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A Decision Analysis Framework for Evaluation of Helmet Mounted Display Alternatives for Fighter Aircraft

Matthew R. Dansereau

A DECISION ANALYSIS FRAMEWORK FOR EVALUATION OF HELMET MOUNTED DISPLAY ALTERNATIVES FOR FIGHTER AIRCRAFT

THESIS
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Abstract

The promise of providing an intuitive and efficient information interface, while allowing the warfighter to perform other critical tasks such as targeting or aircraft control, has led to the growing popularity of Helmet Mounted Displays (HMDs), especially on combat aircraft. Though design and selection of competing systems is critical to optimized performance and safety, structured methods for the evaluation and selection of HMDs are not often used in the acquisition community, leaving selection among alternative designs to the judgment of subject matter experts. However, technical decision-making has been shown to be flawed without the use of a structured decision analysis framework, which can help to overcome narrow focus, potential bias, and human error. This thesis proposes a HMD design evaluation framework using fundamental multi-level performance objectives to assess the value of an alternative. Supported by principles of Human Systems Integration (HSI) and Value-Focused Thinking, the framework can be used by decision makers to create informed, defendable judgments that strive to increase system performance while decreasing maintenance and integration resources. The 17-factor framework is illustrated through application on two possible technology solutions for a fixed-wing fighter platform. Based on the senior decision maker preferences and available system data, Alternative 1 - Scorpion Helmet Mounted Cueing System, scored 0.481 out of 1.0, which was 9.3 percent higher than Alternative 2 - Joint Helmet Mounted Cueing System. The preferred solution was also insensitive to adjusting the primary Human Factors objective weight by 71.1%. This research successfully demonstrated a quantitative method for assessing helmet mounted display system alternatives that incorporate critical Human Systems Integration principles.

Acknowledgments

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- Matt

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I. Introduction

General Issue

Proper design and integration of human-machine interfaces is critical to optimize overall system performance. Technology advancements have produced systems which have the ability to gather and display more information to the human user than her or she can efficiently process to make timely decisions. This often results in high workload and complicated multitasking environments which can be overwhelming, forcing the operator to share attention resources with many tasks simultaneously, degrading the robustness of decision processing. Overcoming these issues necessitates an interface that augments the operator's abilities without inducing additional control tasks or negative physiological effects. The promise of providing an intuitive and rapid interface to information, while allowing the warfighter to perform other critical tasks such has handling a weapon or maneuvering a vehicle has led to the growing popularity of helmet mounted displays across the military landscape. Though attractive as a human-machine interface solution, improper design and integration of the HMD system could lead to undesirable situations. Thus it is critical that the HMD be fit for the intended use and environment.

However, the evaluation of HMD solution options is not always performed in an analytical, repeatable manner. Important considerations like human factors, display usability, and user integration are often taken into account by the best judgment of the decision maker. Subject matter experts are left to evaluate systems that at times weren't designed for the specific platform and mission the HMD will be employed in. These deficiencies can lead to a system that does not meet the user's requirements or ultimately can lead to mishaps, increased cost, and sub-optimal performance. In order to make fair and balanced comparisons, an assessment framework is needed that will allow decision makers to perform robust technology analyses on helmet mounted displays, based upon the value the technology brings to the overall mission objective. This thesis discusses the research conducted on helmet mounted displays and its input into an evaluation framework, which could be used to support HMD integration decisions in fighter aircraft.

Background

In modern combat, lean and agile forces have become the core of the United States military. In order to maintain combat superiority, advanced technology must augment the minimized manpower. Integrated technology multiplies individual and unit capabilities, allowing warfighters to strategically engage larger enemy forces. To achieve the best performance and gain this advantage, system design and implementation must consist of careful fusion of technology with user capabilities and limitations. One such technology, who's advantage is very closely linked to proper human-technology integration is the Helmet Mounted Display (HMD). Rapidly growing in its uses throughout the military, the HMD seeks to enhance the user's overall situation awareness by augmenting human attributes like vision, audition, and system control.

HMD Use in Military Aviation

Described by Melzer and Moffitt, a helmet mounted display has the basic elements of "an image source and collimating optics in a head mount" (J.E. Melzer, 1997). While this description is still accurate when describing modern HMDs, for military aviation it is appropriate to also include a tracking system that is often used to couple the position or orientation of the head or eye with one or more aircraft systems. Figure 1 illustrates the basic components of an HMD with this description.

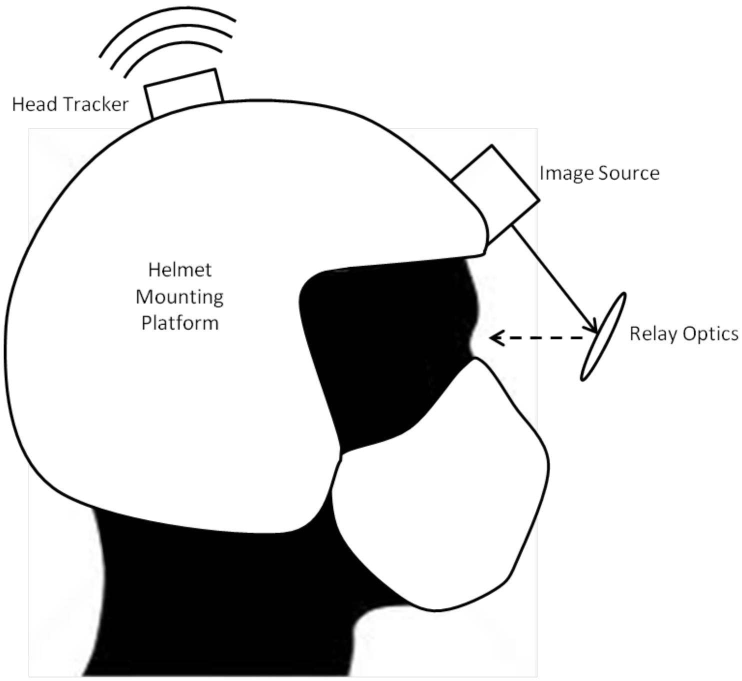

Figure 1 : Basic components of a modern HMD

Primarily used to provide the significant amount of tactical and strategic information critical to successful engagements in the modern battlefield, helmet mounted displays have found functionality across military applications as they can present this information in an intuitive "eyes out" format. Warfighters can maintain enhanced awareness without taking their attention off the very dynamic combat setting. This advantage is most noticeable in the military aviation community, where efficient execution of complex tasks in a high workload environment necessitates an optimized user-machine interface. The user's ability to rapidly acquire, comprehend, and act on changing information is the key to mission effectiveness and survival. An HMD can increase the safety and survivability of a pilot, as well as enhance their lethality by allowing line of sight steering of weapons and sensors. However, if consideration is not given to the specific user-environment combination, a sub-optimal HMD can negatively impact safety and survivability for our warfighters by over saturating attention resources and instigating chronic physiological damage. With the use of thorough analytical design and evaluation methods, followed by intelligent decision making practices, these negative attributes can be avoided.

Human System Integration

Human-technology integration has long been a challenge, due to the variation and often unpredictability of the user populations. Following World War II, experts found that combat systems were at times unsafe and difficult to operate because the human user was not sufficiently considered in the development process. These suboptimal designs led to underperformance, increases in mishaps, as well as higher costs in training and healthcare for the users. In an attempt to alleviate these issues General Max Thurman, eventual Vice Chief of Staff of the U.S Army, stressed "We must quit manning the equipment and start equipping the man" (HPW/HPO). Eventually, in the 1980's, the formal Human Systems Integration (HSI) discipline was conceived. By considering user concerns such as safety, human factors, training and survivability, the ultimate goal of HSI practitioners is to reduce the total life cycle costs of the system while maximizing overall system performance by applying human centric principles throughout the planning and development phases. This holistic design and management approach can be applied to all human integrated systems, including HMDs. Without effective HSI, the program can become a victim of expensive retrofits, unsafe conditions, and subsequent inflated total life-cycle costs (Booher, 2003).

Problem Statement

It is extremely important that design decisions are examined for their implication on the entire integrated system. Too often development programs fail to consider the human and their associated requirements as part of the system (HPW/HPO). To achieve sustainable enhanced performance, the system needs to be defined by more than just the hardware and software components, the operator and maintainer must be included.

There has been a recent resurgence of HSI efforts and it is becoming more common practice to intimately include HSI principles as part of design requirements and key performance parameters (KPPs) in development of new technology. This is a successful approach, when the initial product design can be centered around a particular system and use. But how can we ensure a previously developed piece of equipment, commercial off the shelf (COTS), meets the specific needs of the user in a sustainable, cost effective manner? According to the HSI handbook, “COTS content increases the need for HSI assessment and risk mitigation” (HPW/HPO). Currently, the military acquisition community commonly relies on the judgment of decision makers and technical subject matter experts (SMEs) and their assessments of the proposed technology. The problem with this method is that it can involve a multitude of competing decision criteria and the analysis can miss interactions between expertise domains, which can negatively impact system performance and affordability. Additionally, decisions can be made by parties with differing priorities. A program manager may have different primary goals (e.g., cost and schedule) than the user (e.g., effectiveness and safety) for example, which could impact the resulting products.

What is needed is a design evaluation framework that maintains focus on pertinent system performance objectives and assesses the technology's ability to meet these objectives in a methodical, repeatable manner. Furthermore, a framework should allow for decision makers to perform an intelligent trade space analysis. This research investigates a framework that uses decision analysis techniques to perform a human centric examination of design alternatives, applied to helmet mounted displays. By performing this type of evaluation on material solution alternatives, HSI goals of optimum performance and minimized total life-cycle costs can be managed.

Research Question

The primary research question that will be the basis for this investigation and analysis effort is:

> What is an evaluation framework for HMD designs, allowing for solution comparison and informed decision making?

Investigative Questions

The following are additional investigative questions, used to guide the development of an evaluation framework:

> What are the major objectives for HMD use in a fighter aircraft?
>
> What HMD factors/attributes, with an emphasis on HSI principles, are important when comparing technology solutions?

How should an evaluation framework for HMD designs be created, aggregating the above factors?

How should the factors be weighted?

What are the value metrics for those factors?

How sensitive is the preferred solution to framework parameters?

Methodology

Decision Analysis techniques are used on a daily basis, whether performed formally or not. If one were to buy a house, they might analyze factors such as square footage, style, number of rooms, property, floor plan, and price. The extent of the list and importance of each factor would be different for each person. One may value yard size as the most important characteristic while another sees quantity of bedrooms as the deciding factor. These importance metrics may be based on the decision maker's current state of existence, such as financial resource availability, expected timeline for owning the home, or suitability for the family dynamic. The prospective home buyer would take all these aspects into account before making a decision on which home to purchase. Additionally, disagreements and inconsistencies between stakeholders throughout a decision process can erode efficiency and relationships. It is important to practice an analytical approach to evaluation of technology options, so as to assure the greatest possible chance of choosing the best fit solution.

Value Focused Thinking (VFT) is a method of decision analysis that focuses the decision around the objectives the decision maker (DM) hopes to achieve and the characteristics of those objectives that bring value to the decision. In contrast to alternative based decision making, which starts with alternative solutions and seeks to differentiate them, value based decisions begin with values and objectives before identifying solutions. This is the overarching technique to be used in the development of a design evaluation framework that will allow decision makers to perform a more robust trade space analysis of alternatives. A methodical approach, originally developed by Ralph Keeney and later illustrated by Mark Shoviak (Shoviak, 2001), will be followed for thorough investigation of the problem and alternative analysis. This process begins with an examination of the problem space and elicitation of system objectives, where levels of abstraction will be addressed. Objective hierarchies will then be developed, eventually determining metrics and associated functions to determine how much value the factor brings to the decision. Factor and objective weighting will help specify the solution for the particular decision maker and an example analysis will be performed on technology solution. Finally a discussion of the results will be presented.

Assumptions and Limitations

The research and conclusions described in this document are presented with several assumptions and limitations. The first limitation is that no new experimental data collection will be utilized. Due to resource availability and timeframe considerations, new human-technology experimentation is not advantageous. Furthermore, significant research has previously been performed, providing sufficient amounts of data for the scope of this effort. Therefore, past studies and existing data sources will be levied. The second assumption is with regards to HMD uses. As this technology has been implemented in many forms and environments, the focus of this research will be kept to

HMD integration in fixed-wing fighter aircraft. Another assumption is that current USAF human factors limits, safety margins, along with military standards, requirements, and handbooks will be used for design factor criteria. When applicable, currently accepted assessment methods and metrics are assumed to be accurate and sufficient.

Implications

The results and discussions included in this study could be used by Department of Defense engineers and program managers to enhance the analysis of HMD design alternatives. By using a specialized, analytical process it is believed that an optimum technology-mission fit can be achieved. Human Systems Integration studies have shown that when systems are designed, implemented, and managed with robust user-centric principles, performance and safety will increase while total life cycle costs will decrease. Models created from this study can assist in assuring the initial technology selection is in line with systematic HSI practices and creates consensus on priorities between stakeholders. Furthermore, the principles, methods, and techniques utilized in this study could serve as a baseline for intelligent decision analysis of other human interface technologies.

Preview

The four additional chapters to follow will provide more detail in the research, analysis, and conclusions of this effort. In Chapter 2, a review will be provided of the investigative research accomplished on the topics of helmet mounted displays, Human Systems Integration, and the decision analysis methodology, Value Focused Thinking. The methodology of the research and analysis will be described in detail in Chapter 3, while Chapter 4 provides results of the assessment. The fourth chapter will also include a discussion of the results and their implications. Finally, recommendations and possible future research opportunities will be proposed in Chapter 5.

II. Literature Review

Chapter Overview

Human technology interfaces consist of complicated physical and psychological relationships. Efficient representation, acquisition, and utilization of information must be carefully paired with intuitive system control. Military weapons systems increase the need for optimization of these relationships, as they are critical in life and death situations. Applying an analytical approach to alternative selection will help developers and decision makers consider all relevant factors of total system performance to achieve an optimized solution and avoid costly negative life cycle outcomes.

The research found in this chapter focuses on the main goal of developing a HMD design evaluation framework, by investigating the concepts, technology, and analysis techniques pertinent to the topic. The Human System Integration (HSI) perspective of implementing human centric design and development practices to increase system performance and decrease total life cycle costs will be described, as its principles will be used throughout the framework development. To gain a thorough understanding of the technology under consideration, this chapter will also present helmet mounted display system design considerations, uses, and implications. Finally, the decision analysis approach of Value Focused Thinking (VFT) will be explained in detail, laying out the method to be used for technology examination and framework consideration.

Human System Integration

Technology is constantly advancing and growing in complexity. However, systems have yet to reach a point where the human can be removed from the operational chain. Even, so called, “Unmanned” Aerial Vehicles (UAVs) have human operators that manage and monitor its operations from a remote control station. Therefore, current system designs must include aspects of human technology interaction. A human’s propensity to make mistakes, mixed with a technology interface not optimized for the user can lead to expensive redesigns, increased total life-cycle costs, or even tragic loss of life (Booher, 2003). Though design focus can often be on the technology capability advancement side, the human element must be considered a critical component of the system if one wishes to avoid these negative results.

The Human Systems Integration (HSI) philosophy maintains the idea that not only can catastrophic outcomes be avoided by performing human centric development and management processes, but dramatic increases in performance and decreases in costs can also be achieved (Booher, 2003). This is accomplished by initiating a comprehensive HSI strategy early in the design and development process and maintaining metrics and checkpoints throughout the program.

Human Systems Integration is an all-inclusive management and technical approach, which incorporates various functional areas to address the possible human element impacts throughout the total lifecycle of the system (HPW/HPO). These functional areas, or domains (listed in Table 1), are seemingly independent factors of human characteristics and performance. However, understanding and controlling their interactions are keys to successful HSI implementation. The Department of Defense began adopting HSI principles in the late1980’s with the US Army’s creation of the Manpower and Personnel Integration (MANPRINT) program (Booher, 2003). Training accidents and fratricide incidents magnified the need for Army leaders to shift the focus of technology developers away from "equipment only" and towards the "total system" view, which mandated that soldier performance and limitations be critical considerations in weapon system design.

Table 1 : HSI Domains

HSI Domains
Manpower The number and mix of personnel authorized and available to train, operate, maintain, and support each system acquisition.
Personnel The human aptitudes, skills, knowledge, experience levels, and abilities required to operate, maintain, and support the system at the time it is fielded and throughout its lifecycle.
Training The instruction and resources required to provide personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support the system.
Human Factors Engineering The comprehensive integration of human capabilities and limitations into system design, development, modification and evaluation to optimize human-machine performance for both operation and maintenance of a system. Designing systems that require minimal manpower, provide effective training, can be operated and maintained by users, and are suitable and survivable.
Environment Environmental factors concern water, air, and land and the interrelationships which exist among and between water, air, and land and all living things.
Safety Safety factors are operational characteristics that minimize the possibilities for accidents or mishaps to operators which threaten the survival of the system.
Occupational Health Occupational Health factors are design features that minimize risk of injury, acute and/or chronic illness, or disability, and/or reduced job performance of personnel who operate, maintain, or support the system.
Survivability The characteristics of a system that reduce risk of fratricide, detection, and the probability of being attacked; and the enable the crew to withstand man-made or natural hostile environments without aborting the mission or suffering acute and/or chronic illness, disability, or death.
Habitability Factors of living and working conditions that are necessary to sustain the morale, safety, health and comfort of the user population which contribute directly to personnel effectiveness and mission accomplishment, and often preclude recruitment and retention problems.

