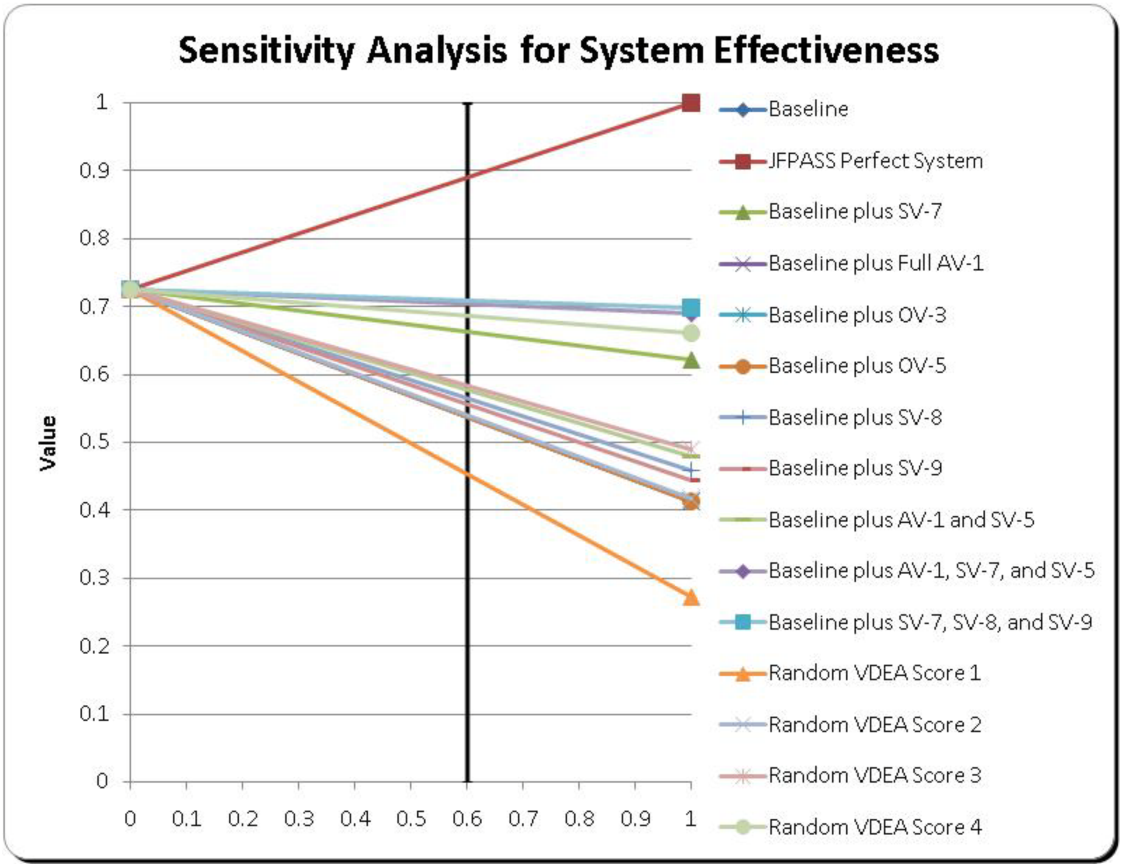


Figure 4.7 *System Effectiveness* Alternative Sensitivity Analysis

4.3.1.1.2 Alternatives *Capability* Sensitivity Analysis

When the *Capability* value is examined, there are significant changes to the alternative ranking that can be affected by changing the weight of the *Capability* value. The Perfect system will of course continue to perform the best of all alternatives as the weight increases. As the global weight of *Capability* approaches approximately 0.4, the Random VDEA Score 4 alternative begins to outperform the AV-1, SV-7, and SV-5 scenario. As the global weight of *Capability* increases or decreases, it may affect the decision that will be made. Depending on the alternative chosen, the amount of adjustment before the decision is impacted alters. In the case of *Capability*, if the weight is incorrect, it will not change the decision from this point. These rankings, as well as the points at which the alternatives change order can be seen in Figure 4.8. If the weight is set to any value between zero and one, a new ranking can be found by observing the order of alternatives. Locally, there are similar changes to the rankings of alternatives when examined.

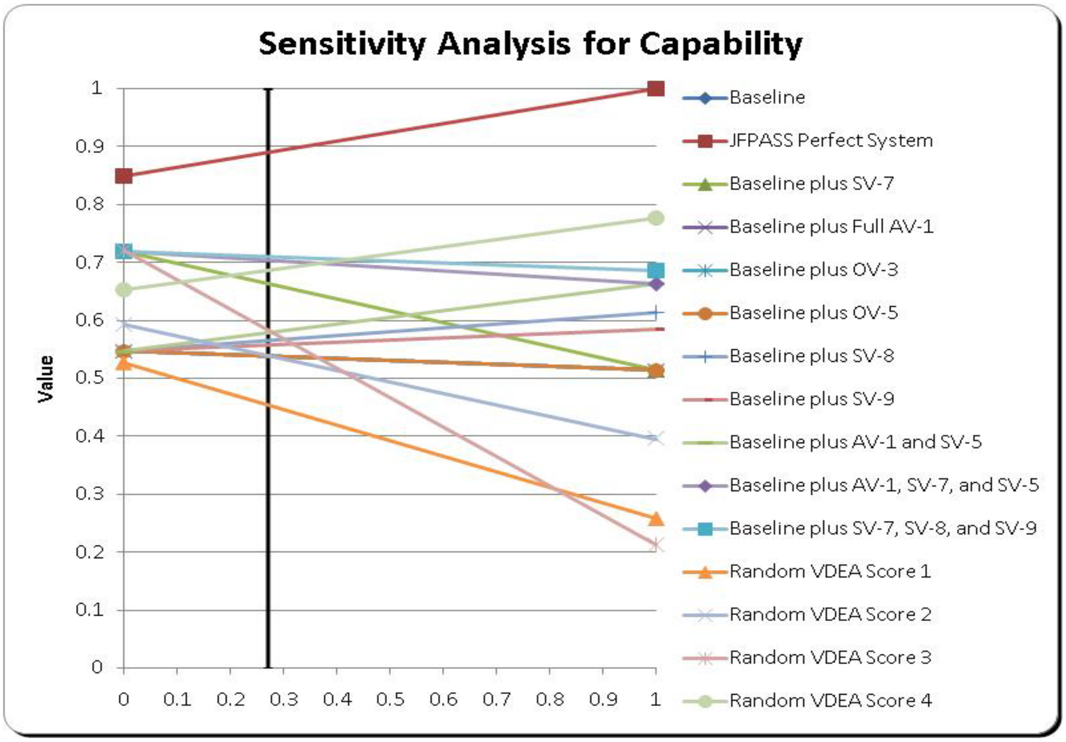


Figure 4.8 *Capability* Alternative Global Sensitivity Analysis

4.3.1.1.3 Alternatives *Maintainability* Sensitivity Analysis

As the global weight of *Maintainability* increases, the ranking of alternatives changes significantly. Several alternatives' values drop to below 0.1 in fact. The range of alternative scores varies between 0.05 and 0.82 (without consideration of the Perfect System). *Capability* however only varies between 0.4 and 0.78. This shows that the current scoring of

Maintainability offers a great deal of opportunities for improvement. It is also evident that in some alternatives, particularly in the mid 0.6 value range, the decision is very sensitive to the weighting of *Maintainability*. The alternatives in which the *Maintainability* measures have attained their maximum value perform much better in a *Maintainability* sensitivity analysis. The random alternatives are the only alternatives that score differently than the generated alternatives. All other generated alternative either rank in the lower or higher group, due to the effect of the *Maintainability* measures. The generated alternatives generally perform together, since the addition of the SV-7 product allows all *Maintainability* measures to maximize. The random alternatives are not bound by all *Maintainability* measures performing together; therefore, they score differently. Locally, the alternatives perform similarly to globally, but the range of values decreases. Figure 4.9 shows the global sensitivity analysis for *Maintainability*.