The concept of Human System Integration has grown and transformed since the Army's initial adoption. The Department of Defense (DoD) recognizes that HSI is an important tenant in various levels of its acquisition practices, requiring a cross functional approach for implementation. Therefore they have placed special emphasis on HSI by listing it as a requirement for all acquisition programs, declaring in DoD Instruction 5000.02, "The Program Manager will plan for and implement human system integration (HSI) beginning early in the acquisition process and throughout the product life cycle" (Defense, 2013). In today's acquisition programs, HSI principals can be found in all phases of the design and development process. Some areas of influence include mission analysis and requirements determination, generation of a systems engineering plan, modeling and simulation, design working groups, test and evaluation, upgrades, and even technology retirement and disposal.

In a system's life cycle, one of the most beneficial times to include HSI practices is during requirements writing and alternative selection. Booher explains that most life-cycle costs are determined by decisions made early in system development and it is at this phase that human-related problems can be most easily and cost effectively addressed (Booher, 2003). It is important, especially with COTS items, to not only create requirements with human-centric attributes, but to have evaluation measures that help determine the degree to which alternatives meet those requirements. It is this background information and underlying purpose that will drive the construction of the HMD evaluation framework at the center of this research topic.

Helmet Mounted Displays

HMD Use in Military Aviation

One of the earliest combat aviation uses of a HMD system was in the 1970s as a control device for the gimbaled gun on the U.S. Army's AH-1G Huey Cobra attack helicopter (Clarence E. Rash, 2000). The system was designed to allow weapon aiming by simply using the pilot's line of sight to place the helmet-mounted reticle over the intended target. After the Army's initial success, the U.S. Navy found use for this head tracking technology in their F-4 Phantom fixed-wing jet aircraft as a means for the pilot to interface with the fire-control radar. Cueing discretes and a visor-projected reticle allowed for daytime, off-boresight, air-to-air targeting of the AIM-9H Sidewinder missile. In both of these cases it was found that the HMD yielded a significant reduction in the time required to engage weapons on a target (Clarence E. Rash, 2000). As with most technology, these simple beginnings gave life to development of more capabilities and integration possibilities between aircraft and users. As seen on platforms such as the Air Force A-10, F-16, and F-35, the modern HMD not only allows for weapons cueing but aircraft monitoring, threat detection, and enhanced synthetic vision. If integrated appropriately, an HMD has the ability to reduce the cognitive demands of aircraft monitoring, while simultaneously allowing the pilot timely and effective acquisition of enemies.

HMD Basics

As described in the introduction, a modern combat aviation HMD primarily consists of four components: the mounting platform, image source, relay optics, and tracker subsystem. There are a variety of ways these components are designed and integrated, depending on the intended use and available technology.

Traditionally serving as a protection device for the aviator, the helmet is typically used as the mounting platform, hence the moniker “Helmet-Mounted Display”. Depending on the vendor, modern HMDs have either included a new helmet as part of the system, such as the Joint Strike Fighter HMD, or have been designed as retrofits to the current helmets in use, like the Scorpion Helmet Mounted Cueing System. Regardless of the design, the helmet mounting platform must continue to not only protect the user but also provide a stable base for the display and tracker. Misalignment between the display and user’s eye caused by slippage or vibrations can make the image look distorted, degrading the utility of the system, or even inducing physiological issues such as nausea, headaches, and dizziness (Clarence E. Rash, 2000).

The image source is the display device used to produce the symbology or sensor video feed that will be provided to the user via relay optics. Early HMDs used cathode-ray-tubes (CRTs) or image intensification tubes as the image source. However, advancing technology such as liquid crystal displays (LCDs) and light emitting diodes (LEDs) have allowed for higher brightness levels, addressability and image contrast while drawing less power and adding less weight to the system.

The relay optics often consist of a combination of lenses for magnification and collimation of the image. Magnification is often necessary as the display is typically formed on a small substrate having a diagonal less than 2 cm. Collimation is important to project the image near optical infinity so the operator does not have to accommodate differently when reading the display information or looking at distant objects. The optics can either form an image on a reflector in front of the eye, precluding the operator from seeing real-world objects or form the image on a combiner in front of the pilot's eye, overlaying the displayed image onto the natural scene. The later design permits the user to "see through" the display, enabling the user to fall back to the use of the natural scene when the display fails. The combiner is typically integrated into the helmet visor itself or as a separate piece mounted between the visor and the user's face.

The requirement for a head tracker is dependent on the intended use of the HMD system. If utilized simply as an information status display, with no need for spatially-referenced symbology, then the head tracker would provide no added benefit to the wearer. However, HMDs have found much of their combat advantage comes from the ability to integrate with aircraft avionics and weapons, allowing for a "point and shoot" enemy engagement along with persistent aircraft information or navigation aids. To provide this capability, the system must know where the pilot is looking, requiring the inclusion of a head tracking device. Additionally, advancements in sensors have created synthetic imagery such as forward looking infrared (FLIR) short wave infrared (SWIR), which can be displayed in front of the pilot's eye, providing an enhanced view of the environment. This capability may also require a head position triangulation if the sensor is mounted elsewhere in the aircraft. There are many technologies currently fielded or in development that can be used to track the helmet position and orientation. These include; magnetic, optical, inertial, acoustic, or a hybrid combination of techniques. Selection of a tracker option must be given special consideration as the technology may have an impact on other aircraft systems. Also, the tracker system has a considerable influence on latency affects, which impact the usability and acceptability of the HMD system (Randall E. Bailey, 2004).

It is the technology selection and integration for these four basic components, along with the processor that interfaces the HMD with the aircraft, which set HMD systems apart from each other. Designers make trades and sacrifices to create the best possible solution for the combat aviator. The following paragraphs will address some of the uses, concerns regarding HMDs, and how design considerations strive to accommodate them.

HMD Uses in a Fighter Aircraft

Helmet mounted displays are finding value in many different environments and in serving many different purposes, to include training, inspections, gaming, fire-fighting, surgical aids, computer-aided design, and remotely-piloted vehicles (Clarence E. Rash, 2000). However, the most use and advancement of HMD technology seems to be in the field of military aviation, as it can bring enhancements to both the pilot's situational awareness (SA) and enemy engagements.

A basic definition of situational awareness is; the user's ability to perceive elements in their environments, comprehend the meaning of these elements, and predict their near future status (Endsley, 1995). For all pilots, attaining and preserving SA means continual cross checks of safety of flight instrumentation while maintaining external visibility for obstacles and aircraft avoidance, communicating with other aircraft and control stations, deciphering maps for navigation, and employing emergency checklists when necessary in order to perceive the current status of the aircraft. Further the pilot must interpret this information and project potential future events to enable rapid decision making when time critical events occur. The combat aviation environment not only requires these elements for SA but add the additional complications of high performance maneuvers and strategic engagements; which call for awareness of information such as weapons management, enemy identification and tracking, multi-aircraft coordination, and other tactical information. A pilot's ability to readily gather this information from multiple sources is the key to maintaining high situation awareness.

As aircraft performance increased, the short-comings of head down displays became apparent. Faster and more maneuverable aircraft meant a more rapidly changing environment. Even the brief time it took for pilots to look down at their displays to gain necessary ownship and environment information could actually degrade their environmental SA. The development of head up displays (HUDs) gave the pilot critical flight data in an eyes-out format. These see-through combiners, fixed directly in front of the pilot's forward view, display ownship information such as attitude, altitude, airspeed, and heading along with tactical information such as tracking cues and warnings.

Though the HUD offers many benefits, and can be found on almost all high performance military aircraft, its limitation is its fixed position. Covering between 15-20 degrees of the forward field of view, the pilot is still required to take their eyes away from possible off-boresight targets, obstructions, or navigation points to gain ownship and tactical information. The helmet mounted display takes the eyes out enhanced SA advantage of the HUD and provides it across the entire viewing range of the wearer. By having the flight critical information persistently within the pilot's line of sight, overall performance and operational safety is ideally increased (Clarence E. Rash, 2000).

The same enhancement found for overall situational awareness can also be seen for the tactical envelope of an HMD equipped aircraft. Currently, pilots are required to look head down at multiple displays to gather 2-D positional and status information about the rapidly changing combat environment. As their attention is transferred back outside the aircraft, they must then translate the information to a 3-D space relative to their position. This information synthesis takes time and cognitive workload, reducing the pilot's reaction time to possible threats. The importance of this mapping process cannot be underestimated as the USAF has lost over 101 lives and 65 aircraft during the past 21 years due to pilot loss of spatial orientation, a problem that is particularly prevalent in fighter and rotor wing aircraft (Miller, 2014) With the advent of the helmet mounted display, the potential exists to assemble the appropriate information for the pilot and to automatically display it in a manner that streamlines data gathering and assembly, permitting faster decisions, enabling more rapid and informed responses to external events.

Target engagement has also been revolutionized by the HMD. Since the boresight mounted machine guns of World War I, fighter pilots have been cuing weapons by pointing the nose of the aircraft in the direction of the target. Propulsion and maneuverability have been key components to survival in this combat dynamic, a philosophy that was unchanged until fourth generation missiles appeared (Clarence E. Rash, 2000). These air-to-air weapons, capable of more than 50G turns, could be released on targets at very large off-boresight angles. Without an HMD, aircraft radars and sensors are used to cue missile seeker heads, often requiring the pilot to maneuver into a position that may not be tactically advantageous. HMDs can be coupled to the missile seeker or aircraft sensor to allow for a "look and shoot" capability, which can allow the pilot to cue and fire a missile without having to give up a position of advantage (C. Arbak, 1988). By using the HMD as a cuing tool, inferior aircraft armed with GEN-4 weapons have a distinct advantage in an air-to-air engagement, where aircraft performance is now outweighed by the speed and accuracy at which a missile can be deployed.

HMD Concerns and Design Considerations

As with any human machine interface, helmet mounted display designs must take into account not only technology performance but also how that technology interacts with human characteristics and limitations. There are physiological and psychological concerns that can make the system unusable or even endanger the operator if not considered. The primary design factors for see-through HMDs will be discussed here.

Weight, Center of Gravity, & Overall Size

The head borne weight and center of gravity (C.G.) of the HMD is extremely important to the design of the system. In high performance, ejection seat aircraft these characteristic have a large impact on operator fatigue and safety. Any weight deviation from the normal C.G of the user's head will cause additional muscle strain and tend to fatigue the pilot, especially during high g maneuvers. In addition, overall weight could affect the chances of survival during an ejection event as the neck is exposed to extremely high loads during the catapult phase and as the seat reaches the wind stream. The slam-back effect caused by the sudden blast of air, and exacerbated forces with the extra weight, can be catastrophic. Further, added weight has the potential to induce operator fatigue, especially when the helmet-mounted display is worn throughout the entire mission and potentially could add to chronic musculoskeletal injury over years of use.

The overall size of the helmet portion is also important, as head space is often limited in a fighter aircraft. The display must be small enough to allow the pilot to perform full scanning patterns, including the check six maneuver (turning to look behind the aircraft). Advances in materials and electronics have greatly reduced these hazards, but not to the point of completely eliminating them.

Ocularity and Field of View

Ocularity refers to whether the HMD displays imagery in a monocular, binocular, or biocular manner, defined by:

Monocular – single image source, viewed by a single eye

Binocular – each eye views an independent image source

Biocular – single image source, viewed by both eyes

(Clarence E. Rash, 2000)

The ocularity of a device should be determined by how it is to be used, as a tradeoffs must be made with the additional weight, optical alignments, visual rivalry issues and power consumption that multiple or single image sources would require. Table 2 shows some of the advantages and disadvantages between the ocularity options.

Table 2 : HMD Ocularity (Clarence E. Rash, 2000)

Ocularity	Benefits	Downside
Monocular	• Minimum weight • Less stringent alignment • Typically least expensive • Eye without display continues to sample outside world	• Possible visual rivalry between eyes • Possible asymmetric C.G. • Smaller F.O.V • No ability for stereoscopic display
Binocular	• Can provide stereo viewing • More symmetric C.G • Wider F.O.V. than monocular • No ocular rivalry between eyes	• Heaviest weight • More complex alignment and adjustments • Most expensive
Biocular	• Wider F.O.V. than monoculor • No ocular rivalry between eyes • Potentially less expensive and lighter than binocular	• Heavier than monocular • Typically reduced luminance • Heavier and more complex alignment than monocular

Display Field of View (F.O.V) describes the size of the apparent image space, more formally defined as the maximum image angle of view that can be seen through an optical device (Clarence E. Rash, 2000). As a reference, the total binocular F.O.V of the human visual system is about 200º horizontal by 130º vertical. The F.O.V required for a HMD is highly dependent on intended usage and input symbology/imagery. A wider F.O.V is useful to create an immersive visual environment but will add extra wieght to the display. If the display is to be used for weapons cueing and a minimum amount of information communication, a smaller F.O.V is accetpable.

Display Resolution

An important aspect of determining the “sharpness” of the imagery of a display can be described as the resolution. A low resolution image will lack detail and may appear blurry. Typically, this metric can be described as the pixel count in a display, width × height. For example, current high-definition liquid crystal display (LCD) and light emitting diode (LED) televisions are said to have a resolution of 1080 or 1920 pixels wide by 1080 pixels tall. However, the size of the display can have an effect on the clarity of the image as the pixels are often scaled to keep the same count. Therefore, the more accurate definition of resolution would be the number of pixels (or lines) that can be adequately distinguished across the scene (Information Display Measurements Standard, v1.03, 2012). For this effort, pixel density, or pixel per degree of vision, will be the metric used to help define the HMDs resolution.

Display Brightness and Contrast for See-Through Displays

The challenge with see-through displays, such as the HUD or HMD, is designing a combiner with acceptable transmission qualities while still providing an image with high contrast when viewed against a high luminance ambient scene. This type of HMD necessitates a higher brightness image source to maintain a contrast that allows the display to be legible under all ambient (environmental) conditions. This concept is shown in Figure 2, where 'L' represents *luminance* or brightness (measured in foot-Lamberts), 'T' represents *transmittance* or the amount of light allowed through the medium (measured in percent of incoming light), and 'R' represents *reflectance* or the amount of light bouncing off the medium (measured in percent of incoming light).

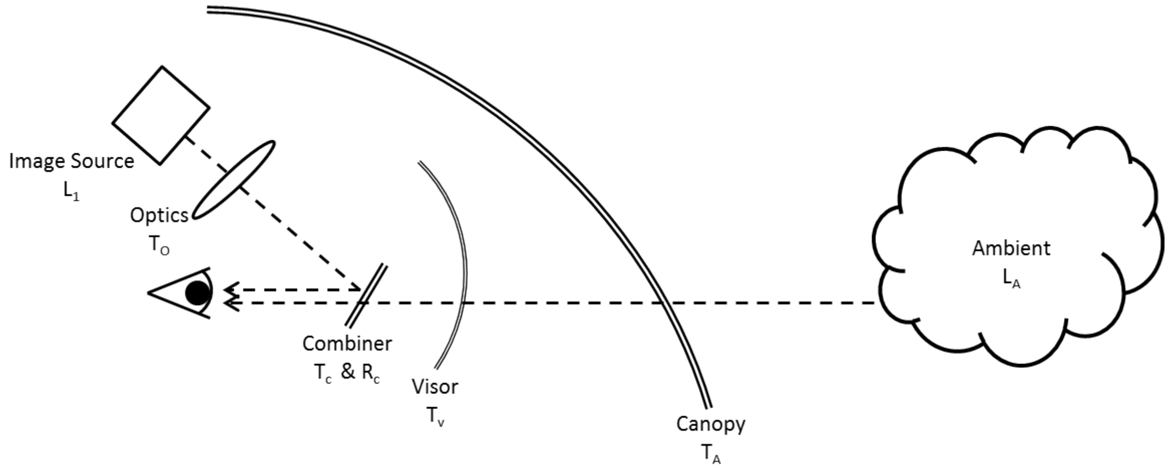

Figure 2 : Affects on Display Brightness

The contrast is calculated by the ratio between the brightest part of the display and the darkest. In the case of a see-through display, the darkest part would be the luminance of the ambient scene observed by the pilot (L_o) and the brightest would be that luminance plus the luminance added by the image source (L_{HMD}). This ratio is shown below in Equation 1.

$$CR = \frac{L_{HMD} + L_O}{L_O} \qquad \text{Eq. 1.}$$

Where

$$L_{HMD} = L_1 \times T_O \times R_C \qquad \text{Eq. 2.}$$

$$L_O = L_A \times T_A \times T_V \times T_C \qquad \text{Eq. 3.}$$

And where

L_1 is the luminance of the image source

T_O is the transmittance of the optics

R_C is the reflectance of the combiner

T_C is the transmittance of the combiner

L_A is the luminance of the ambient scene

T_A is the transmittance of the canopy

T_V is the transmittance of the visor

The transmittance and reflectance characteristics of the visor and other HMD components are carefully calculated to maintain a sufficient contrast ratio in all possible environments.

System Latency and Accuracy

System latency, for the purposes of this research, refers to the flawed alignment of the symbology overlaid on the real world as the user moves their head and occurs as a result of the time delay from sensor input to display projection. On an aircraft, this latency is contributed to by not only all components of the HMD system and the communication between them but the systems of the aircraft platform that feed information to the HMD system. The HMD system contributors are; the time to determine head position, which is communicated to the display processor, then the time to process the data and compute the new graphic, which then creates the new image and communicates to the image display which then refreshes to render the new image on the combiner. Each component function adds to the total latency time and can cause nausea and other physiological issues if not minimized. Advanced processing and refresh rates have significantly reduced the total system latency in HMDs but can still be a problem as no systems have yet to reach true zero latency.

Accuracy, is similar to latency in that it is a measure of deviation in symbology location relative to real world references. However, latency is used to express a time delay in symoblogy placement or a lag found during head motion, while accuracy can be thought of as the difference in a static scene. Very intuitively, if there is a significant amount of inaccuracy in the system, operations and safety can suffer severe detriments, especially in a crowded airspace environment where it is important to delineate between types of air traffic. A system's accuracy is dependent on the tracker type being used and the processing power of the system.