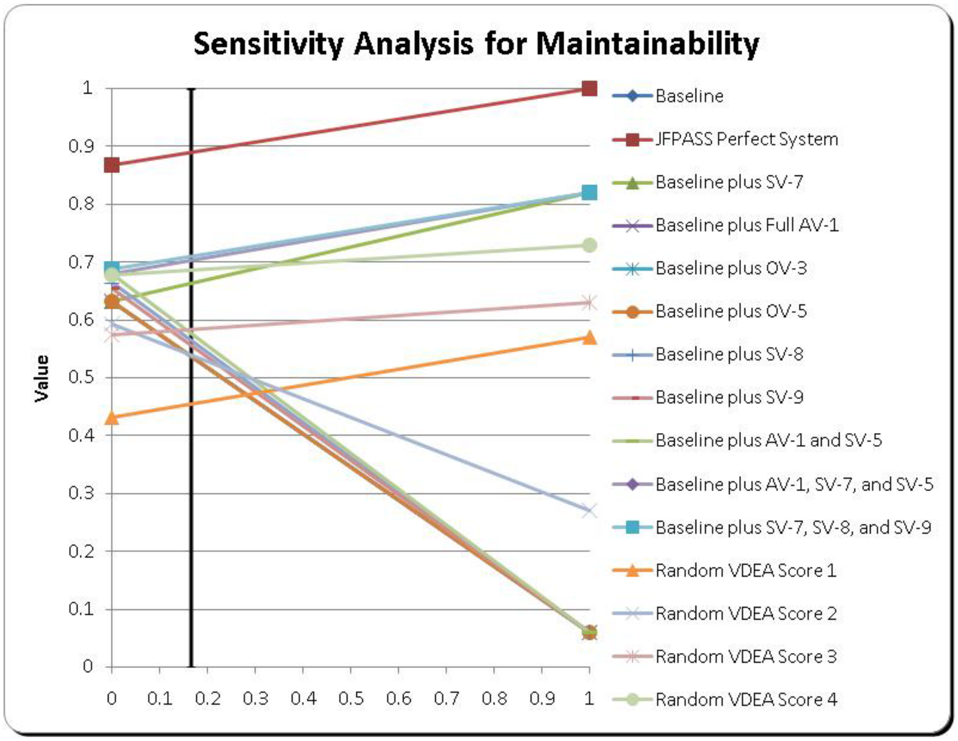


Figure 4.9 *Maintainability* Alternative Global Sensitivity Analysis

4.3.1.1.4 Alternatives *Interoperability* Sensitivity Analysis

The sensitivity analysis for *Interoperability* shows that again the random alternatives are the only one that performs significantly differently. All other alternatives converge to the same value of approximately 0.6 as their global weights approach one. As the weights approach zero, their values diverge slightly from their current state, but the rankings do not change. This implies that in order to affect any significant change to the final score, the *Interoperability* measures must score differently than they do in the majority of the alternatives. In this case, the weight of *Interoperability* can have a major effect on the decision. If the weight of *Interoperability* is increased to 0.5, the SV-5 is the next best choice. Until that point, the decision remains unaltered. In an analysis of the scoring of each alternative, it is apparent that each of the random alternatives has differing scores for the *Interoperability* measures, causing their changes in the sensitivity analysis. Figure 4.10 shows the global sensitivity analysis for the *Interoperability* value.

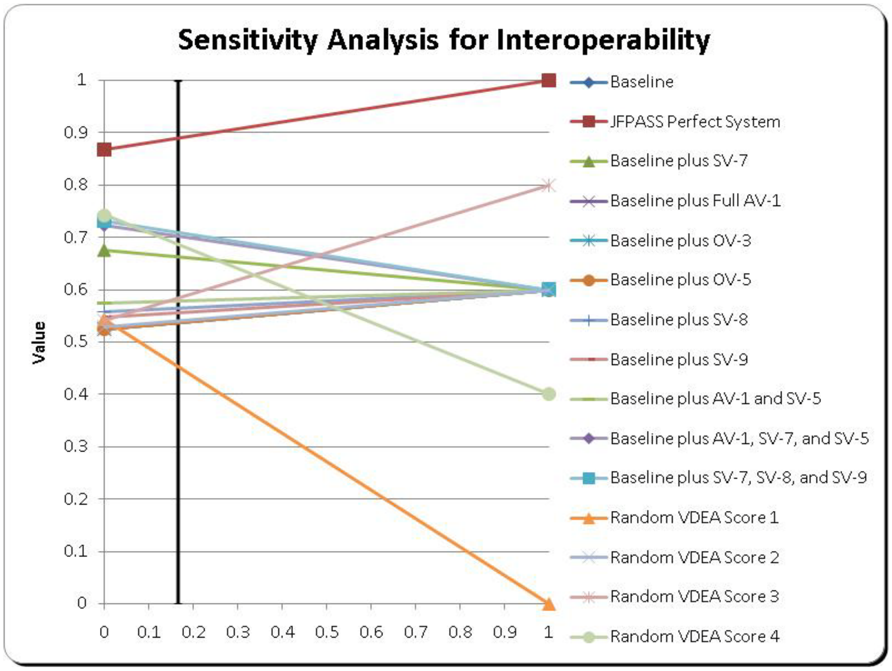


Figure 4.10 *Interoperability* Alternative Global Sensitivity Analysis

Chapter 5. Conclusions and Recommendations

This chapter provides an overview of the research completed and the results of the JFPASS system analysis. The research questions for this effort were answered by leveraging the Value-Focused Thinking (VFT) process. Recommendations for the existing architecture as well as future architecture developments in the Joint Force Protection Advance Security System (JFPASS) project were also determined. In addition, suggestions for improvement of the Value-Driven Enterprise Architecture (VDEA) tool are discussed.

5.1 Evaluation Result

The research questions for this effort were "(1) Can the VFT process be applied to an evaluation of a set of architectural products? (2) What is the resulting Hierarchy to evaluate a force protection system? (3) What are the related weights and measures for the hierarchy? (4) What score does the provided architecture score based on this hierarchy and where are the shortfalls and potential areas of improvement?" Each of these questions were answered during this effort.

It was shown that the VFT process could be applied to evaluate a set of architectural products. Through research into existing guidance and documentation and interviews with decision-makers, it is possible to determine what values are important to those decision-makers in architectural design. Through the use of the VFT process, a Value-Driven Enterprise Architecture methodology was found. Even with a single alternative, the VFT process was able to output a score for the system as a whole to be used as a baseline for future improvements. In addition to giving the decision-maker a baseline, the VFT process allowed for the creation of alternatives that could show the possible future maturation and development of the project.

These alternatives gave the decision-maker a set of comparison criteria to determine the future direction of project development.

The resulting hierarchy for JFPASS evaluation was developed in two major branches: the *System Effectiveness* Branch and the *Architecture Quality* branch. This effort determined a possible hierarchy for *System Effectiveness* evaluation. This Hierarchy is shown in Figure 5.1.

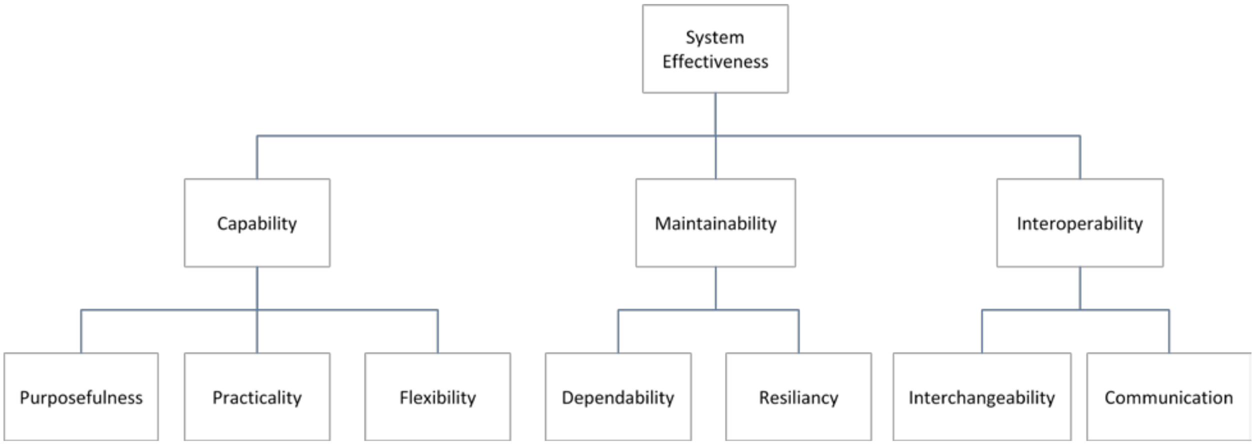


Figure 5.1 *System Effectiveness* Hierarchy

In addition to the hierarchy, weights were assigned to each value and measures of effectiveness assigned to each lowest tier value. The weights assigned to each value were determined through both research of the guidance and documentation and interviews with subject matter experts (SMEs) in the field of force protection (FP). The resulting 16 measures allow the decision-maker to determine the effectiveness of the system in question.