Display Symbology and Clutter

As with any cockpit displays, the selection of symbology or imagery to be displayed is as important as the technical specifications that describe the image source. For the military, symoblogy shapes, colors, and mechanics are standardized and can be found in documents such as MIL-STD-1472, Human Engineering or MIL-STD-2525 Common Warfighting Symbology, and others. Issues like unstandardized symbology sets, over clutter of information, and lack of intuitive mechanization can cause serious problems, including loss of situational awareness, task saturation, and negative training. Designers of modern HMDs have accounted for this by allowing symbol customization. The customer is then responsible for determining symbology schemas, using sound human factors practices for display design.

User Acceptance

All of the above factors combine to create the user acceptance aspect. An HMD system must be usable by many body sizes and personalities for long periods of time.

Any features that can possibly cause discomfort or affect efficient usage could cause the system to be unacceptable. Building in user adjustability, such as selectability of display position, brightness settings, and declutter options are often necessary to account for the variation in pilot population and uses.

Below in Table 3 is a summary of some of the HMD systems that have been developed in the past four decades.

Table 3 : Selection of fixed-wing HMD programs (Clarence E. Rash, 2000)

Time Frame	System Name	Developer	Aircraft Platform
1970s	Display And Sight Helmet (DASH) series	Elbit Systems Ltd	Fielded on Israeli F-15, F-16, F/A-18C Romanian Mig-21
1980s	Agile Eye	Kaiser Electronics	Unfielded; Experimental System
1990s	Viper series	GEC-Marconi Avionics Ltd	Unfielded; Experimentally flown on F-16, AV-8B, Tornado
1990s	TopSight/TopNight	Thales Avionics	Fielded on Mirage and Rafale
1990s	Joint Helmet Mounted Cuing System (JHMCS)	Vision Systems International (VSI)	Fielded on F-15, F-16, F/A-18
2000s	Scorpion Helmet Mounted Cueing System (HMCS)	Gentex Corporation	Fielded on F-16, A-10
2000s	Helmet Mounted Display System (HMDS)	Vision Systems International (VSI)	In development for F-35
2000s	Striker HMD	BAE Systems	Fielded on Eurofighter Typhoon and Gripen

Decision Analysis – Value Focused Thinking

Decision analysis, at its core, is a logical, repeatable approach to illuminating best solutions to complicated problems. At the end of an analysis, the decision maker is provided with the information necessary to make the most educated quantified judgment of the alternatives.

One method for applying the decision analysis process is called Value Focused Thinking. Introduced by Ralph Keeney, this approach consists of two overarching activities; first deciding what you want and then figuring out how to get it (Keeney, 1992). While it sounds simple and intuitive, Keeney points out that we often do not follow this logic. In fact we have learned most of our decision making practices based upon how decisions have been posed to us throughout our lives. For example, would you like to wear shorts or long pants? Would you like to write with a pen or a pencil? This method of starting with what's available and taking the best from your choices is known as Alternative-Focused thinking (Keeney, 1992). While this may be the "natural" way of making a decision, in complex situations it can limit the understanding of the problem space and lead to negative unforeseen consequences. Value-Focused Thinking (VFT), while more difficult and time consuming, is meant to thoroughly examine the full problem context and uncover objectives or opportunities not readily apparent to the decision maker. By starting with a problem and first determining important aspects of the decision that bring value to the decision maker, one can avoid inadequate fixes that can stem from impetuously attempting to force-fit a solution.

Value-focused thinking involves defining the decision context and objectives, or something that one desires to achieve. Both Parnell and Keeney recognize the delineation of two types of objectives, fundamental and means. Fundamental objectives are those that represent the end goal of a decision while the means objectives describe how the fundamental objectives will be met (Gregory S. Parnell, 2013). These fundamental objectives are often missed in alternative-focused thinking, by jumping straight to means objectives and limiting the solution options to be examined. As illustrated in Figure 3, if only means objectives are identified one can miss solutions that may more fully meet their higher level fundamental objectives.

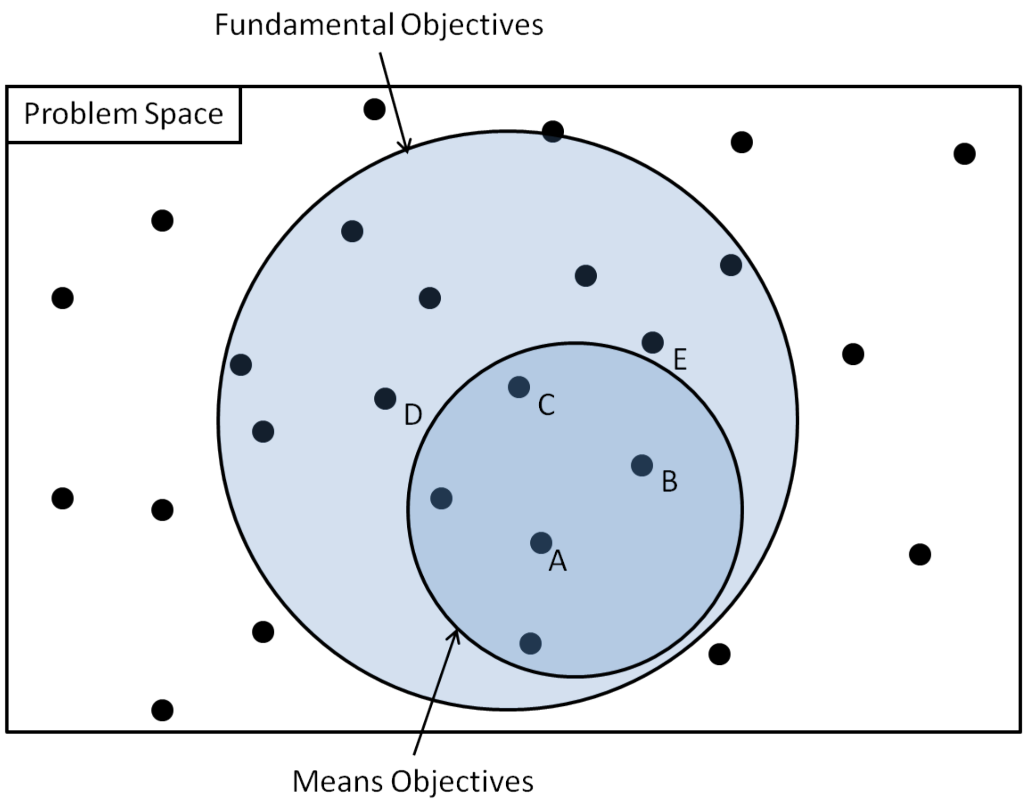

Figure 3 : Alternatives in problem space

Shoviak (2001) has broken down the concepts of value-focused thinking into a ten step model development process that helps to define the decision space by eliciting the objectives and developing values with associated metrics. An analysis can then be performed to determine a best-fit solution, ultimately giving the senior decision maker the information needed to make an informed decision. This process is laid out in Figure 4.

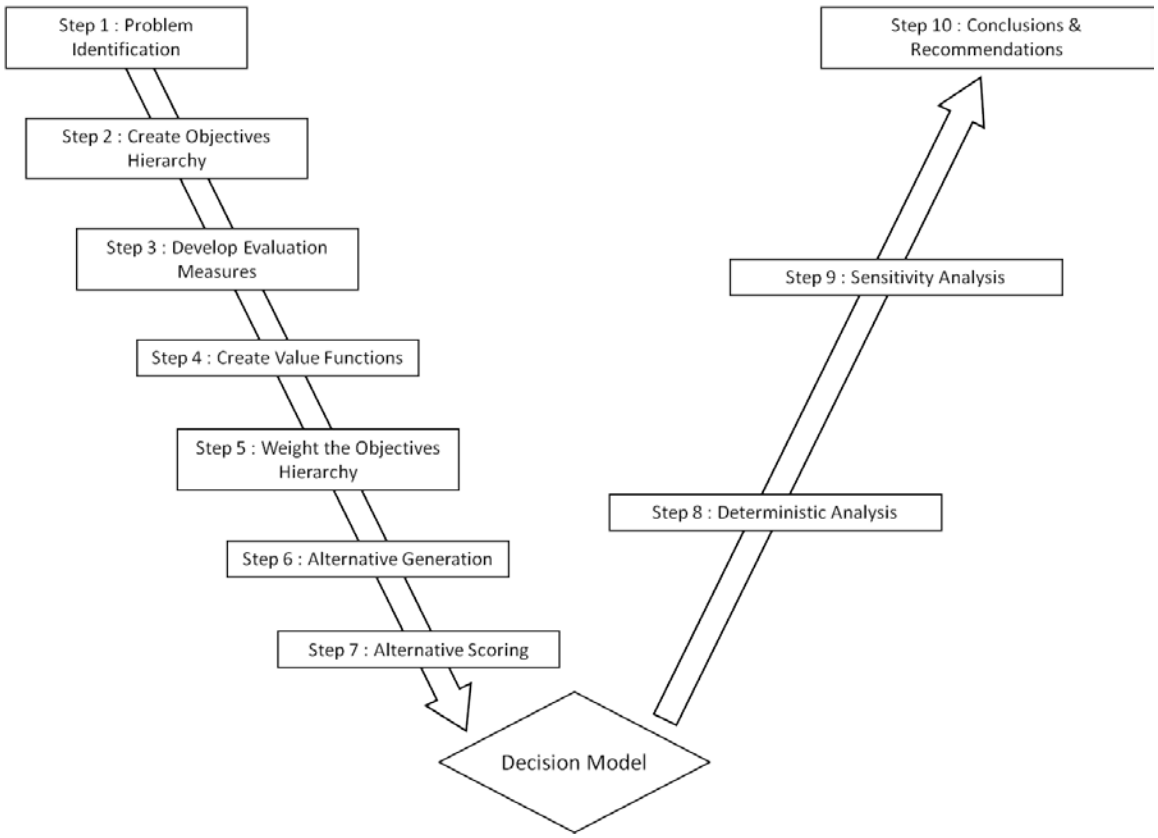

Figure 4 : Value-Focused Thinking Process

Step 1 : Problem Identification

The goal of this first step is to develop a well-defined statement of the problem that ensures complete understanding of the decision. Characterizing this decision frame is key to understanding and determining the important factors, objectives, and decision boundaries. This process can be accomplished through interviews with the senior decision maker, user community, and other stakeholders. Questions should be proposed with the purpose of eliciting the information that will make clear the possible courses of action that may be considered and which may not (Gregory S. Parnell, 2013). This step will be the basis for which objectives and values are created, then further translated into metrics and alternative analysis. The frame will also help to focus the analyst and decision makers to a certain scope. Inadequate problem identification or decision framing can cause a failure of the end goal by proposing a solution that meets the defined problem but doesn't solve the REAL WORLD issue.

Step 2 : Create Objectives Hierarchy

In this next step, objectives important to the decsion makers are elicited from relevent stakeholders and used to construct a hierarchy that will be decomposed into something that is complete, measurable, mutually exclusive, and concise. To be considered complete, the hierarchy must include all relevant factors for the decision frame. These factors, or objectives, are used for evaluating the desirablity of eventual alternatives or consequences of a decision. It is at this point the first prominent difference between alternative-based thinking and value-focused thinking can be seen. The objectives, and not the available alternatives, should be the driving force behind decision making. One should begin at the highest level objective, or strategic objective, and decompose into objectives that bring value to the high level. For example, if your startegic objective is to 'buy the best home for your family', you might decompose that objective into lower, operation level objectives to consider such as: 'size of house', 'location', 'property', etc. Those would then evantually be broken out again into objectives, known as the tactical level, where specific values can be measured and weighted. Examples of these lowest level values would be ‘square footage’, ‘distance to schools or parks’, ‘yard size’, etc. When moving down the hierachy, each subsequent level should answer the question “What do you mean by that?” about the preceeding level. By following this decomposition hierarchal process a complete examination of the objectives and values can be accomplished. To meet VFT requirements these lowest level attributes must be measurable, whether through a natural, constructed, or proxy method. They must also be mututally exclusive in that they are independent of each other and so changing the value of one does not in turn change the value of another. The ultimate goal of this step is to create this complete hierarchy in a concise manner to facilitate calculations and communications with the senior decision maker.

Step 3 : Develop Evaluation Measures

After completing the objectives hierarchy, the next step is to determine evaluation measures (metrics) for the lowest level objectives. These metrics are meant to be quantitative scales that will eventually be the basis for determining how much value the attribute brings to the decision space. The measures can be classified as natural, constructed, or proxy (Keeney, 1992). It is important to recognize the type of metric that is being used, as it can add or subtract validity to the findings. Natural measures are those with common interpretations or uses, as in using ‘number of accidents’ for a measure of the objective “minimize the accidents at an intersection”. These are the most desirable measures for a decision analysis process as they are widely accepted and are conducive with ease of communication. Sometimes a natural metric doesn’t exist for a given objective. In this case one might construct a measure that is specific for the decision context. For the objective “maximize the local acceptance of a new store” there is not a natural metric. However, one can be constructed that assigns a scaled measure for the ‘number of groups that publicly oppose the new store’. The final type of metric is known as a Proxy measure. This is a metric that indirectly indicates the impact on an objective and should only be used if a natural or constructed measure cannot be determined. Regardless of the type of measure used, the scale should be clear and meaningful to the decision maker. It is also important to remember to choose the appropriate scale bounds for the decision context. If an alternative arises that is not within the bounds then it cannot be compared to other options without rescaling the values.

Step 4 : Create Value Functions

At this point it can be seen that the evaluation measures developed in the last step will be a collection of different units and scales, which will prohibit direct comparison and summations to obtain a total score. To transform these evaluation measures into a common ‘unit of value’ a value function is developed for each objective. This function can be represented on a coordinate plane with one axis labeled as the metric and the other as the perceived value, which is scaled from least value (0) to max value (1). The plotted function should be shown as monotonically increasing or monotonically decreasing (Gregory S. Parnell, 2013). In other words as the objective measure increases the value will always be either increasing or decreasing. Furthermore, the slope of these trend lines would represent a change in the rate of return. In the monotonically increasing Figure 5, Function 1 would represent a decision maker who believes the rate of return gradually decreases as the evaluation measure is increased. Alternatively, Function 2 represents an increase in the expected rate of rate of return as the measure increases. Function 3, shows a decision maker who believes in a constant rate of return throughout the range of the bounded evaluation measure. An S-Curve (Function 4) is used when there are inflection points or changes in rate of return at specific values of the measure. This can often represent an "optimum point". Piecewise linear forms of these curves types are also common (Function 5), if there are known points with unchanging value rates between them.

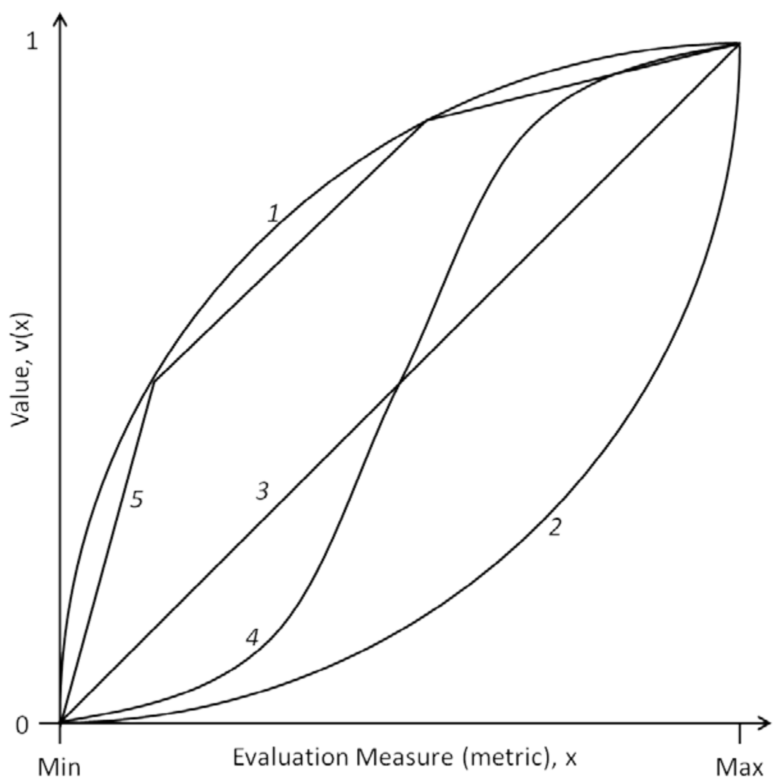

Figure 5 : Value function types

When the evaluation measures have a small number of discrete points that add value, a bar graph type plot can be used. Occasionally value functions that are not monotonic can be found, i.e., they rise then fall or vice versa. This often happens when two evaluation measures are combined instead of being kept separate (Gregory S. Parnell, 2013). For example, the value of the number of bedrooms in a house may increase up to 4 bedrooms then decreases. This decrease could represent the decision maker's belief that there would be too many rooms to clean or it would drive an increase in utility bills. While these are legitimate trade-space points, it is better practice to keep the evaluation measure independent of each other (Gregory S. Parnell, 2013).

When creating these value functions, one method is to start with a linear (increasing or decreasing) trend line based upon current knowledge of the decision maker and other stakeholders' feelings toward the metric. Any deviation to the trend line, such as creating a concave, convex, s-curve or asymptotic shape would follow an elicitation from the decision maker or subject matter expert that rationalizes a belief in a change in the rate of return for that particular metric.

Step 5 : Weight the Objectives Hierarchy

While the objectives hierarchy created in step 2 illustrates all the relevant objectives, it must be recognized that not all of them are equally important to the decision maker. To create an accurate model, the decision maker's preference between them must be taken into account. By determining a weighting value for each objective, the relative importance of each can be represented.