Finally, the JFPASS was assigned a score of 0.538 of 1.000 possible value units through a deterministic analysis. This score includes the value earned by both the *System Effectiveness* and the *Architecture Quality*. This is also an “earned value” as opposed to a final score. At this point in time, the JFPASS has earned 0.538 of its possible value units. As it is still early in its development, there is time to earn additional value for this system and improve the score. This score also serves to show the level of development of the current system, as well as which areas are lacking. The shortfalls and suggested areas of improvement are presented in the next section.

5.2 Recommendations

Through deterministic analysis and sensitivity analysis of the system, several recommendations were generated, both for improvement of the current system and for future development of the system. These recommendations are intended to help guide work on the JFPASS project with the final system value in mind. Final determination of the course of future system development lies in the hands of the decision-maker and system sponsor, but the scores and sensitivity analysis provide a justification for possible changes to system development.

5.2.1 Future View Development

Several areas of evaluation in *System Effectiveness* require more information or additional views to properly score. The addition of these views would allow for the scoring of certain measures of effectiveness, providing more value to the overall system. Through a sensitivity analysis of the current measures, it was possible to determine the maximum benefit provided by each measure and view. Table 5.1 shows the maximum benefit that the creation of each new view would have on the total score.

The JFPASS Perfect System alternative exists for decision-maker comparison, not as a practical alternative. The highest scoring realistic alternative is one which incorporates a complete SV-7, SV-8, and SV-9. The next alternative in the ranking requires three additional views, each of which builds on the information in others. By creating these additional views in a specific order, value can be added more quickly. For these recommendations, the random alternatives are not considered. They are included in the analysis as a basis of comparison for the decision-maker. These recommendations may be applied to cost-benefit analysis.

Table 5.1 Maximum Value Benefit of New Views

Alternative Name	Score	Maximum Value Benefit
JFPASS Perfect System	0.890	0.352
Current System plus AV-1, SV-7, and SV-5	0.704	0.166
JFPASS Random 4	0.686	0.0148
Current System plus SV-7	0.663	0.0125
JFPASS Random 3	0.583	0.045
Current System plus AV-1 and SV-5	0.578	0.040
Current System plus SV-8	0.565	0.027
Current System plus SV-9	0.557	0.019
JFPASS Random 2	0.540	0.002
Baseline	0.538	0.000
Current System plus Full AV-1	0.538	0.000
Current System plus OV-3	0.538	0.000
Current System plus SV-5	0.538	0.000
JFPASS Random 1	0.454	-0.084

Based on this analysis, the next most beneficial product to create would be the SV-7, System Performance Parameters Matrix. This view allows the architect to add information regarding the parameters to which system components are designed. This includes three of the four *Maintainability* measures required for this evaluation. The information contained in the SV-7 product may already be used in the system design, but without the SV-7, there is no other place in the architecture that the information can be found. For the system to be properly designed, it must have some parameters by which system components are designed, specifically regarding their supportability, reliability, and recoverability. These ideas must simply be included in the architecture to ensure compliance with the parameters and proper representation to the reader. By simply adding the SV-7 product, the total system score has the potential to increase by 0.125 value units (if all required information is included).

Following the creation of the SV-7, an SV-5, Operational Activity to Systems Function view would create the next highest value benefit. The SV-5 is intended to show the reader which components are accomplishing which functions. By tracing those functions up to operational requirements, it is possible to determine how the operational needs of the system are being met, i.e. using which system components. For the SV-5 to be of any benefit, though, the AV-1 must also be updated with an explicit list of the operational requirements for the system. The AV-1 currently includes a discussion of the purpose of the system, but lacks any specific discussion of the problems that the system will solve and the constraints by which the system is being designed. It was of great importance to the decision-maker that the system accomplishes its goals. Therefore, those goals must be outlined explicitly. The AV-1 provides the best context for this discussion. These details may also be included in some appendix to the architecture, but should be included with the architectural package. Without a list of operational needs or requirements, the SV-5 is of no benefit to the system. If the SV-5/AV-1 update is completed following the creation of the SV-7, the three updates have a positive cumulative effect on the system score. They will cause a positive change of 0.166 value units to the final score.

The next most beneficial view would be the SV-8, Systems Evolution Description. The inclusion of the SV-8 allows the architecture evaluator the ability to score the ADAPTION measure. There are currently no details included in the architecture regarding the *Flexibility* of the system. The SV-8 has the ability to show the reader how the system may evolve not only further into the acquisition and design process, but under operational constraints. The inclusion of an SV-8 with the necessary information to score Adaptability may cause a benefit of 0.027 value units.

Finally, the SV-9, Systems Technology Forecast view would provide the next most benefit to the system score. The inclusion of the SV-9 has the ability to add 1.9 value units to the total score. The SV-9 product allows the reader to determine the current Technology Readiness

Level (TRL) of the components included in the architecture. The TRL of each component is required to determine the overall system TRL for the TECHNOLOGICAL AVAILABILITY measure.

The OV-3, while included as supporting documentation for some measures, is not required for this system. It is possible to determine the information included in the OV-3 without its inclusion for scoring. The OV-3 may include other information of use to the architect or decision-maker, therefore its inclusion should not be complete discounted. The architect is also bound by the milestone decision point requirements for architecture products. In other force protection systems, this view may be required to score the architecture. The addition of an SV-5 alone will not add any value either, unless it is added with the AV-1 updates. Conversely, the addition of a complete AV-1 will not have any positive effect on the system score without the SV-5.

5.2.2 System Strengthening

In addition to future development of views, several steps may be taken to strengthen the current system and its score. In some cases, more value may be earned by improving upon information already included or updating design decisions based on the decision-maker's most important values. In other cases, a measure may already score full value, but the inclusion of additional information may make the architecture more easily scored and read.

The THREAT DETECTION, THREAT ASSESSMENT and WARNING PLAN measures were all scored positively. Though they were scored at their highest level, it is possible to make them more easily accessible to architecture readers. Each of these measures refers to the inclusion of a plan related to the measure. To determine the degree of attainment of these measures, the OV-5 product was used. Since the activities required to accomplish each of these concepts were included, they were scored positively. Including actual text versions of the plans may assist not only the architecture readers, but also future users of the architecture. Each installation is required, regardless of service component to have official, written plans for these concepts. The inclusion of skeleton versions of these plans in the architecture would assist in the scoring and ensure compliance of each installation.

The ENVIRONMENTAL IMPACT measure was scored "CONUS and Contingency constratints." This measure is capable of earning 0.2 additional value units by adding Host Nation constraints to the current consideration. Including international environmental policy documents in the TV-1 would allow this measure to be scored at a higher level. It may also be possible to include the environmental policies of several nations that the U.S. military historically operates and has standing military commitments (or Status of Forces Agreements (SOFA)) with.

The MONETARY PRACTICALITY measures refer to the budgetary constraints that all government programs are subject to. The ability to construct a system within budget is of major concern to all stakeholders in a project. The inclusion of specific cost information to the architecture would not only allow the scoring of these measures, but would add verification to the stakeholders of a system's fiscal viability. A total system estimate and program budget must of course be included as well in order to compare the cost information to. The OV-5 product has the ability to display this information. Initial cost and life cycle costs may also be included in the AV-1 product, although the costs would not be itemized by component.