One technique for assigning weights is the direct weighting method. In this technique the decision maker directly assesses the importance of one objective over another independently, that is without consideration as to how much the individual objective will contribute to the overall score (Shoviak, 2001). Using Figure 6 as an example, one would start at the lowest level objectives (C) of the hierarchy, creating local weights for C1 and C2 against each other, and C3 and C4 likewise. This is done by asking the decision maker which of these objectives is the least important. The indicated objective would be assigned a variable, X. Then the decision maker would be asked for a value that represents how much more important the next one is than the one assigned with variable X. This question is repeated for each of the values in the connected branch and creates an algebraic expression that is set equal to one. After solving for X, each value has a unique local weight, or *w* as it will be labeled in Equation 4. This methodology is used on each of the lowest objective branches, working up one level at a time until every objective has a weight relative to the others in the same level.

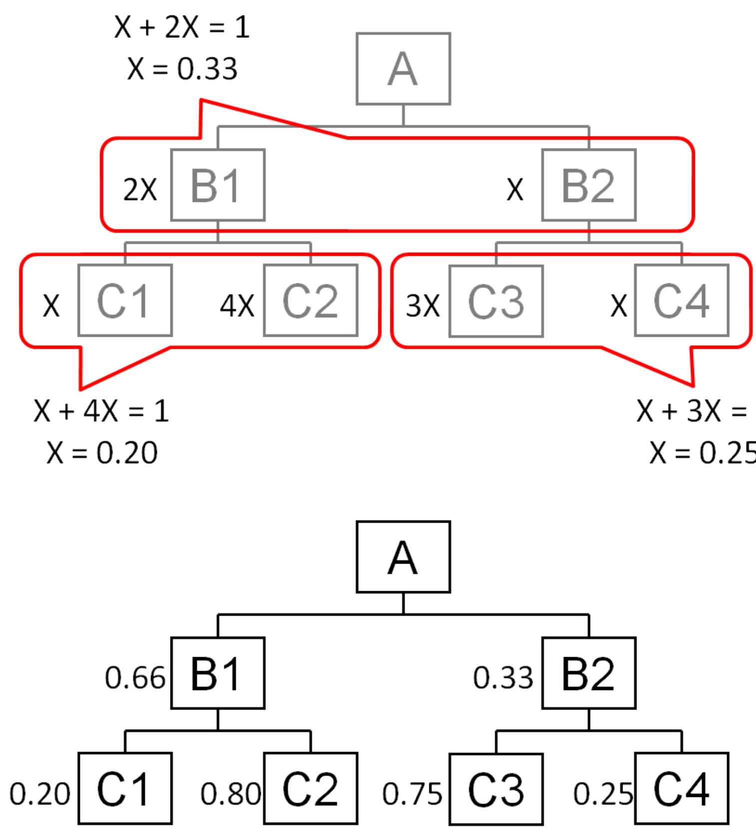

Figure 6: Example Hierarchy and Weighting Method

The following equation (Eq. 4) is then used to create a value measure, based on the value function curve and weight described above, for each of the objectives.

$$V(\overline{x}) = \sum_{i=1}^{n} w_i \cdot v_i(x_i) \qquad \text{Eq. 4.}$$

Where,

$V(\overline{x})$ is the alternative's value of x objective

$\overline{x} = \{x_1, x_2, x_3, ..., x_n\}$

$v_i(x_i)$ is the value function for a given evaluation metric x_i

w_i is the weight for a given value measure

Step 6 : Alternative Generation

After following the VFT unique method of identifying the objectives and values first, it is at this point where alternatives are brought forward. Generating a good set of alternatives is important to any decision making process as it can severely affect the outcome. While this may sound obvious, there are specific characteristics of an alternative set that determine if it is adequate, such as being *feasible, complete, compelling* and should strive for *diversity* in the options (Gregory S. Parnell, 2013). The *feasible* term should apply to the final set to be evaluated; each alternative must be a course of action that can be taken. In other words, a barrier cannot exist that would make it impossible to purse one or more of the alternatives, such as a non-negotiable timetable/cost constraint. However, alternative generation should be an iterative process, so it is often helpful to ignore constraints in the early brainstorming phases as sometimes initial constraints can be relaxed (Gregory S. Parnell, 2013). A *complete* set of alternatives has a full description of each option. Parnell gives the example, "if a decision is to be made on how to deploy a military battalion in an exercise, each alternative should specify mission tasking for every unit within the battalion" (Gregory S. Parnell, 2013). Another important characteristic of the alternative generation step is each option should have something that makes it appealing, or *compelling*, over at least one other choice. Kirkwood uses the term dominance to explain this concept (Kirkwood, 1997). Alternative *A* dominates alternative *B* if all the attributes of *A* are at least as preferred as all those in *B*, with at least one attribute of *A* being more preferred. If an alternative is dominated by another, according to this description, it can be removed as an option. An alternative set that meets these characteristics, and is as diverse as the problem space allows, should make for a thorough analysis and provide the decision maker valuable information.

Step 7 : Alternative Scoring

As the decision model has been developed and the possible alternatives have been derived, it is at this point that the evaluation measures are populated with the alternative characteristics. Each alternative is assessed on the value function scales created in step 4. Depending on the metrics, this could be a very simply "plug and chug" process or could involve user evaluation and feedback. The end goal of this step is to have a value measure for all relevant aspects of all the alternatives.

Step 8 : Deterministic Analysis

At this point, the Decision Model has been created and the required data from the alternatives has been input. The deterministic analysis takes the inputs from step 7 and calculates the global value score for each alternative, producing a number that can be a point of initial comparison between them. There are several mathematical functions that can be used to perform this evaluation. The simplest is the additive value function, which assumes mutual preferential independence (Gregory S. Parnell, 2013). In other words, this method can be used if the value function of one evaluation measure does not depend on the level of another. The equation presented in Step 5 of this section is used by the additive value function method to calculate the aggregate value of multiple objectives.

Step 9 : Sensitivity Analysis

Once the global values are determined for each alternative it may provide valuable insight to the decision maker to see how the alternative rankings would change if particular data in the model was adjusted, essentially determining the sensitivity of the preferred alternative to a change of assumptions (Gregory S. Parnell, 2013). This can be done by varying the weights, value curves, or evaluation measures for the alternatives. It is important to remember that when changing the weighting numbers, always insure that they sum to 1. Changing evaluation measures and/or weights can provide essential information if the alternative design or environment influence is subject to change in the decision process. For example, it is possible that a senior decision maker responsible for choosing a new air to ground ordinance may want to see how the preferred alternative might change if one of the competing contractors assured a new targeting sensor technology could be integrated during the development of their product. This would mean changing the evaluation measures for the effected objectives, such as accuracy. The decision maker might also be curious about alternative rankings if a changing fiscal environment drove a change in tactics that meant this new ordinance only needed to be deployed by one type of aircraft. The DM could go into the model and alter the weight (or relative importance) of the 'achieve multi-platform integration' objective.

Step 10 : Conclusions and Recommendations

The final step of any decision analysis process is to provide conclusions and recommendations to the decision maker and stakeholders. The format of this presentation will vary depending on what the DM has requested, but generally the analyst will gather necessary data and illustrations to clearly communicate their findings and any insights gained during the analysis process.

Summary

This chapter has provided information pertinent to the research and methodology, including the topics of human system integration (HSI), helmet mounted displays, and value-focused thinking. While proven to be important, HSI still faces challenges in its implementation and practices. One challenge is simply resistance to change in the acquisition community. Additions of new practices and checklists are seen as extra workload instead of a truly beneficial philosophy incorporation. This can only be overcome by support from leadership and HSI concept training for the workforce.

The other important challenge has to do with the inherently difficult nature of incorporating a human into a technology system. Robust evaluations frameworks are necessary to improve this relationship, so the HSI principles of human centric design will be prevalent throughout this decision analysis process as objectives and values are defined.

The description of HMD technology, their human impacts, and the discussion of current systems have provided context for the alternatives and characteristics to be evaluated. The modern warfighter is the most technologically advanced in history. Not only have the weapon systems, like fighter aircraft become more complex, but the tactics they employ have been revolutionized by the HMD. This critical technology requires a robust evaluation methodology to assist in solution selection decisions so as to gain the best possible combat advantage.

The Value-Focused Thinking (VFT) decision analysis process, applied in Chapters 3 and 4, can provide an analytical, repeatable assessment based on the value a HMD alternative brings to the overall objectives.

III. Methodology

Chapter Overview

Chapter III employs the Value-Focused Thinking method of decision analysis described in Chapter II to create an evaluation framework for HMDs. This chapter will focus on the left side of the VFT "V" (shown below in Figure 7) and begins with problem identification, followed by the development and thought processes behind construction of the objective hierarchy. Assignment of evaluation measures and creation of their associated value functions will then be explained. Decision maker inputs will then be used to establish weighting values for the objectives presented in the hierarchy. When completed, these guidelines and measures can be used to robustly determine an optimum HMD solution for a fighter aircraft platform.

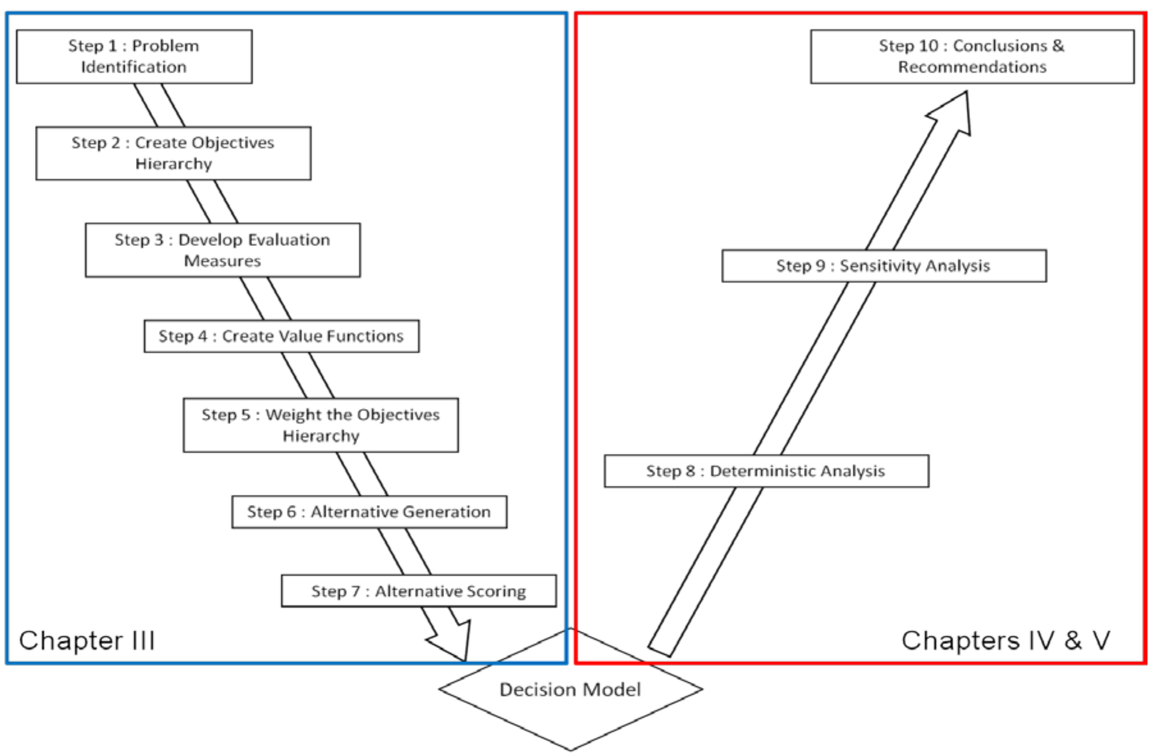

Figure 7 : VFT Process as it will be applied

Step 1 : Problem Identification

Uniquely difficult to evaluate in a robust manner is the field of human factors and human systems integration. Much of these types of evaluations are conducted with qualitative human subject feedback and standards that cannot account for the entirety of the user population, explore the impact of a small number of factors while constraining all other factors to a fixed value, and often aren't tailored to the system's specific operational environment. While a recent emphasis on HSI has brought a renewed focus to the issues of human centric design in new large development efforts and future programs, there is still the issue of how to make interface design decisions in a quantitative, repeatable manner. Further exacerbating the problem is the push to use more commercial of the shelf (COTS) equipment for modernization efforts of legacy aircraft and to include a more diverse user population. COTS items are developed by commercial industry companies to be useable by a variety of platforms and mission environments, in an attempt to gain the most business with a diverse customer pool. This approach poses a problem in the human factors realm because optimizing the technology-user relationship necessitates building a system to the specific user-mission combination, which often requires tailoring for very unique attributes not found across multiple platforms. As stated in the HSI Handbook, the human interface of COTS products are not usually customized for the unique operational needs of the Air Force, including the critical nature of many tasks (HPW/HPO). To accommodate the use of COTS equipment into a unique military environment it is imperative that the evaluation and selection process of these items be as tailored and robust as possible. Current methods for early technology down-selection and evaluation generally involve subject matter expert development of requirements, followed by user feedback of the possible system solutions. While this technique has been used for many years, it is susceptible to bias errors and inadvertent omission of important factors, leading to non-optimized performance and increased costs to sustain the system. So, to formalize the problem statement; the DoD lacks a robust, objective method for human centric evaluation of COTS HMD equipment alternatives. The efforts of this research will focus around the integration of a helmet mounted display onto a legacy fighter platform, proposing a user centric system analysis process with the purpose of allowing robust and repeatable decision making in technology selection.

As the primary purpose of this research is to demonstrate a quantifiable method for a COTS HMD selection process, the Value-Focused Thinking method of decision analysis will be followed for the remaining 9 steps using the hypothetical problem that an Air Force Acquisition Fighter Aircraft Program Office needs to make a decision on which HMD system to integrate into their aircraft. Step 1 of the VFT process is problem identification and as described in Chapter II, it involves the formalization of the problem space, boundaries, and assumptions.

Problem: A fixed-wing fighter platform needs a helmet mounted display solution to provide an advantage in its primary roles of air-to-air and air-to-ground combat. The System Program Office (SPO) has been tasked with determining an optimum technology solution, but no robust evaluation framework exists to support decision-making.

Boundaries: Due to fiscal constraints, the development of a new, unique HMD system for this platform is not an option. Commercial off the shelf (COTS) products must be used to the greatest extent possible.

Assumptions: It is assumed that minimum performance requirements have been developed by the user command. All alternatives to be examined have met these requirements and so will be compared for their added value beyond the minimums. Also, programmatic topics such as funding and schedule have been determined and will be addressed separately outside of this analysis.

Step 2 : Create Objectives Hierarchy

To paraphrase the HSI Handbook, the goal of human systems integration is to acquire optimized systems that enhance performance and reduce life cycle costs. So the goal of the objective hierarchy for this effort was to determine what factors and relationships would impact the HMD system's ability to optimize performance and operational effectiveness of the weapon system. The first realization was that there are multiple levels of system performance that can be optimized, as shown below in Figure 8.

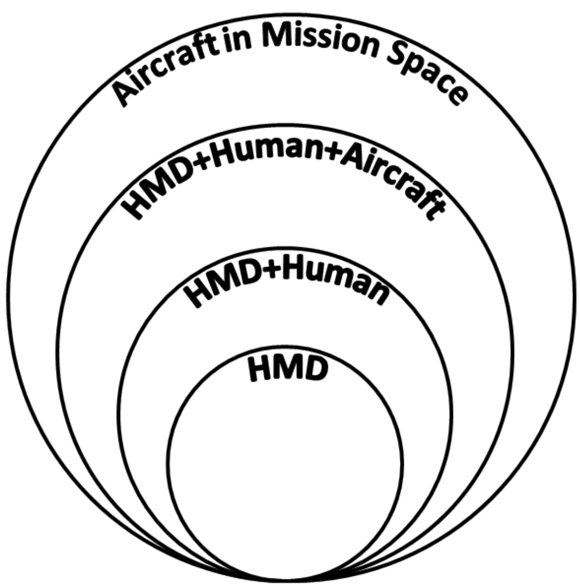

Figure 8 : Levels of Performance

Not all of these levels, such as 'Aircraft in Mission Space", can be quantitatively evaluated during an early COTS equipment selection process. Consequently, technology evaluation is often done in a bottom-up approach, evaluating attributes in the lower two levels and assuming they impact the upper levels of performance in a proportional fashion. The methodology used for this effort was to take a user-centric point of view and start at the top, working down to determine exactly what measurable technology characteristics are important to the overall goal of a HMD. This was accomplished by asking stakeholders such as pilots, engineers, maintainers, and program managers questions like "What is the ultimate goal of a helmet mounted display addition to the weapon system?" The responses are presented and explained below.

Increase Operational Effectiveness

This objective is a measure of the impact the system brings to the combat environment. Fighter aircraft serve a critical role in the military airspace and fulfill missions such as air interdiction, close air supports (CAS), offensive and defensive air-to-air as well as air-to-ground engagements. The fundamental goal of a capability addition, such as a HMD, should be to have a positive effect on all aircraft responsibilities.

Increase Lethality and Survivability

The primary role of a military combat aircraft is to engage in high risk scenarios where survival is often dependent on the ability to destroy the enemy target in a timely and effective manner. In a fighter aircraft, this can mean being the first to deploy weapon loads and avoiding imminent threats. Capability additions should strive to enhance the platforms ability to strike first and accurately, and provide defensive awareness for increased chances of survival.

Increase Safety

An additional capability or system should, at a minimum, avoid increasing a safety risk. The possibilities for accidents or mishaps to operators should be carefully addressed and controlled. The goal of many aircraft additions, in particular pilot vehicle interfaces such as HMDs, is to reduce safety hazards in both high risk and benign environments by offering additional situation awareness so as to avoid obstacles and assist in basic flight.

This type of question would be followed up with "In order to accomplish these fundamental objectives, what means objectives must a helmet mounted display meet?"

Enhance Situational Awareness (SA)

An aircraft interface, such as a display, should seek to clearly and accurately provide situation information in a manner conducive to the Perceive, Comprehend, and Prediction of future state goal of situational awareness. For fighter pilots, general SA can be decomposed into administrative and tactical situational awareness. Administrative SA can be thought of as anytime in the sortie when the pilot is not engaging an enemy. While tactical SA is required during the engagement timeframe and requires concise communication of threat location and characteristics as well as ownship and wingman data important to coordination. Examples of possible symbology sets to augment SA are: target locator lines, weapon engagement zones, ownship airspeed and altitude, aircraft designators, and navigation aids. HMD design of the display and symbology should strive to enhance the users understanding of the situation in both phases of flight, allowing for increased safety, survivability, and lethality.

Enhance Weapons Employment

Essential to survival in a combat aviation environment is the pilot's ability to defend against and strike an enemy target. Air-to-air and air-to-ground engagements are the most common mission scenarios for fighter aircraft. The outcomes for these contests are determined in a matter of seconds, often by who has the ability to fire a weapon first. The HMD is intended to provide the advantage of being the first to acquire and engage a target, while maintaining a position of advantage. When integrated with advanced air-to-air and air-to-ground missiles, the HMD advantage increases lethality and chances of survival in a combat environment.

Minimize Potential Harm

Another aspect of increasing safety is to minimize the risk of potential harm caused by the system itself. Human-Machine interfaces must always be developed with the user in mind, as a poor design could inadvertently cause chronic health issues or fatal injuries. Additionally the system must be reliable. A failure of essential systems, such as an interface that provides critical flight information could cause the pilot to lose control of the aircraft.

Continuing further into the solution space and performance levels, it was important to find out information like, "What HMD attributes bring value to those objectives?"

Provide Best Display Performance

This means objective has to do with how well the technology performs, with the purpose of supporting the enhancement of weapons employment and situation awareness objectives. The display must perform at a high level so as not to induce negative physiological symptoms that would degrade pilot SA and tactical performance, such as nausea, dizziness, or headaches. Included in this attribute will be the functionality of the pertinent HMD system technology including; tracker, processor, image source, and display optics.

Provide Best Human Factors

The physical relationship between the technology and the user is very important to safety and usability of the system. This attribute will examine the interface metrics determined to be pertinent to the higher level objectives such as pilot usability, head-borne weight, and C.G.

Maximize Reliability

An aircraft and its capabilities or only valuable if they are available when needed. A system must be reliable enough so the user is confident that it will function properly when required. The probability that the system will fail must be controlled and minimized when possible. Intuitively, the less likely the system it to break, the less time needed to repair it. This is also important because user acceptance is always a metric of concern for new technology or capabilities and can often be associated with the system's reliability.

Provide Sustainable System

To accomplish the objective "Maximize Reliability" a sustainable system must be required. Additionally, as the overall goal for HSI is to increase performance and decrease cost for entire life cycle of the system it is important to develop metrics that will predict how well a system will meet this goal. The sustainment phase of most programs is where the majority of the spending occurs. Reducing this expenditure is a key step in minimizing total life cycle cost.

Minimize Maintenance Burden

The amount of time necessary to perform an aircraft retrofit and maintenance actions has a direct effect on the availability and reliability of the system. A large maintenance burden is an indicator of a system that is more likely to fail during operations and therefore decrease the safety and operational effectiveness of the platform.

A/C Capability Integration

A unique attribute of modern helmet mounted displays are their ability to provide additional SA by moving displays to the pilots line of sight and enhancing target engagement by cueing weapons. Both of these capabilities are dependent on how the HMD interfaces with aircraft systems and what capabilities can be communicated through the processor. This is very dependent on the aircraft and how engineers design the avionics and weapon system management interfaces. Advancement and proliferation of processor technology has seen to it that almost all HMD systems have the ability to transfer any sort of data required by an aircraft. Therefore, while important to the fundamental goals of an HMD, the manner in which the HMD is integrated into the aircraft will not be an evaluation measure for this effort. It is assumed that any of the alternatives to be examined can meet the desired aircraft interface requirements determined by the program office.

Decomposition of these stakeholder objectives and goals led to an objectives relationship hierarchy (Figure 9) with tailored lists of system characteristics for the intended user-mission environment.

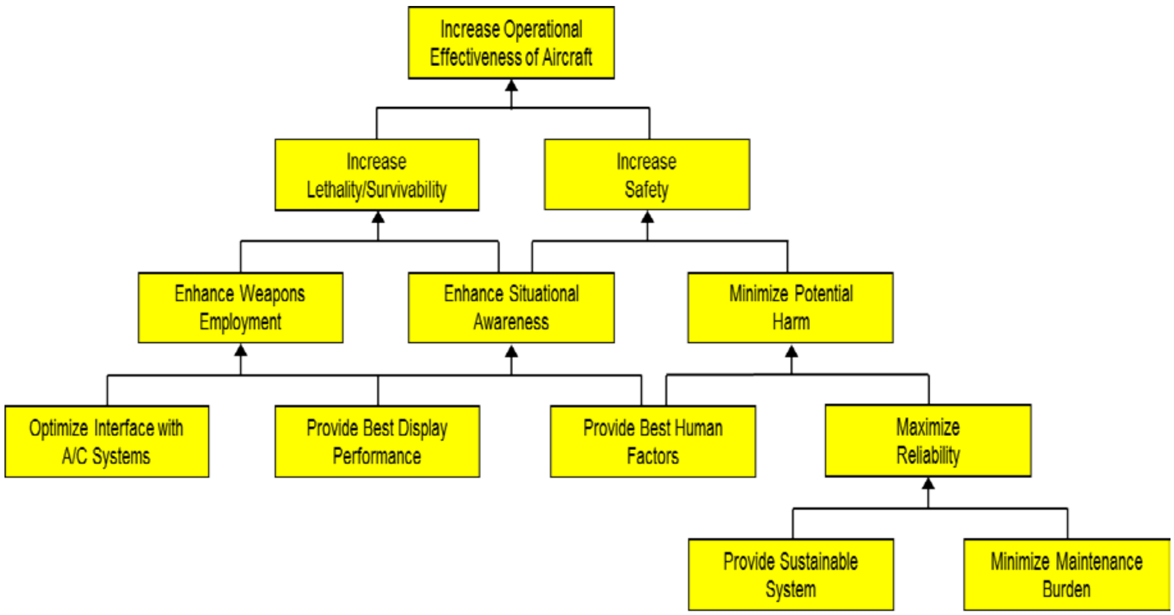

Figure 9 : Objectives Relationship Hierarchy

While this was a very important step to determine a pool of required HMD attributes, to be usable for a decision analysis process the hierarchy must be made of factors that are measurable, mutually exclusive, and collectively exhaustive. To meet the mutually exclusive constraint, the lower level objectives must not impact multiple high level objectives. In other words, a change in one value factor cannot affect a change on more than one upper level factor. While the current state of the hierarchy demonstrates a crossover of influence for multiple factors, to be used for a quantitative decision analysis, the bottom levels of each branch from the relationship hierarchy were congregated to create a value hierarchy that retains the user-centric methodology. A single overall measure, that will become the basis for alternative value comparison, was created to sum up the lower level values. It is labeled as the *HMD Value, Impact on Operational Effectiveness.* Figure 10 shows the final iteration that will be the basis for the remainder of the DA process.

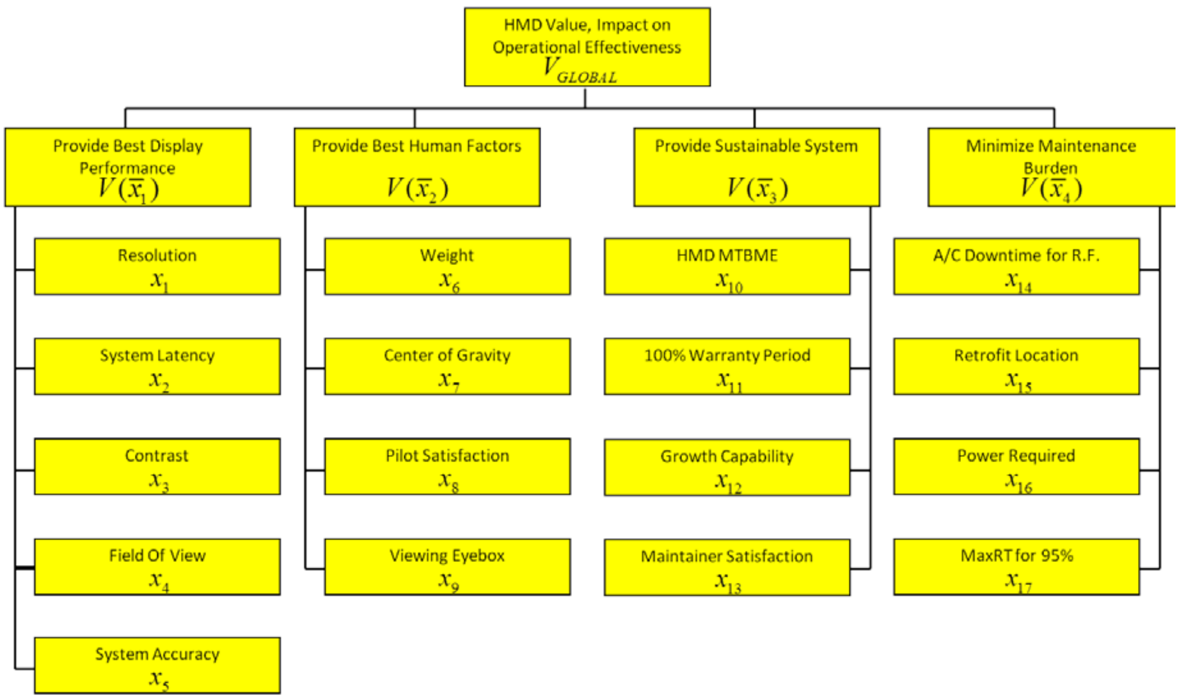

Figure 10 : Value Hierarchy

Step 3 and 4 : Develop Evaluation Measures and Create Value Functions

The lowest level of the value hierarchy shown above, in Step 2, are evaluation metrics determined to be appropriate for the framework. Deriving and down-selecting the measures was an iterative process that began with a large list; accumulated based on literature review, the author's personal experience with helmet mounted displays and fighter aircraft, and discussions with technical experts in the field. This initial collection is shown in its entirety in Appendix A. As is good practice for the decision analysis process, inputs from subject matter experts, the senior decision maker, and stakeholders themselves were used to remove those metrics that were not under HMD vendor control, would be fully defined in a requirements document, or were deemed not important to the specific decision space because of decision maker preference or technology capabilities.

Once the objectives and associated values have been elicited and refined, the metrics and value function curves must be developed. For this study, Steps 3 and 4 are presented together, describing each of the evaluation measures determined to be important to the decision space and developing their associated value function curves based upon examination of past research efforts and discussions with relevant HMD subject matter experts. Each value function shows the metric on the abscissa and the value of the measure on the ordinate axis, 0 (least value) to 1 (most value).

Display Performance

Resolution

As described in Chapter II, the resolution of the display is an indication for how clear the symbology or video will appear to the user. For the purposes of this research, a pixel density measure will be used to attain a value number for the resolution of an alternative. An increasing density (number of pixels per degree of Field of View) means the image will appear sharper. A sharper display is desired for operational use in order to delineate between symbology sets and avoid "jagged" lines and curves. Discussions with Air Force Research Lab HMD technical experts have shown the requirement for display resolution is very dependent on what is being displayed. Sensor or synthetic imagery require much higher contrast levels than for basic symbology, so as to allow the wearer to delineate details in the scene. However, the contrast of the sensor imagery is limited by the sensor itself as the HMD cannot show more detail than the sensor input is providing. Recognizing that a future application of this framework could include multiple curves for evaluation of imagery contrast as well as basic symbology, Figure 11 shows the value function of display resolution for symbology only. The developed curve indicates a rapidly increasing value as the pixel density increases to about 60 pixels per degree and then trailing off to show a lower rate of return as the resolution increases beyond 60.

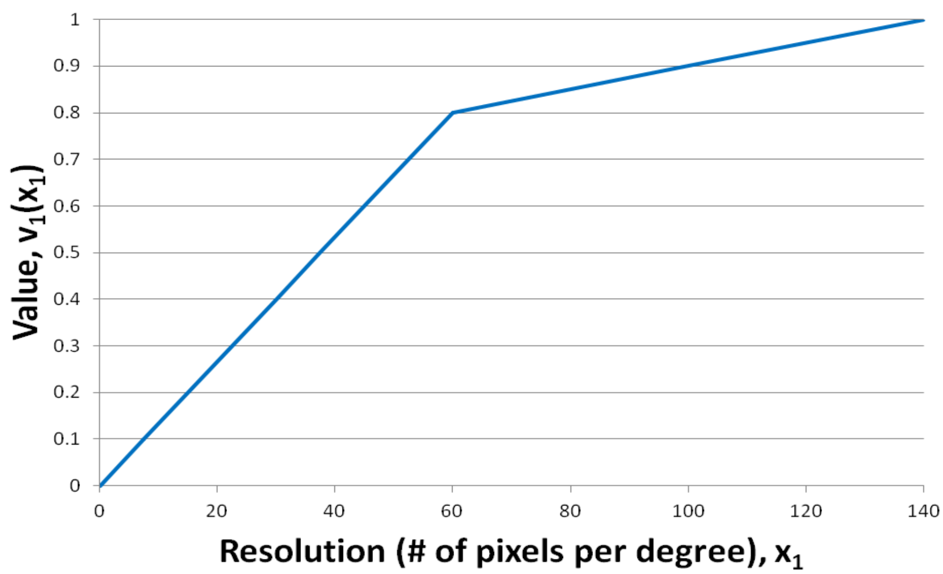

Figure 11 : *Display Resolution* Value Function

System Latency

This metric is a global way of describing many individual HMD component performances. The system latency, given as a time metric, is affected by the update rate of the tracker system, the speed of the processor, and the refresh rate of the image source.

One goal of HMD system design is to lower this time chain as much as possible, until there is no noticeable lag in symbology or video as the pilot moves their head. It is also important to note that the apparent latency of an HMD is also a function of the aircraft systems that drive the image or provide the data. The speed at which the sensor or avionics generates the information and transfers it to the HMD processor plays a role in the apparent latency to the pilot. However, this aircraft based aspect is considered to have an effect on all HMD alternatives equally and so is not taken into account for this framework. Discussions with Air Force Research Lab HMD technical experts revealed there could be multiple latency requirements for an HMD system, based upon its use and what is being displayed. A lag in sensor or synthetic imagery would be much more noticeable and detrimental to a pilot than basic symbology and therefore would have more stringent bounds and curves. To achieve simplicity in this initial framework proposal, the value function (Figure 12) has been formed based upon basic symbology display only, recognizing that a future application of the framework could include a curve for imagery. It shows the value of the alternative will decrease as the system's latency increases. The steepest part of the curve, located between 2 ms and 5 ms, indicates the greatest rate of value return for achieving a lower latency between these points.

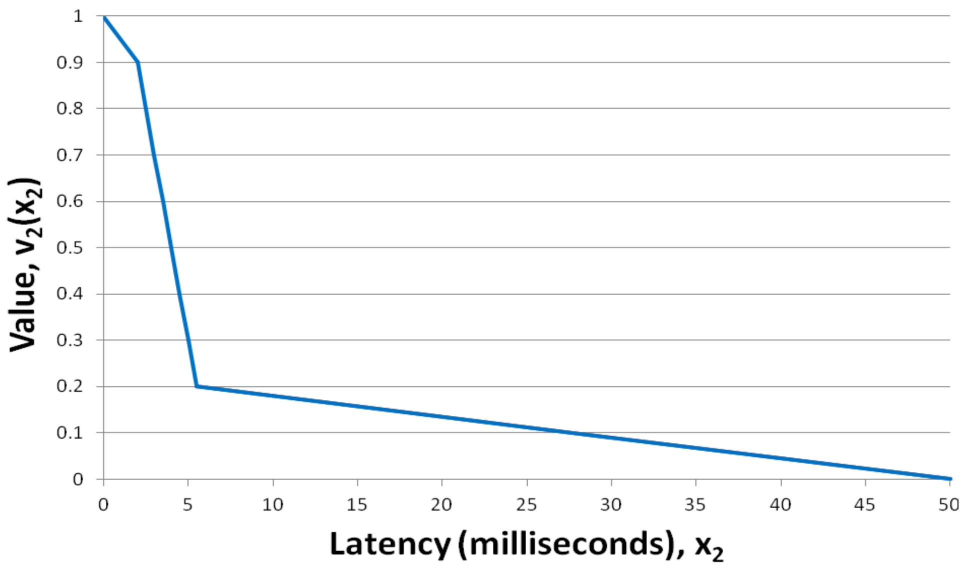

Figure 12 : *System Latency* Value Function

Contrast

The contrast of a visual medium is given by the ratio between the darkest part of the display and the lightest part. This characteristic is important to readability because a low contrast would make the symbology appear washed-out and difficult to delineate. For a see-through HMD it is desired to be able to view the display in all ambient lighting conditions, and of most concern would be the high brightness scenes such as looking into the sun or viewing snow covered ground on a sunny day. While display luminance can be increased in an attempt to increase contrast, i.e. making the bright part sufficiently brighter than the dark parts, the transmissivity of the combiner and helmet visor can also be decreased to decrease the apparent ambient brightness reaching the user's eye. However this decrease in visor transmissivity could have detrimental effects as the overall scene will appear darker. Research has shown that, to be readable, the contrast of an image or text should be at least 1.2 (Clarence E. Rash, 2000). Through discussions with Air Force Research Lab HMD technical experts, it was found that (similarly to latency) there could be multiple contrast value function curves. This is because the intended use of the display would have different contrast requirements. Night viewing contrast would be easier to achieve because of the darker ambient scene, therefore changing the metric bounds to a higher level. Also, sensor video or synthetic imagery would require a higher contrast for best usability than basic symbology information. The following value function (Figure 13) has been created to indicate the decision makers preferences towards a day, symbology only, environment; recognizing that the shape and bounds could change for other uses. The display contrast ratio for the system used for this value function is that which is measured against a 10,000 fL ambient scene, a brightness commonly used in performance specifications. The curve shows a lower bound at the minimum acceptable contrast of 1.2 and an increasing value as the ratio reaches about 10. It then has a gradually decreasing slope to indicate a decreasing rate of return for value.