The two Net-Centric Enterprise Solutions for Interoperability (NESI) measures also have room for improvement. Currently, the NESI DEVELOPMENT measure is scored positively, but its assessment may be improved by explicitly including the NESI documents in the TV-1. The assessment for this measure was done by comparing the included system design and design documents to the NESI guidance and determining that the system was being constructed with Net-Centricity in mind. Including the NESI documents in the architecture would show the architecture reader that the system was in fact designed with these concepts in mind. In addition to including the Net-Centricity documents, a NESI evaluation should also be completed on the architecture. Simply completing the evaluation would allow for a positive score of the NESI EVALUATION measure, but inclusion of the evaluation in the architecture, as well as a positive score would assist in the scoring of the architecture.

5.3 Model Strengths

The creation of the Value Driven Enterprise Architecture tool allows a force protection architecture to be objectively evaluated. This tool gives the decision-maker an objective numerical score from which to base future revisions and additions to the architecture. This baseline combined with analysis of the score shows the most beneficial views to be created in the future and improvements that may be made to the existing architecture.

In interviews with several force protection experts, the system was found to be all inclusive of the important values for force protection. Each of the SMEs found no major areas of force protection that were not included in the values of this model. By creating a system built around the values alone, a comprehensive force protection system may be constructed.

This model allows a project stakeholder or sponsor to “score” a system based solely on its architecture. This is useful since many acquisition decisions are made based solely on architectural products. Having a tool to evaluate them allow for objective evaluation of the architecture.

5.4 Model Weaknesses

While the model is useful for the decision-maker, there are limitations and several areas that may be improved. The extensibility of the measures under the *System Effectiveness* branch may be limited. The measures as presented here were useful for a force protection system in the very early stages of development. As the system matures, new measures will need to be created to keep up with the changing needs of the system. At some point, it may be necessary to improve the granularity and objectivity of measures to better evaluate increased complexity.

Another weakness of this model is associated with the inherent uncertainty of a VFT model. The Single Dimension Value Functions (SDVFs) and weights are based on input from the decision-maker and subject matter experts. They were constructed to match the values of the people involved in their construction, but in the end these instruments are only the opinion of those who were involved in their creation. There are other possible combinations of weights and SDVFs which may also measure the system.

There remains a certain level of ambiguity and subjectivity involved in the scoring of the architecture. Though the scores were reached by consensus and taken directly from the architectural products, some scores may not be accurate. The descriptions included in Chapter 3 allow for repeatability, but some subjective decisions must still be made regarding the scores.

5.5 Future Research

This effort has opened the door for several additional areas of research. The research may be extended to refine values, measures, and SDVFs and update the hierarchy to include future assessments of the same system. The value hierarchy derived in this study may be applied to other force protection systems. Individual projects outside the scope of JFPASS may also use the methodology to objectively score their viability. Component selection may also be influenced by the value hierarchy or the VDEA score.

The JFPASS system is currently in an early stage of development and will continue to mature. As the project grows, some measures may be revised to reflect the updated system. Several measures currently determine the existence of certain concepts, but in the future, they may be used to measure quality of the achievement of these values.

The hierarchy derived in this study includes all of the major values associated with any force protection system and perhaps different types of systems. The hierarchy may be applied to FP systems outside the JFPASS to complete similar evaluations. It may also be used to design future FP systems in order to ensure their compliance with the most important aspects of the force protection.

The JFPASS system will have several individual projects created under its “umbrella.” As they projects emerge, they may also be scored using the same model. The *System Effectiveness* branch will allow for the evaluation of any force protection system, particularly those within the purview of JFPASS. Outside the context of JFPASS, other Force protection projects may also be compared using this architecture. As projects are submitted to the JFPASS office, they may be compared using this architecture. The hierarchy allows for project selection from a number of alternatives in addition to its ability to generate new alternatives.

Appendix A. Ilities Master List

- accessibility
- accountability
- accuracy
- adaptability
- administrability
- affordability
- agility
- applicability
- auditability
- availability
- capability
- changeability
- communication
- compatibility
- complexity
- compliancy
- composability
- configurability
- consistency
- constructability
- controllability
- credibility
- customizability
- data integrity
- degradability
- demonstrability
- dependability
- deployability
- diagnoseability
- distributability
- durability
- effectiveness
- efficiency
- evolvability
- extensibility
- feasibility
- fidelity
- flexibility
- functionality
- installability
- interchangeability
- internationalizability
- interoperability
- learnability
- maintainability
- manageability
- mobility
- modifiability
- modularity
- nomadicity
- openness
- operability
- performance
- personalizability
- portability
- practicality
- precision
- predictability
- produceability
- protectability
- purposefulness
- quality
- readability
- recoverability
- relevance
- reliability
- repairability
- repeatability
- reproducibility
- resiliency
- responsiveness
- reusability
- robustness
- scalability
- seamlessness
- securability
- security
- serviceability
- Simplicity
- Stability
- stakeholder involvement
- subscribability
- supportability
- survivability
- susceptability
- sustainability
- tailorability
- testability
- timeliness
- traceability
- trainability
- transactionality
- understandability
- upgradeability
- usability
- utility
- versatility
- vulnerability

Appendix B. *System Effectiveness* Groups and Synonyms

Group 1: Capability

- Subgroup 1: Purposefulness
    - Synonyms: Relevance, Applicability, Utility, Performance, Robustness, Functionality
- Subgroup 2: Practicality
    - Synonyms: Deployability, Affordability, Produceability, Constructability, Efficiency, Feasibility, Installability, Operability
- Subgroup 3: Flexibility
    - Synonyms: Modularity, Responsiveness, Configurability, Versatility, Adaptability, Mobility, Agility

Group 2: Maintainability

- Subgroup 1: Dependability
    - Subgroup 1.1: Supportability
        - Synonyms: Repairability, Sustainability, Serviceability, Maintainability
    - Subgroup 1.2: Reliability
        - Synonyms: Dependability, Degradability, Fidelity, Stability
- Subgroup 2: Resiliency
    - Subgroup 2.1: Survivability
        - Synonyms: Susceptibility
    - Subgroup 2.2: Recoverability
        - Synonyms: Diagnosability

Group 3: Interoperability

- Subgroup 1: Communication
- Subgroup 2: Interchangeability
    - Synonyms: Compatibility, Internationalizability

Appendix C. Supplemental Deterministic Analysis Charts

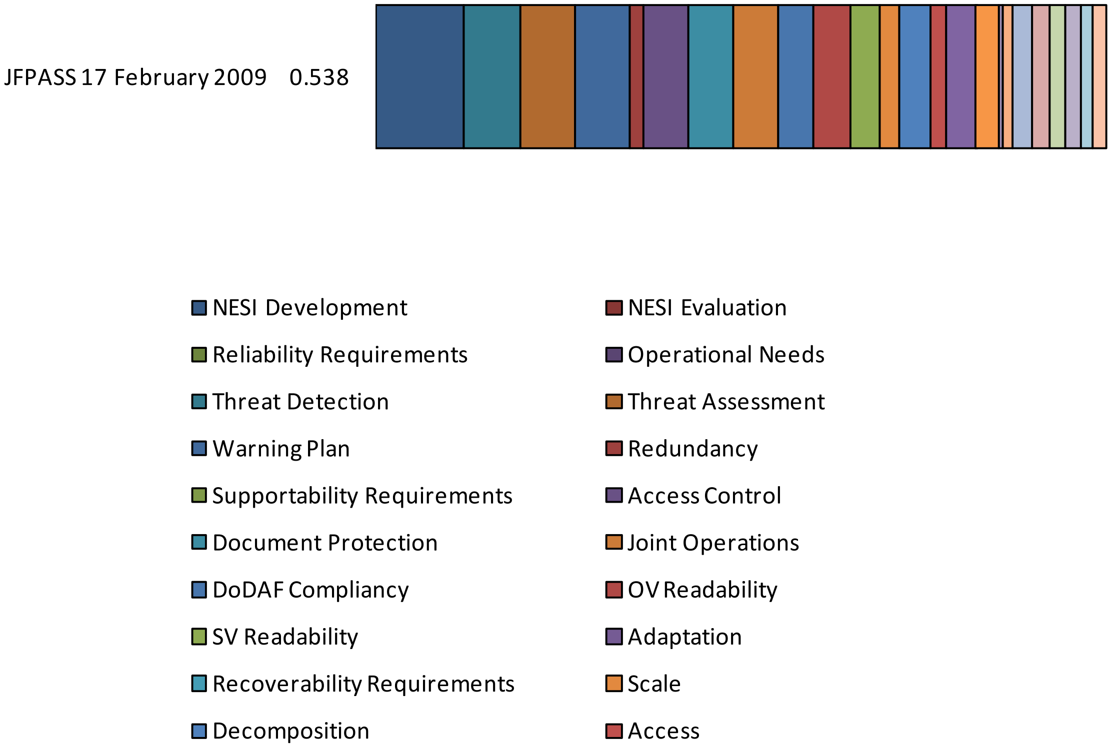


Figure C.1 JFPASS Score Fundamental Objective - Measures

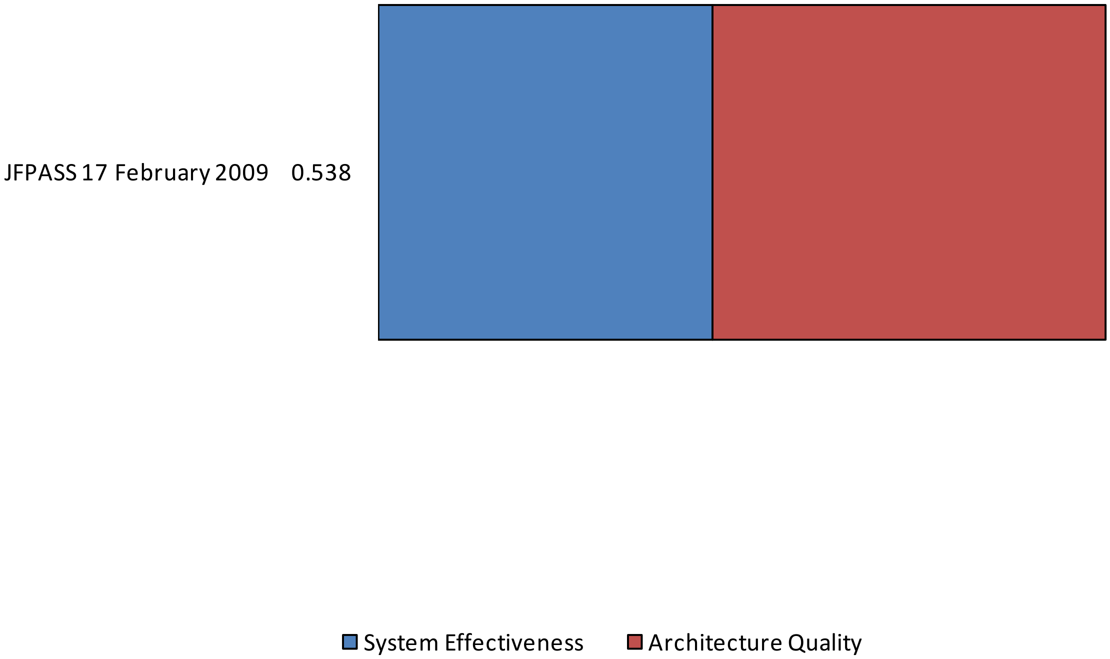


Figure C.2 JFPASS Score Fundamental Objective - Values

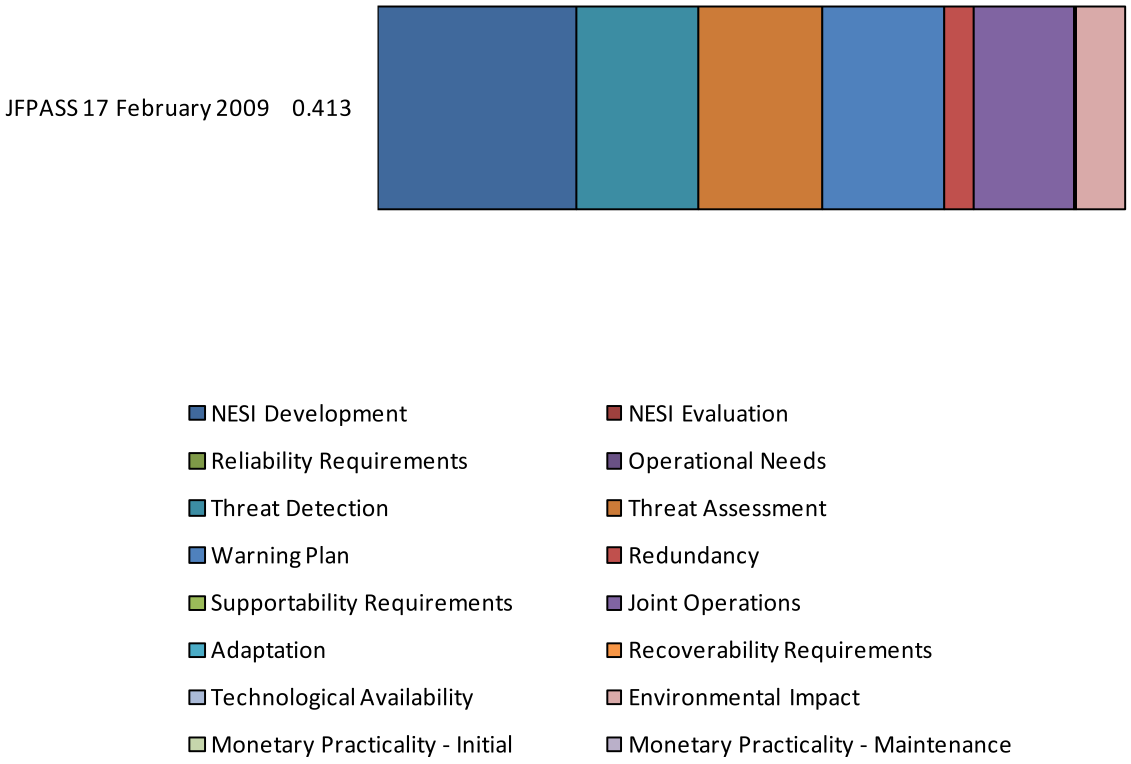


Figure C.3 *System Effectiveness* Score - Measures

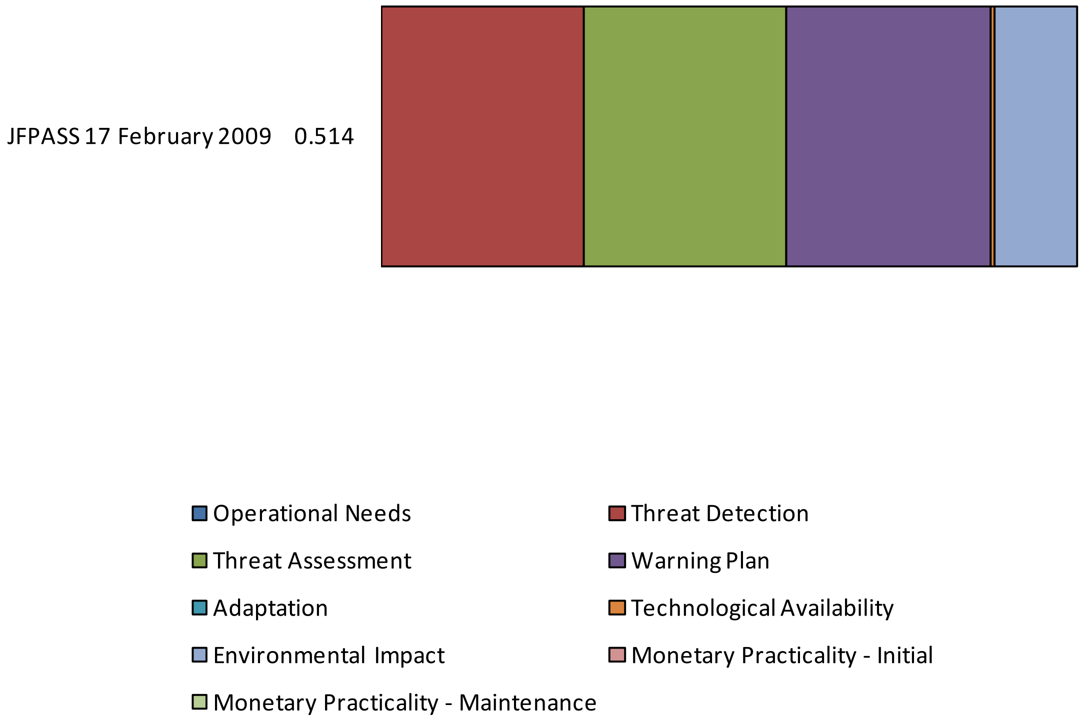


Figure C.4 *Capability* Score - Measures

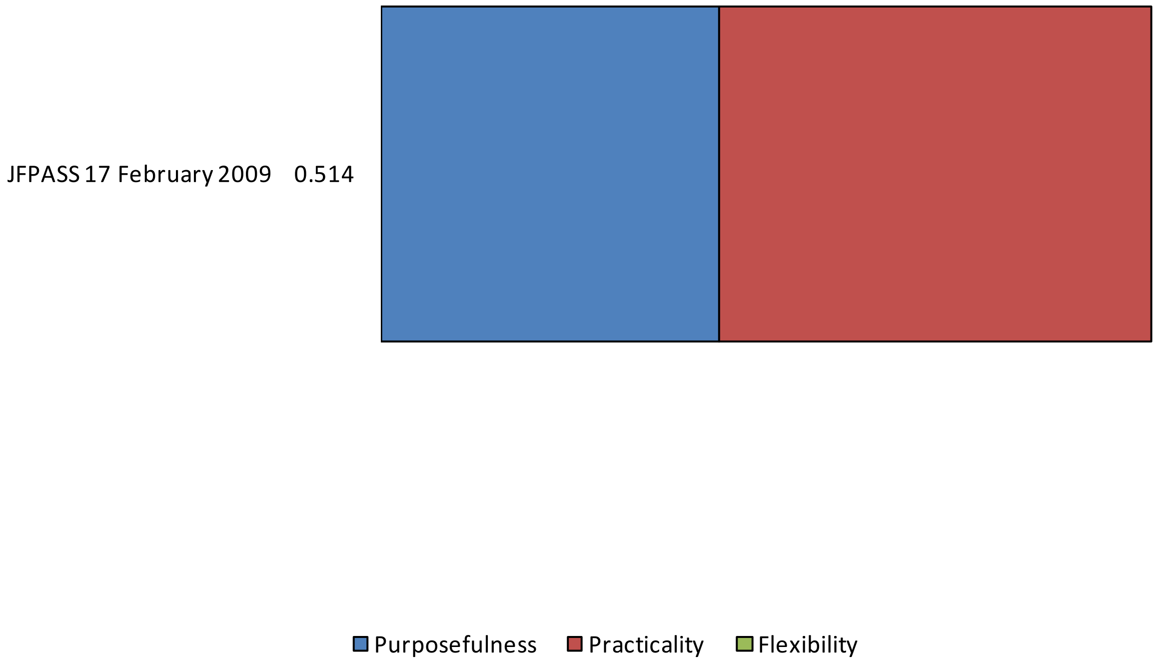


Figure C.5 *Capability* Score - Values

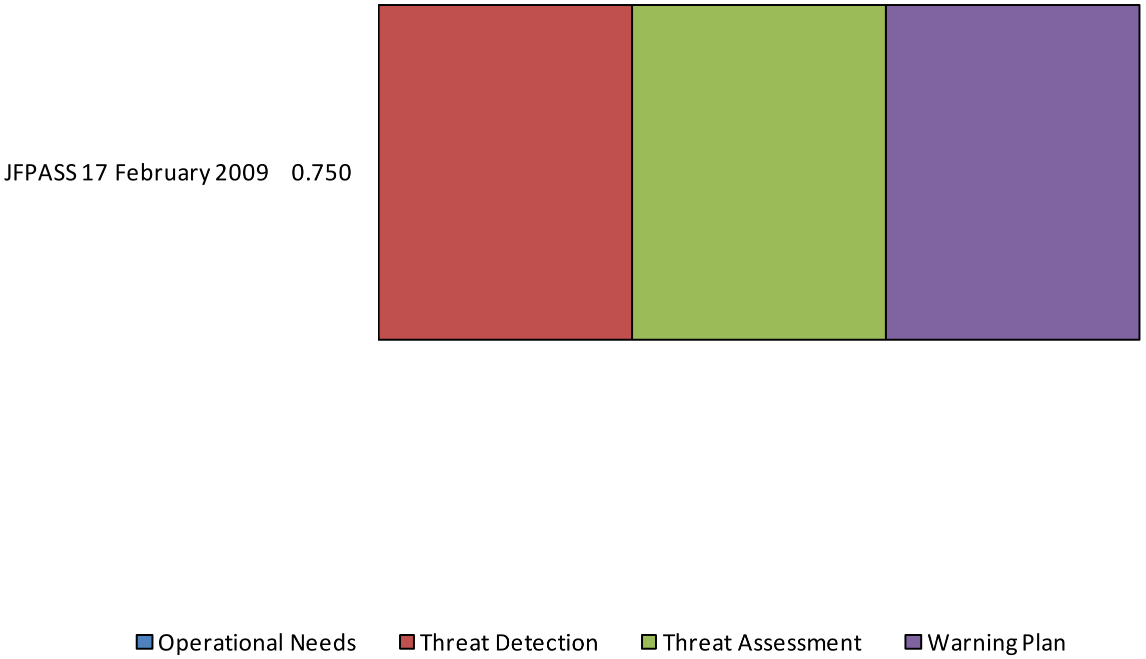


Figure C.6 *Purposefulness* Score - Measures

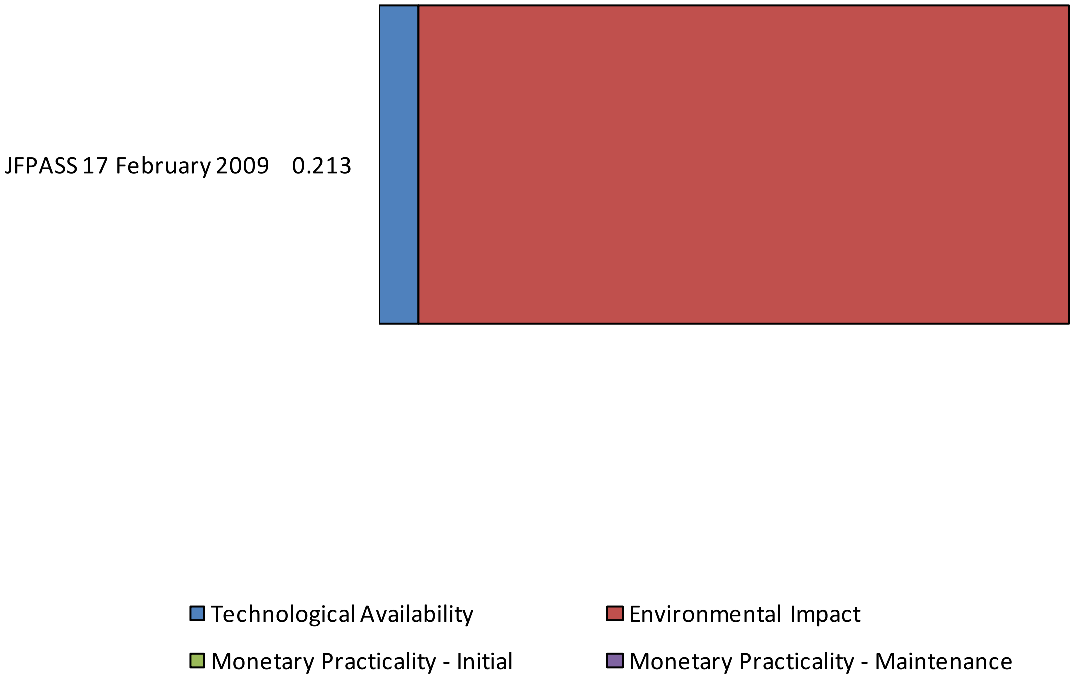


Figure C.7 *Practicality* Score - Measures

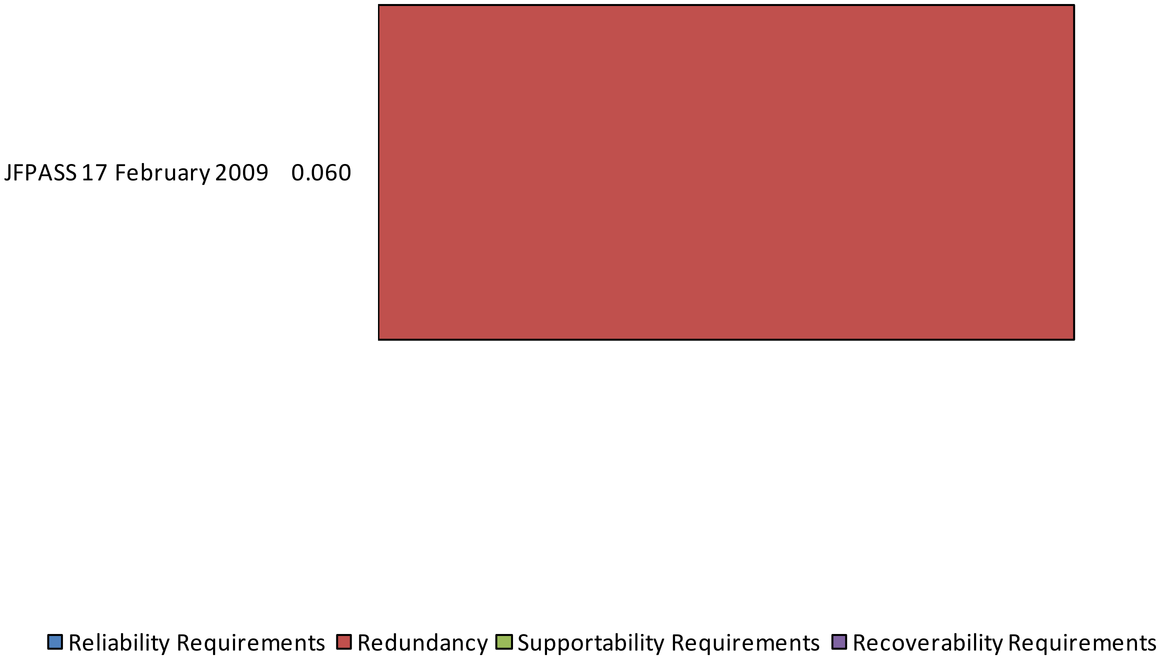


Figure C.8 *Maintainability* Score - Measures

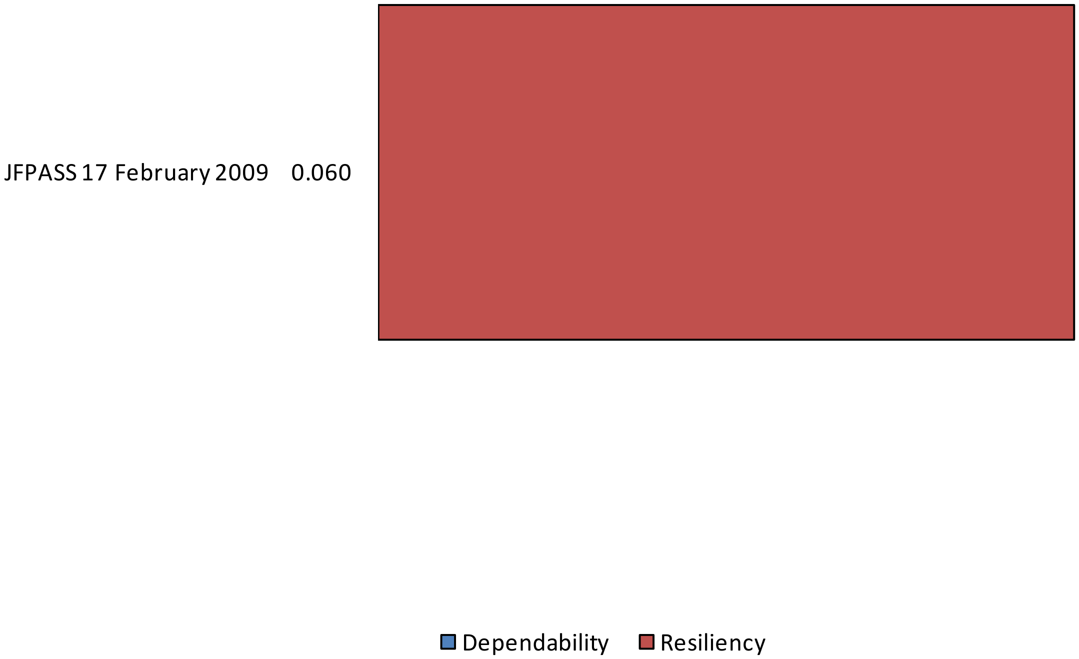


Figure C.9 *Maintainability* Score - Values

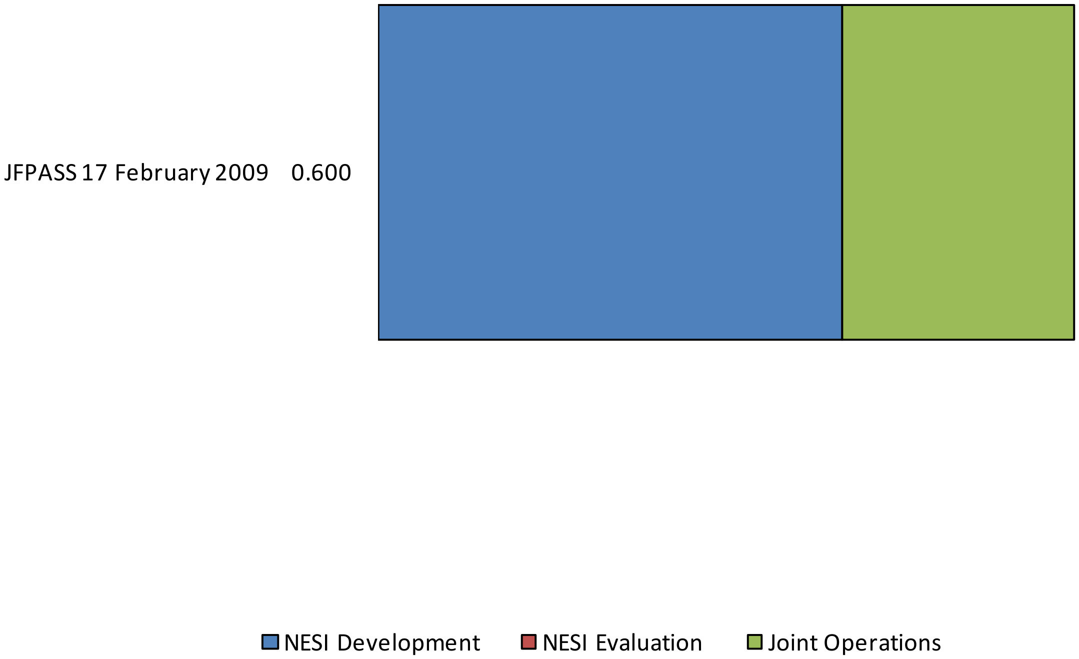


Figure C.10 ***Interoperability*** **Score - Measures**

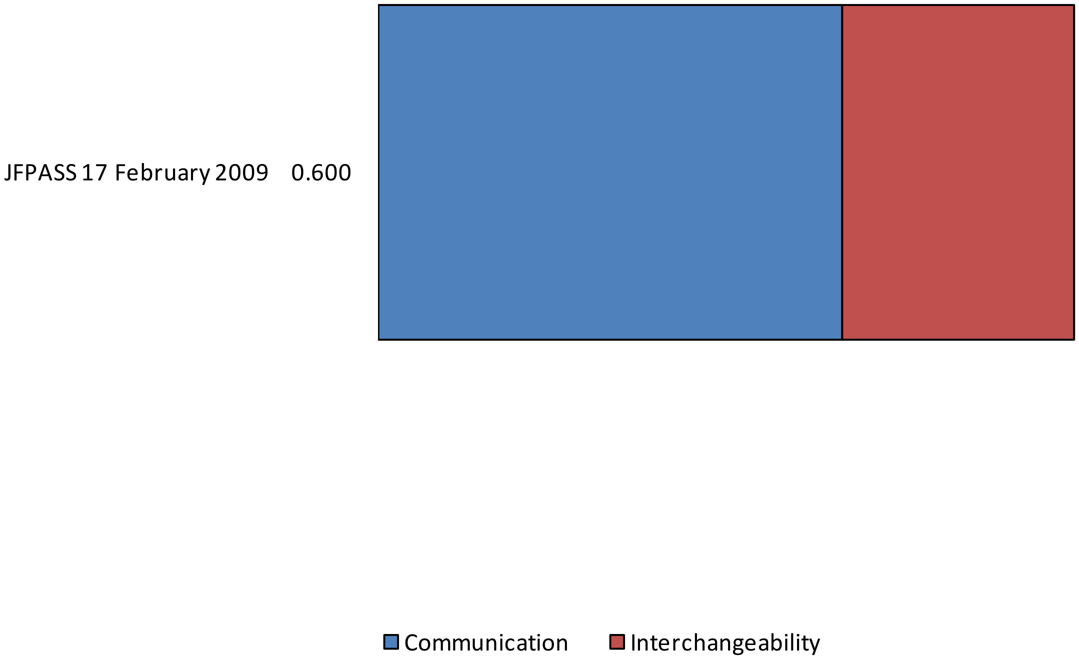


Figure C.11 ***Interoperability*** **Score - Values**

Appendix D. Alternative Scores

Alternative Name: Baseline	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: JFPASS Perfect System	
Measure Name	**Measurement**
OPERATIONAL NEEDS	1
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 9
ENVIRONMENTAL IMPACT	CONUS, Contingency, and Host Nation constraints
MONETARY PRACTICALITY - INITIAL	< 95% budget
MONETARY PRACTICALITY - MAINTENANCE	< 95% budget
ADAPTATION	Minimal effort
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	Yes
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	Yes
RELIABILITY REQUIREMENTS	Yes
REDUNDANCY	All systems, multiple redundancy
RECOVERABILITY REQUIREMENTS	Yes
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus SV-7	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	Yes
RELIABILITY REQUIREMENTS	Yes
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	Yes