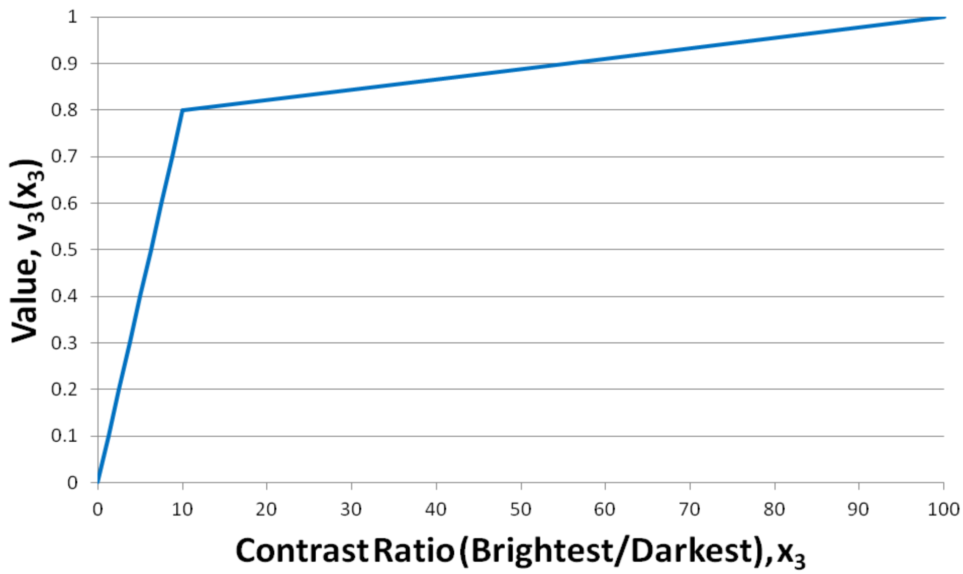

Figure 13 : *Display Contrast* Value Function

Field of View

Field of View (FOV), with respect to a HMD, describes how much of the viewer's instantaneous visual space can be overlaid with symbology or video. With square or rectangular type displays, this can be measured in a vertical by horizontal manner. However, there are some HMDs that incorporate a circular or oval projection medium, often measured in a single diameter dimension. Therefore, this exercise will use circular diameter measure as the value metric, which can be taken from a rectangular (or square) display by inscribing an oval (or circle) and measuring the largest diameter. As the measure (degrees) increases, the value also increases in a gradually decreasing rate of return manner. This shape is based upon reviewed literature, which finds a 20 degree FOV is sufficient for easy tasks, while 60 degrees may be required for more demanding tasks (M.J Wells, 1989). This trend can be seen in Figure 14.

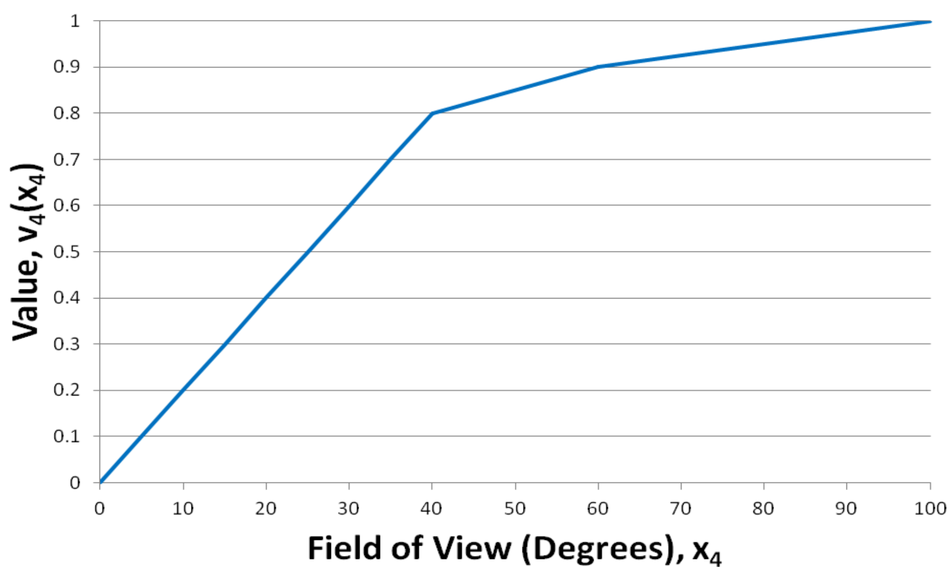

Figure 14 : ***Field of View*** **Value Function**

System Accuracy

The accuracy of the system is determined by the measurable deviation between the symbology and the real world object it is intended to overlay; therefore a larger displacement means a less accurate system. It is recognized that due to tracker and processor characteristics the accuracy of HMD systems may vary through the pilot's field of regard (F.O.R), generally decreasing as distance from aircraft boresight is increased. Performance requirements are typically written for different threshold and objectives at certain sections of the F.O.R. This study will use the measured accuracy for the forward facing section, about 45 degrees of either side of the aircraft boresight. Also, if displaying a sensor fed video picture, the accuracy of the image will be very dependent on the accuracy of the aircraft sensor that is driving the image. Therefore, in an effort to achieve simplicity in this initial analysis, the accuracy of symbology only will be evaluated and not video imagery. If evaluating video or synthetic imagery displayed, the value function curve may have a different shape. The value function curve in Figure 15 is based upon research (Richard L. Newman, 1997) and discussions with Air Force Research Lab HMD technical experts who have described a decreasing value as the accuracy displacement increases to about 5 milliradians. The curve then levels out towards 0 value to indicate little to no value of the system, if less accurate than 5 milliradians.

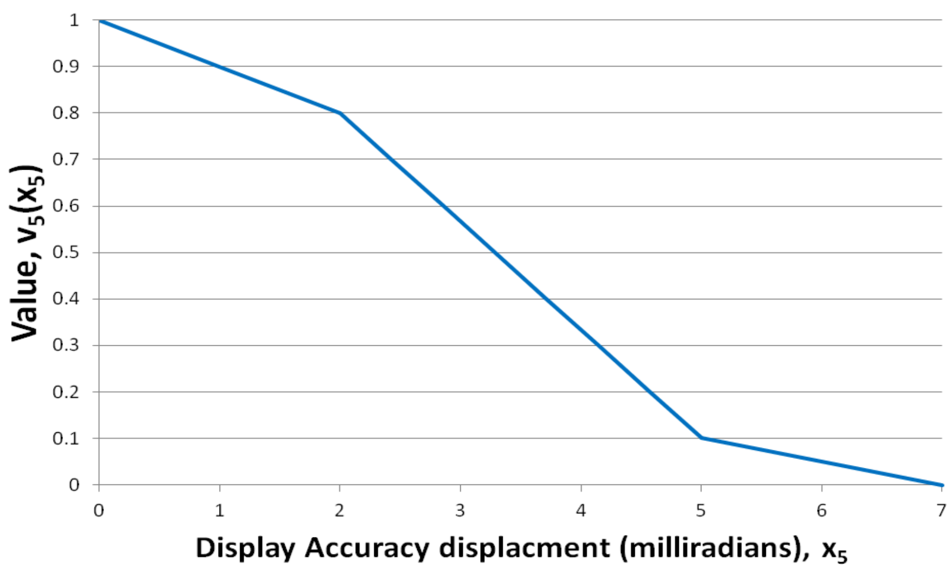

Figure 15 : *System Accuracy* Value Function

<u>Human Factors</u>

Weight and Center of Gravity

In 1991, the Air Force Research Lab conducted a study to determine head and neck criteria with respect to weight and center of gravity limitations for ejection seat aircraft. The report entitled “Interim Head/Neck Criterion” (F.S Knox, 1991), plotted the recommended boundaries based upon the entire head borne weight (helmet + mask), measured on a Large ADAM manikin head. A total weight limit of 5.0 lbs was established to insure survival during an ejection event and limit pilot fatigue and performance detriments. Center of Gravity limits were given in reference to the X, Y, and Z axes as illustrated in Figure 16. These boundaries were -0.8 to 0.5 inches (x-axis), ±0.15 inches (y-axis), and 0.5 to 1.5 inches (z-axis). The space enclosed within these coordinal limitations is known as the "Knox Box".

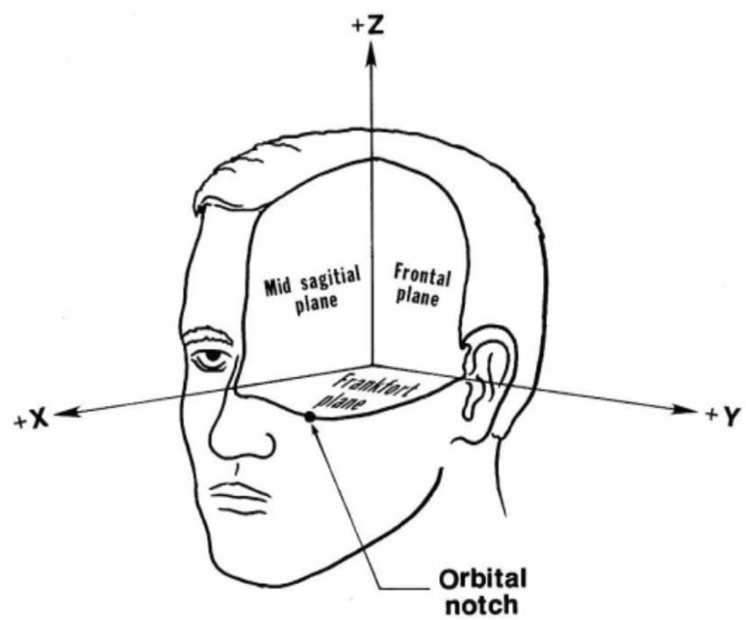

Figure 16 : Center of Gravity Axes for the Head

Figure 17 and 18 are the Total Weight and C.G deviation value functions based upon the "Knox Box" boundaries. The weight value function shows an increase in value as the weight is decreased from the "Knox Box" requirement of 5 lbs, gradually decreasing in rate of value return as the weight is decreased.

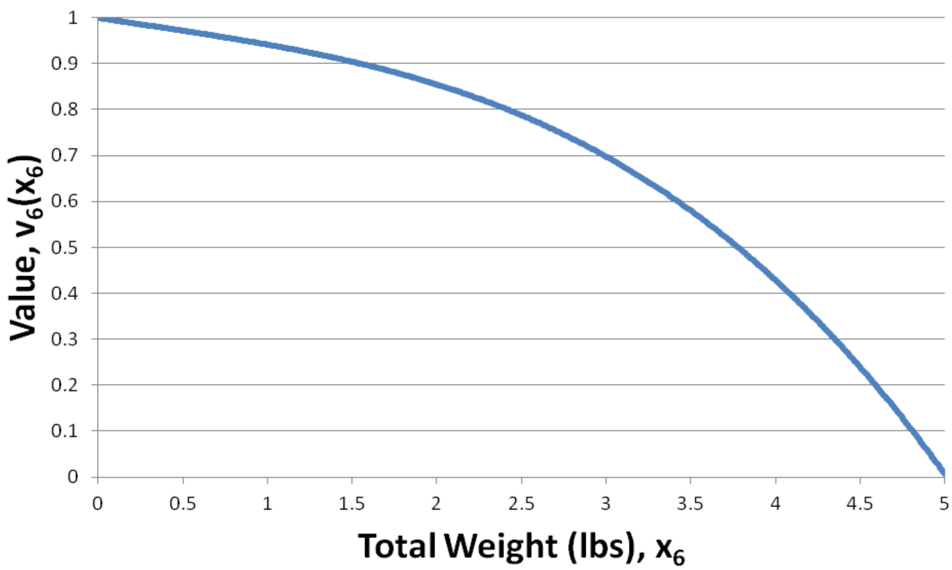

Figure 17 : ***Headborne Weight*** **Value Function**

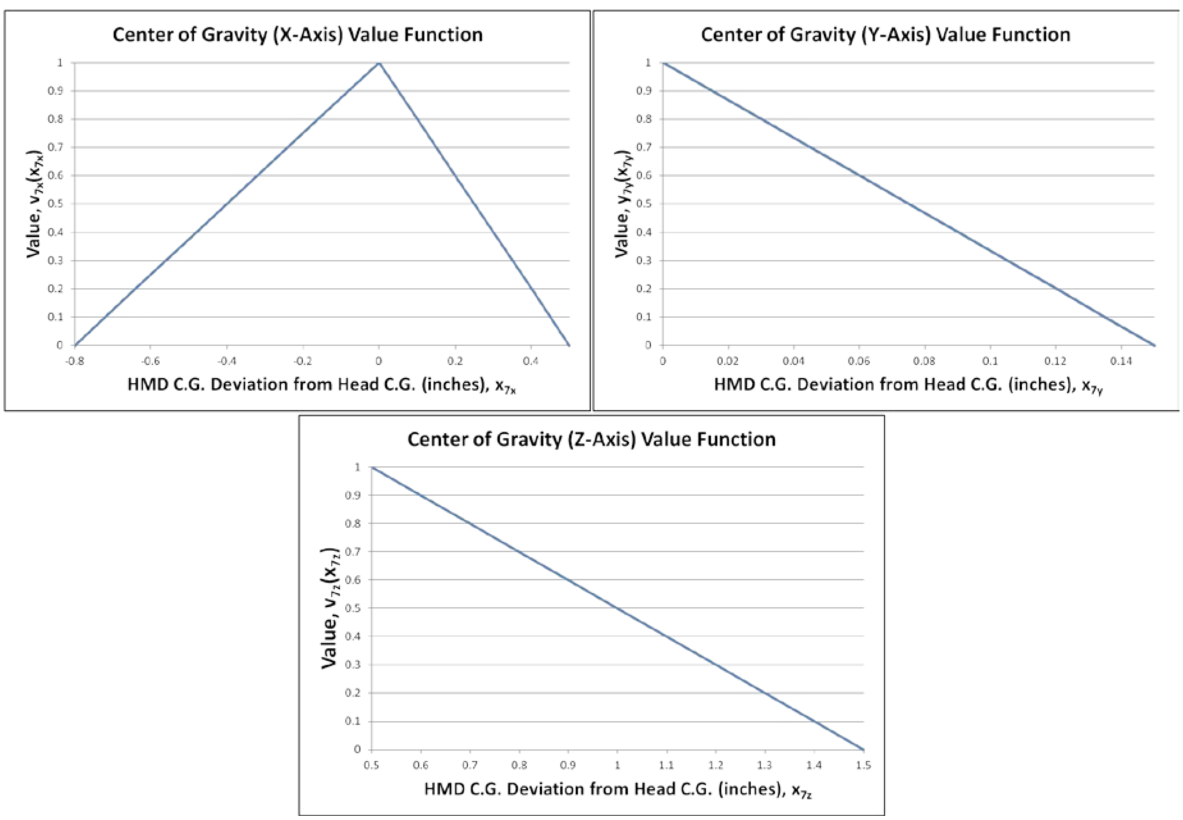

Figure 18 : ***Center of Gravity*** **Value Function**

The center of gravity value functions are broken out into the 3 axes to align with the "Knox Box" requirements. Each of the curves indicates the highest value is gained when the center of gravity deviation is zero, or the same as the C.G. of the head. The x-axis curve reflects the different measure requirements of the "Knox Box, aft to forward of head C.G., with the more value being gained the closer the HMD C.G. is moved toward that point. In order to calculate a single value measure for the center of gravity metric, the additive method will be applied using equal weights for each axis value function.

Pilot Satisfaction (Usability)

As expressed in Chapter II, user satisfaction with the system is an extremely important metric for a successful program. An interface that is not user friendly or impairs any critical tasks is not acceptable. Yet, this is one of the most difficult characteristics to grade in a quantitative, repeatable manner as it is very subject to user bias and personality. Utilized commonly in the human factors engineering community, pilot feedback questionnaires will be the basis for scoring this metric. Questions will be posed to elicit approval scores on important aspects of the interface such as; Ability to don/doff the system, interactions with canopy and other obstructions, effect on external field of view, fit and comfort, etc. Example questionnaire can be found in Appendix B. The scores for each question are added together to create a single Pilot Satisfaction score, maximum of 100. This score is used to create the value function seen in Figure 19.