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus Full AV-1	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus OV-3	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus SV-5	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus SV-8	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Minimal effort
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus SV-9	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 9
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus AV-1 and SV-5	
Measure Name	**Measurement**
OPERATIONAL NEEDS	1
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Random VDEA Score 1	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0.8
THREAT DETECTION	No
THREAT ASSESSMENT	No
WARNING PLAN	No
TECHNOLOGICAL AVAILABILITY	TRL 7
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	> 105% budget
MONETARY PRACTICALITY - MAINTENANCE	> 105% budget
ADAPTATION	On-Site acceptable effort
JOINT OPERATIONS	No
NESI DEVELOPMENT	No
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	Yes
REDUNDANCY	Some systems, multiple redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Random VDEA Score 2	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0.01
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	No
TECHNOLOGICAL AVAILABILITY	TRL 4
ENVIRONMENTAL IMPACT	Cannot be built
MONETARY PRACTICALITY - INITIAL	> 105% budget
MONETARY PRACTICALITY - MAINTENANCE	> 105% budget
ADAPTATION	On-Site acceptable effort
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	No
NESI EVALUATION	Yes
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	Yes
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Random VDEA Score 3	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0.205
THREAT DETECTION	No
THREAT ASSESSMENT	No
WARNING PLAN	No
TECHNOLOGICAL AVAILABILITY	TRL 4
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Between 95% and 105% budget
MONETARY PRACTICALITY - MAINTENANCE	> 105% budget
ADAPTATION	On-Site acceptable effort
JOINT OPERATIONS	No
NESI DEVELOPMENT	Yes
NESI EVALUATION	Yes
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	Yes
REDUNDANCY	All systems, multiple redundancy
RECOVERABILITY REQUIREMENTS	No