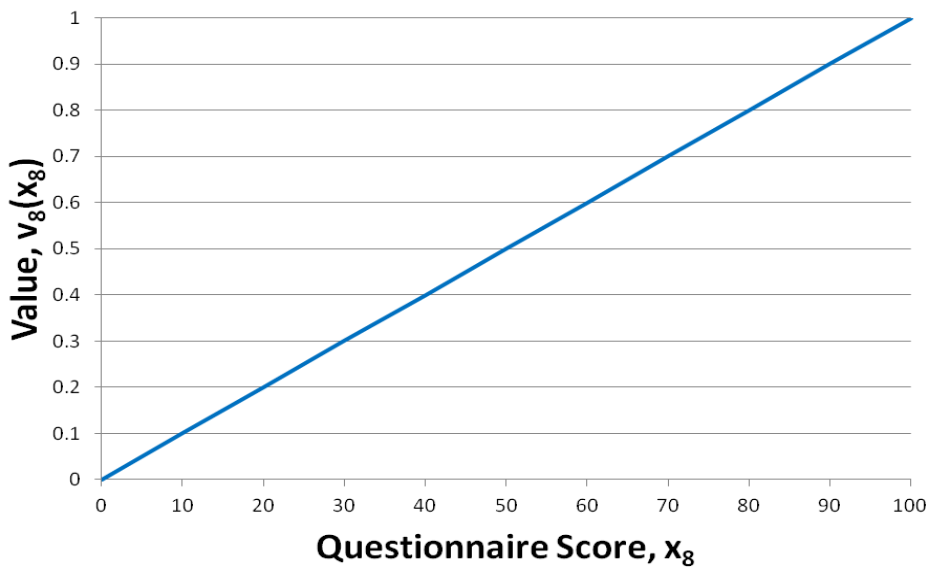

Figure 19 : *Pilot Satisfaction* Value Function

Viewing Eyebox (Exit Pupil)

An optic's Viewing Eyebox is the area in which the eye can be placed and still see the image. Depicted in Figure 20 , the user could lose some or the entire image if the HMD shifts to the point that the eye is no longer within the viewing eyebox. There are two optical design approaches common in HMDs, pupil-forming and non-pupil-forming. While not necessary to get into the details of each design, it is important to note that in pupil-forming optics, the viewing eyebox is also known as the exit pupil and there will be no image available directly outside the exit pupil. And in a non-pupil-forming design vignetting or clipping of symbology will be seen as the viewer moves outside the eyebox.

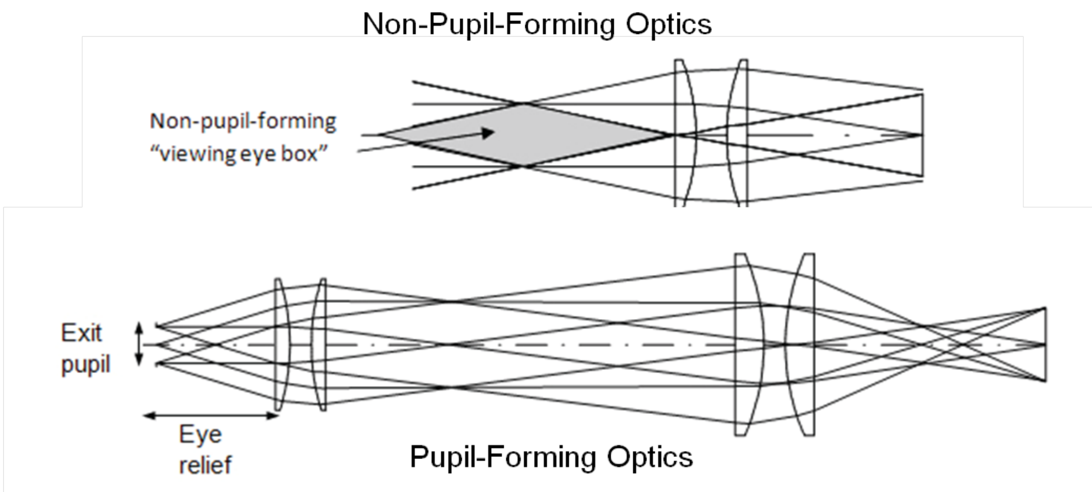

Figure 20 : HMD Optic Designs

No matter the optic choice of the developer, it is important to have a sufficiently large viewing eyebox so as to insure the display is still useable within an expected amount of helmet shift. Research has shown a minimum of 12 mm is acceptable, though the operationally successful IHADSS HMD has just a 10 mm exit pupil (Clarence E. Rash, 2000). For this effort a minimum boundary of 10 mm was used and the shape of the curve was created based upon discussions with AFRL technical experts to show a rapidly increasing value as the eye box size is increased to about 20 mm, followed by a gradually decreasing slope to indicate a decreasing rate of value return. The function is shown in Figure 21.

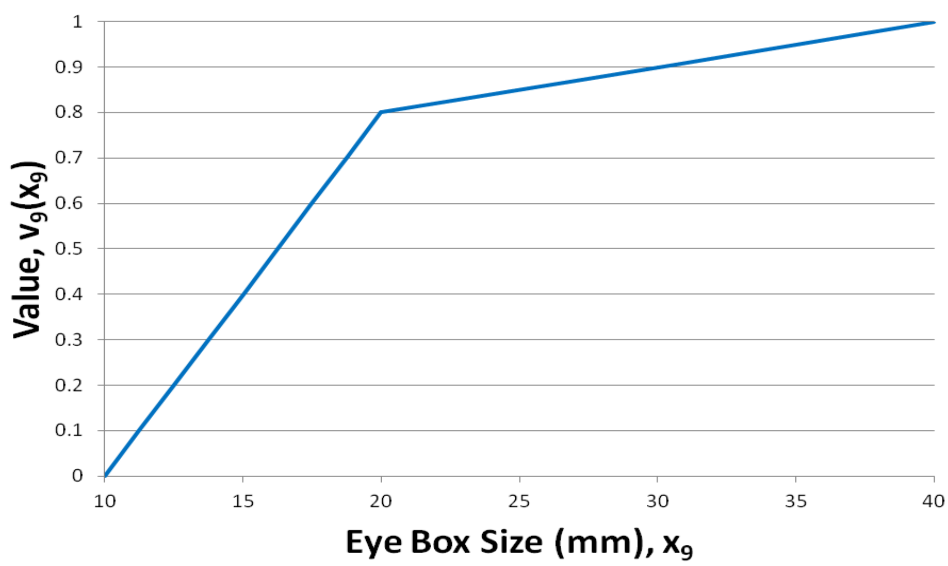

Figure 21 : *Viewing Eyebox* Value Function

<u>Provide Sustainable System</u>

HMD Mean Time Between Maintenance Event (MTBME)

One metric for the HMD maintainability and thus sustainability is the time between the scheduled and unscheduled maintenance events that require repair of the equipment on or off the aircraft. These events consist of preventative or corrective maintenance actions required to retain or restore system hardware in a functional state. This mean time between maintenance events (MTBE) should be maximized to ensure continued availability of the system. The bounds of this measure are very dependent on the aircraft platform and the decision maker's preferences. Elicitation of the example senior decision maker's preferences has determined a lower and upper bound of 800 and 1200 hours respectively, with a linear (unchanging rate of return) between the bounds. Figure 22, shows a value function curve for MTBME derived from the example SDM.

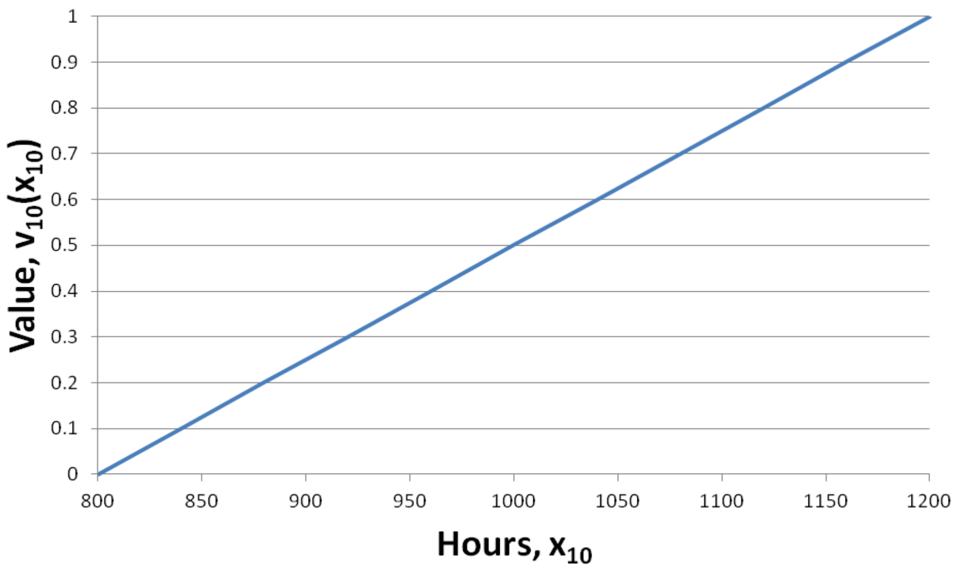

Figure 22 : *MTBME* Value Function

100% Warranty Period

Another indicator of the expected sustainability of the system is the amount of full coverage warranty the seller agrees to apply. As the contractor's primary goal is to make money, they're warranty period should be directly related to how long they expect the system to function well. A longer warranty offer could indicate less likelihood for maintenance action during that time period, and therefore better sustainability. This increasing linear trend for number of warranty years and value is shown in Figure 23.

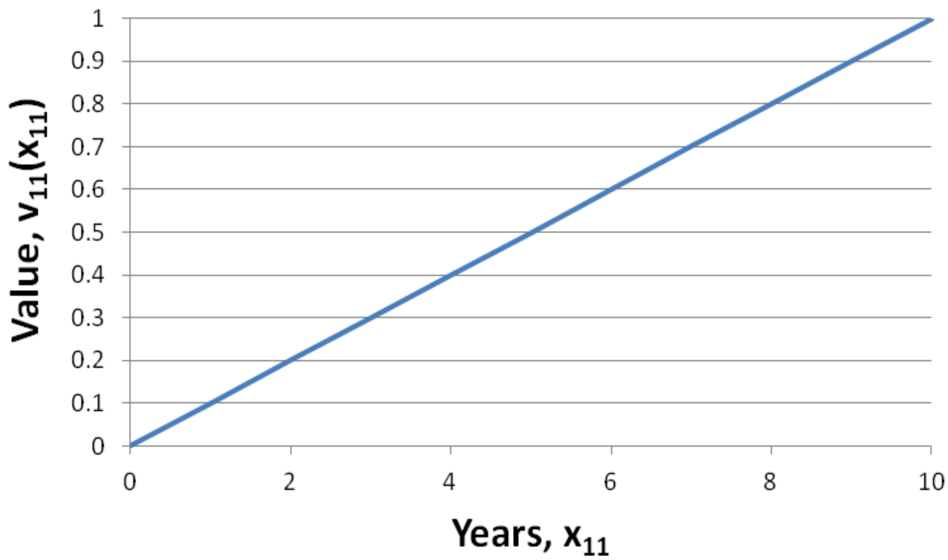

Figure 23 : *Warranty Period* Value Function

Growth Capability

As aircraft platforms are modernized and upgraded, software mods will require extra amounts of memory and processing capacity. This is an expected and understood requirement and an alternative's capability to account for this should bring extra value. It was found that the important metrics for determine ability to accommodate system growth were CPU process utilization, memory capacity, and disk space/storage. To synthesize a single value measure from these three metrics, a similar technique as the center of gravity metrics was used. Each of the respective growth metrics were given their individual value functions and then a direct weight (equal weights), additive method was used to calculate a Growth Capability value. The curves are based upon the percent of the total metric that is unused in the delivered system, i.e. the amount available for future upgrades. Intuitively, the higher available percentage, the more value is gained. Figures 24 shows the three value function curves for the individual metrics.

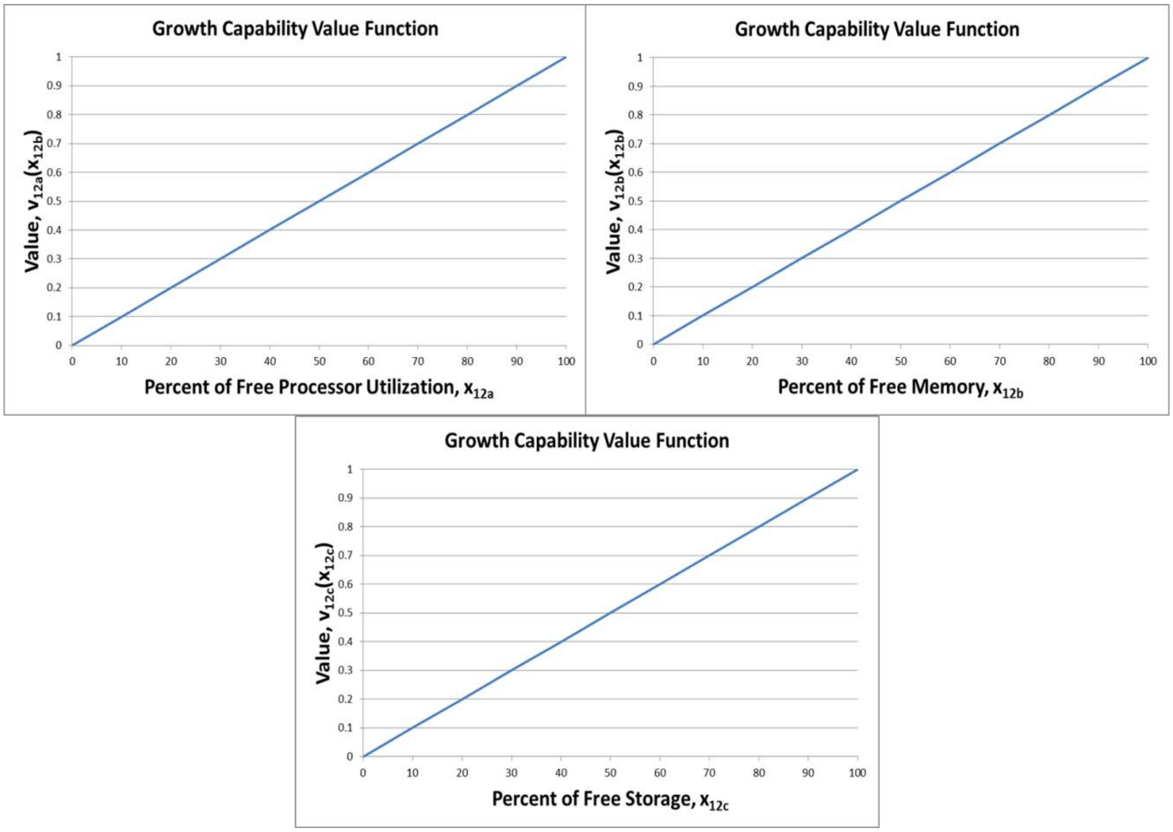

Figure 24 : *Growth Capability* Value Function

Maintainer Satisfaction

This metric is very similar to the Pilot Satisfaction score described earlier in this section, with the exception of being taken from the maintainer's point of view. The questionnaire was focused on the maintainer's ability to dismantle the necessary components, ease of daily maintenance tasks, preflight checks of the system, etc. (questionnaire can be found in Appendix B). These same scoring method and additive weighting functions were used to create the Maintainer Satisfaction score. Again, this score is plotted against value to create the value function found in Figure 25.

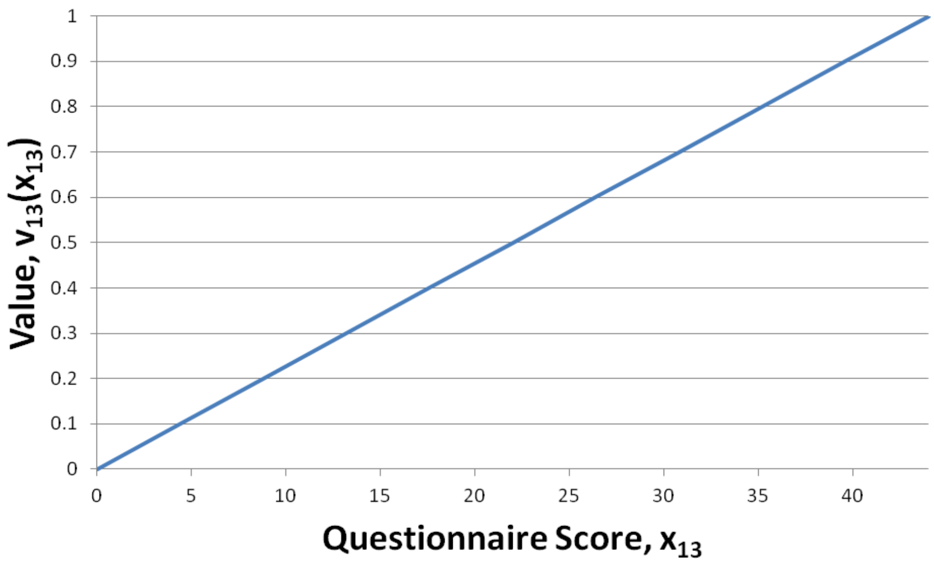

Figure 25 : *Maintainer Satisfaction* Value Function

<u>Minimize Maintenance Burden</u>

A/C Downtime for Retrofit

The amount of time the aircraft is unavailable during the hardware retrofit process is a metric that can be used to determine system complexity and maintenance burden. It is reasonable to associate a lower retrofit downtime with a less complex system. The boundaries of what is acceptable would be determined by the senior decision maker for the platform under consideration. In Figure 26, the value function for retrofit downtime is shown with boundaries (10-40 hours) suggested from the example decision maker.