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Random VDEA Score 4	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0.866
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS, Contingency, and Host Nation constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Between 95% and 105% budget
ADAPTATION	Minimal effort
JOINT OPERATIONS	No
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	No
RELIABILITY REQUIREMENTS	Yes
REDUNDANCY	Some systems, multiple redundancy
RECOVERABILITY REQUIREMENTS	Yes
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus AV-1, SV-7, and SV-5	
Measure Name	**Measurement**
OPERATIONAL NEEDS	1
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 1
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Static
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	Yes
RELIABILITY REQUIREMENTS	No
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	Yes
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

Alternative Name: Current System plus SV-7, SV-8 and SV-9	
Measure Name	**Measurement**
OPERATIONAL NEEDS	0
THREAT DETECTION	Yes
THREAT ASSESSMENT	Yes
WARNING PLAN	Yes
TECHNOLOGICAL AVAILABILITY	TRL 9
ENVIRONMENTAL IMPACT	CONUS and Contingency constraints
MONETARY PRACTICALITY - INITIAL	Cost Unknown
MONETARY PRACTICALITY - MAINTENANCE	Cost unknown
ADAPTATION	Minimal Effort
JOINT OPERATIONS	Yes
NESI DEVELOPMENT	Yes
NESI EVALUATION	No
ACCESS	Access between 3 and 7 days
PRODUCT LOCATABILITY	Less than 5 min
ACCESS CONTROL	Appropriate protection implemented
DOCUMENT PROTECTION	Plan exists, all products controlled
FILE MANAGEMENT	No system
FILE FORMAT	General File Format
SCALE	Most views
DECOMPOSITION	3+ Levels
TOOL FORMAT	All views
DODAF COMPLIANCY	0.83
REQUIREMENT TRACEABILITY	0
INTERNAL CONSISTENCY	0.83
EXTERNAL CONSISTENCY	0.83
SME EFFECTIVENESS	No Plan
SME INVOLVEMENT	No involvement
SUPPORTABILITY REQUIREMENTS	Yes
RELIABILITY REQUIREMENTS	Yes
REDUNDANCY	Some systems, single redundancy
RECOVERABILITY REQUIREMENTS	Yes
CONNECTIONS	0.83
ARCHITECTURE REDUNDANCY	Between 0 and 1:500
ARCHITECTURE ECONOMY	No
OV READABILITY	0.8
SV READABILITY	0.6

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14. ABSTRACT

The U.S. military has placed a strong focus on the importance of operating in a joint environment, where capabilities and missions are shared between service components. Protecting U.S. forces is a major consideration in the joint environment. The Joint Force Protection Advanced Security System (JFPASS) architecture has been created to fill a critical gap in Joint Force Protection guidance for systems acquisition. The systems engineering (SE) field has made wide use of system architectures to represent complex systems. As fundamental SE principles become more widespread, analysis tools provide an objective method for the evaluation of the resulting architectural products.

This study used decision analysis to develop a standardized, yet adaptable and repeatable model to evaluate the capabilities of the JFPASS for any installation or facility belonging to the United States Department of Defense (DoD). Using the Value-Focused Thinking (VFT) methods, a value hierarchy was created by consulting with subject matter experts. The resulting model, named Value-Driven Enterprise Architecture (VDEA) score, provides an analysis tool, which enables DoD decision-makers to use JFPASS architecture products to quickly and easily evaluate the value provided by the system; VDEA provides insight into the overall quality and capability of the system. Through the scoring and sensitivity analysis functions, capability gaps and potential improvements can be identified. Future studies in this area will provide a vehicle for rating not only operational level systems, but also individual functional projects against other alternatives.

15. SUBJECT TERMS

“Value-Focused Thinking,” “Joint Force Protection,” “Architecture Analysis,” Systems Architecture,” “Enterprise Architecture,” “Architecture Evaluation,” “DoDAF,” “JCIDS,” “Acquisition Reform,” “Value-Driven Enterprise Architecture,” “VDEA,” “System Acquisition,” “Program Development,” “JFPASS,” “Effectiveness Measures,” “Value Hierarchy”

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