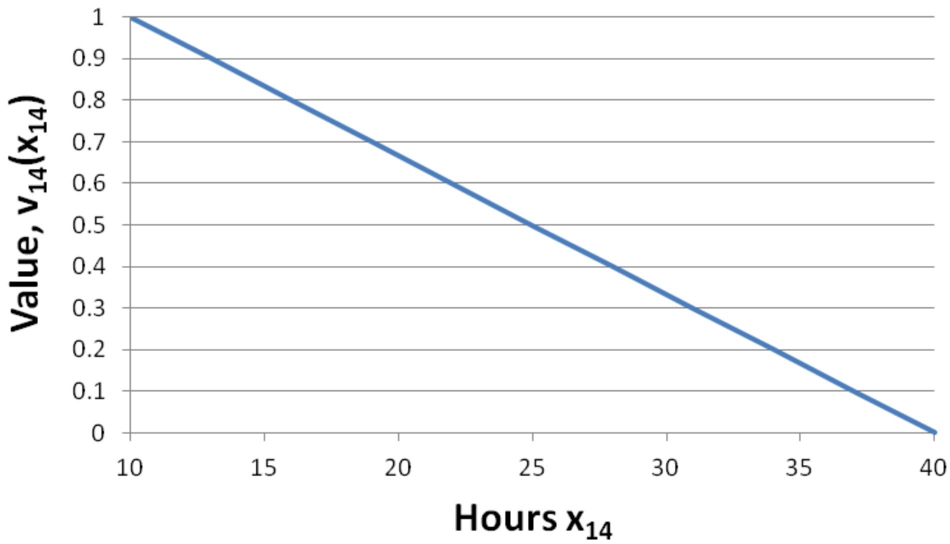

Figure 26 : *Retrofit Downtime* Value Function

Retrofit Location

The location at which the retrofit must be performed indicates the level of complexity of the process and therefore can have an effect on the future reliability. The simplest retrofits can be performed in the field, i.e. at operational bases, by DoD employees. For more involved modifications, the effort would have to be accomplished at a Depot location with more availability of expertise and tooling. If the contractor determines that the modification is very complicated or doesn't want to accept the risk of someone else performing the retrofit, it can often be done by their own personnel, sometime at their own location. As system complexity is an aspect that the decision maker would be interested in minimizing for the purposes of maximizing reliability, a decreasing categorical value function can be used since there is no intermediate gradation between location types (Figure 27).

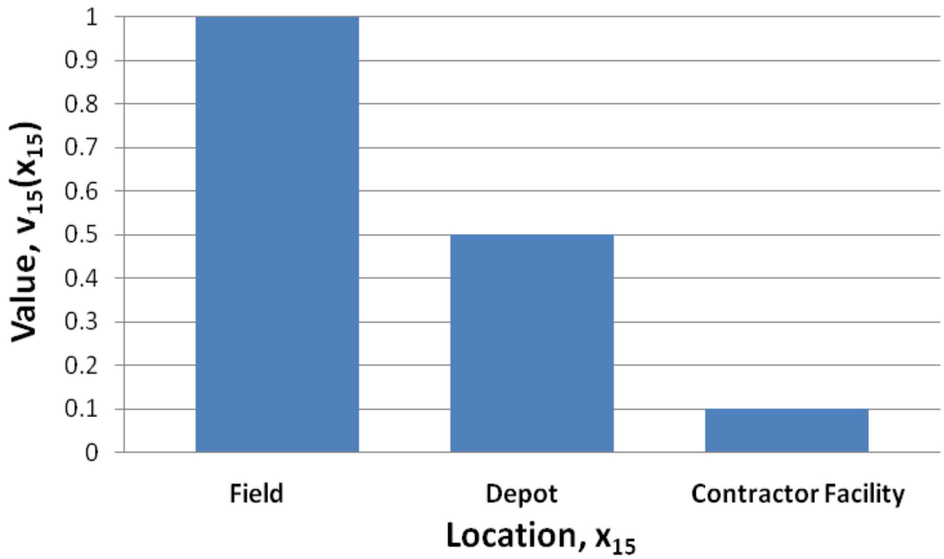

Figure 27 : *Retrofit Location* Value Function

Power Required

This is an evaluation metric whose boundaries and importance are very dependent on the application and specific customer platform. Aircraft must share power supply with many systems at once and thus allowance to new systems is carefully controlled so as not to cause detriment to other more critical components. Generally the maximum allowable power consumption is a requirement levied on all alternatives. This value function (Figure 28) shows a decreasing value as the percentage of that maximum is increase. In other words, if an alternative only requires 25% of the allowable requirement it will gain more valuable compared to another that needs 75% of the maximum.

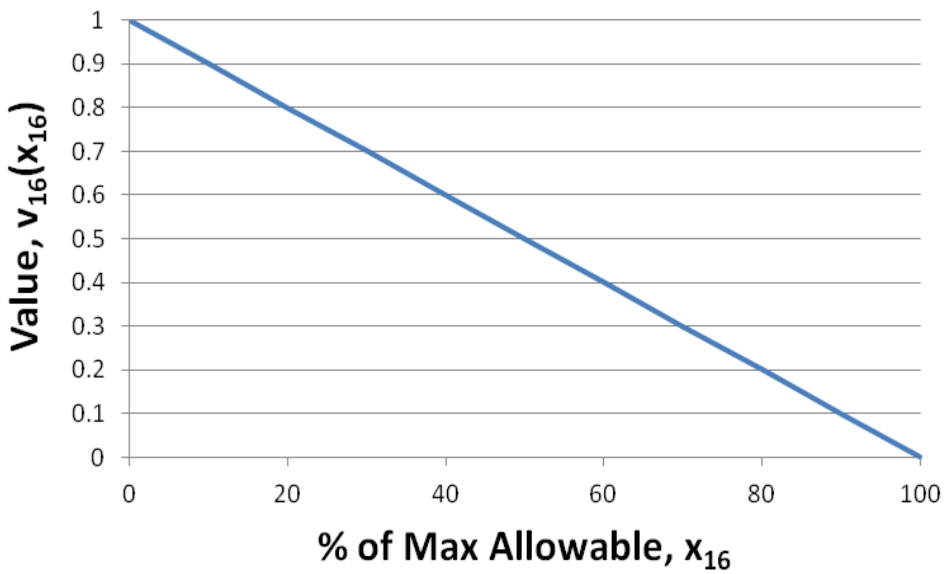

Figure 28 : *Power Required* Value Function

Maximum Repair RT (MaxRT) for 95% of Off-Equipment Repairs

Off-equipment maintenance is considered to be those actions that require removal of HMD components from the aircraft to be fixed in the maintenance shop. If parts of the system are removed from the platform, then the particular aircraft has lost functionality of the HMD. Typically spare parts can be used to immediately restore operation, but then the spare pool is also being impacted. The amount of time expected to return those parts to full working order is an indication of the maintenance burden for the total system. This evaluation measure is the amount of time 95% percent of all off-equipment repairs can be completed. Decreasing this amount of time adds value to the system, as indicated in Figure 29.

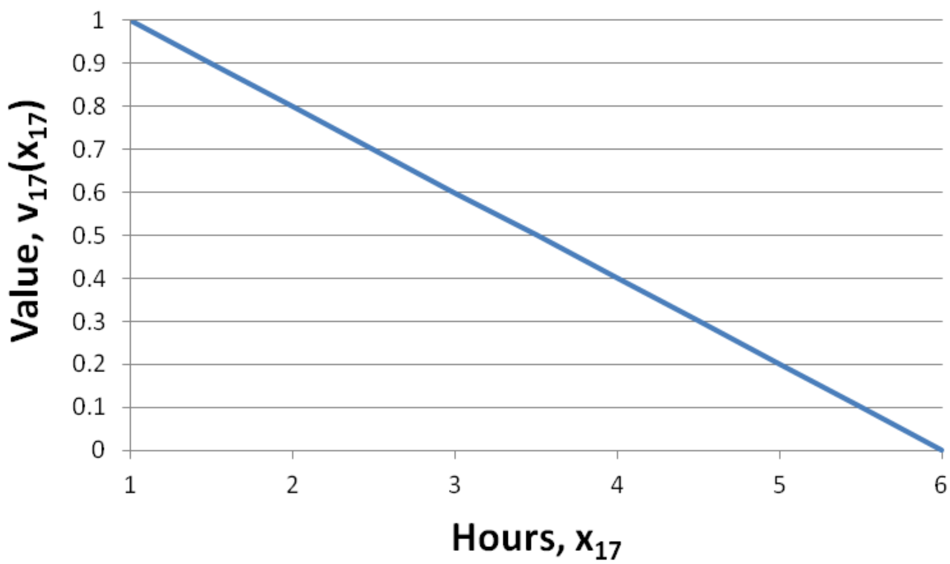

Figure 29 : *MaxRT for 95%* Value Function

Step 5 : Weight the Objectives Hierarchy

While the value hierarchy offers a thorough understanding of the important evaluation measures to the decision space, it must be recognized that not all the measures are of equal importance to the decision. Therefore a weighting schema must be employed to account for the decision maker's preferences between the factors. A bottom up approach was used, in that the local weights of the lowest level objective values were found using the direct weighting method and repeated for each higher level of the hierarchy. An example of the elicitation process is shown in Figure 30 for one of the lowest branches of the value hierarchy, where X represents the metric with the lowest amount of weight indicated by the decision maker and the multipliers represent the DM's answer to the question "By what multiplying factor do you believe this one is more important than the lowest?". For example, "Pilot Satisfaction is five times more important than the Weight".

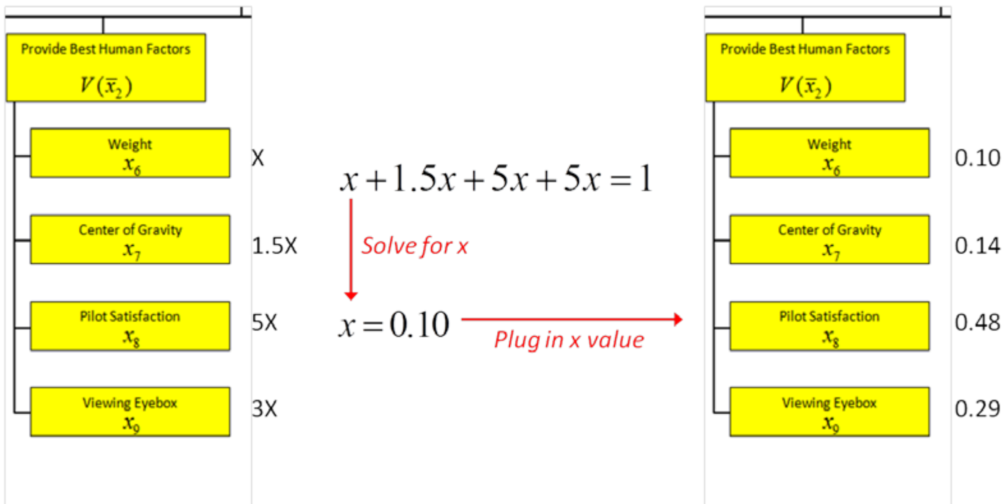

Figure 30 : Example of Weight Elicitation Process

The following Table shows the local weighting results of the example senior decision maker preference elicitation process.

Table 4 : Calculated Local Weights

Display Performance	**0.33**
Resolution	0.22
System Latency	0.22
Contrast	0.22
Field Of View	0.11
System Accuracy	0.22

Sustainable System	**0.17**
HMD MTBME	0.33
Warranty Period	0.17
Growth Capability	0.08
Maintainer Satisfaction	0.42

Human Factors	**0.42**
Weight	0.10
Center of Gravity	0.14
Pilot Satisfaction	0.48
Viewing Eyebox	0.29

Maintenance Burden	**0.08**
A/C Downtime for RF	0.13
RF Location	0.13
Power Required	0.25
MaxRT for 95%	0.5

Figure 31 below, illustrates the value hierarchy with the associated calculated global weights, or impact on total HMD value.

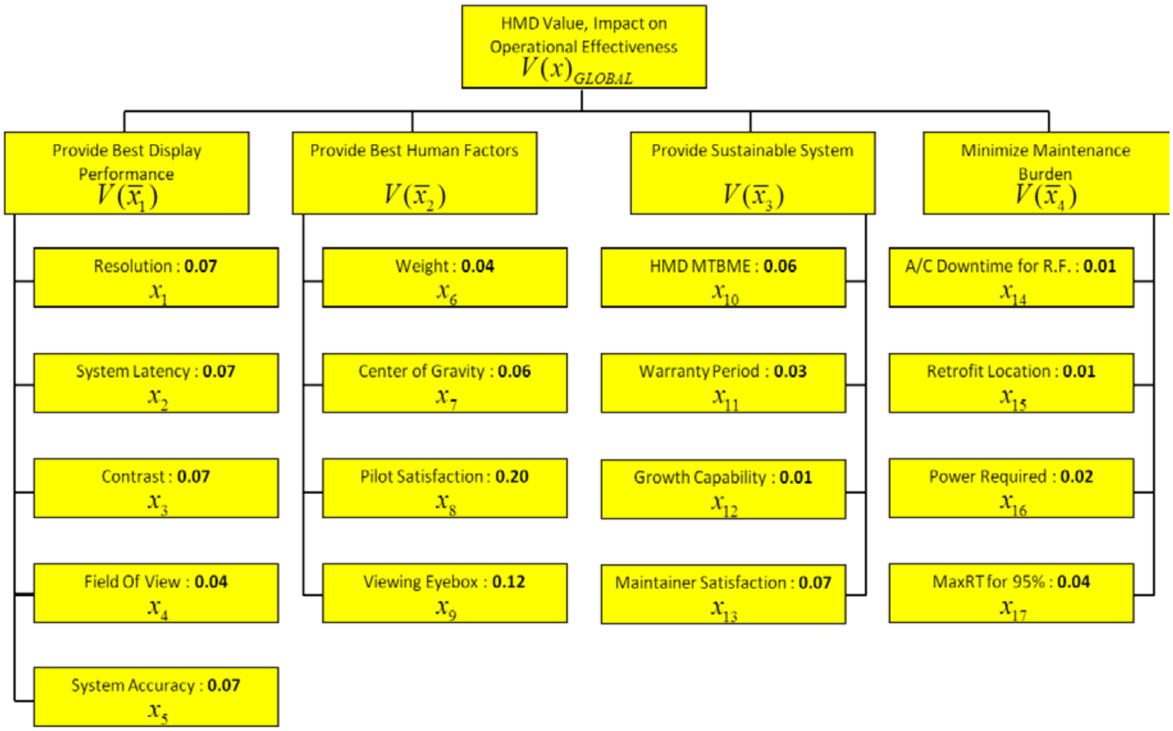

Figure 31 : Value Hierarchy with Global Weights (rounded to the hundredth)

Step 6 : Alternative Generation

This is the step where the alternatives and technical details are collected. The two alternatives to be evaluated in this framework are the Scorpion Helmet Mounted Cueing System and the Joint Helmet Mounted Cueing System (JHMCS). These alternatives were chosen because they have been fielded and used on U.S. Air Force fighter aircraft for years and should have readily available technical information. Ideally, alternatives would include those solution that may still be in development or test along with legacy hardware.

Scorpion Helmet Mounted Cueing System

Figure 32 : Alternative 1-Scorpion (Thales Visionix Technical Overview)

The Scorpion Helmet Mounted Cueing System, depicted above in Figure 32, was developed by Gentex Visionix, a division of Gentex Corporation that is now a subsidiary of Thales Group. Designed in the mid 2000s, this HMD features LCD waveguide technology to present full color symbology or video imagery on a monocular display module positioned in front of the pilot's eye. This display position is adjustable to accommodate differing pilot sizes and additional head worn protection devices such as laser eye protection spectacles, which can be worn between the monocle and pilot's eyes. Originally, the Scorpion system incorporated a magnetic type tracker system only, but has expanded to include a hybrid-inertial tracker option. The Hybrid Optical based Inertial Tracker (HObIT) technology uses an inertial sensor to determine head orientation and is recalibrated by the integrated optical sensor. The HObIT system employs fiducial stickers mounted to the aircraft canopy in a constellation pattern above the pilot's head.

These stickers each have bar code designs printed on them, and relay unique light patterns back to the optical sensor on the helmet, creating a triangulation type calibration. Scorpion has a nighttime color cueing capability, as the banana bar that supports the display and tracker components also incorporates the same NVG mount currently in use. Legacy goggles can be attached and are deployed immediately forward of the monocle, so the pilot would look through the display then the NVGs.

Joint Helmet Mounted Cueing System (JHMCS)

Figure 33 : Alternative 2 - JHMCS

The Joint Helmet Mounted Cueing System (JHMCS), pictured above in Figure 33, is a HMD system produced by Vision Systems International (VSI) as part of a joint development and acquisition program between the U.S. Air Force and Navy. The system incorporates a magnetic type tracker and aircraft mounted processor unit. The CRT image source projects monochrome symbology, synthetic, or sensor pod imagery directly onto the pilot's visor and provides a 20 degree circular F.O.V. Night vision cueing capability is offered with night module options such as, the Night Visions Cueing Display (NVCD) which consists of a set of modified legacy night vision goggles that attaches a small display generator on the end of the NVG tube.

Step 7 : Alternative Scoring

To score each alternative, system specifications were examined and questions were inquired of the respective manufacturers to gain the necessary information. In a real world application of this model, it would be ideal to have the Pilot Satisfaction score come from an operator who has used all the HMD alternatives on the platform under consideration. This would assure answers on the questionnaire were tailored to the aircraft-mission combination. However, as this research was an academic effort and not an actual alternative examination, it was not possible to gain these scores from a single pilot on all the alternatives. Therefore, pilots familiar with the alternatives themselves were sought out and their questionnaire scores were used. This will be a subject of note during the Conclusions and Recommendations section of the research. The metrics were input to an Excel based tool, which then calculated the value scores and performed the additive weighting function.

Summary

This chapter has provided a detailed review of the first seven steps of the Value-Focused Thinking methodology, applied to the '*lack of HMD'* problem space. After defining the problem and determining what objectives would bring value to the solution, evaluation measures and associated value functions were developed. Continuing down the left side of the VFT process "V", preference weights were elicited from the decision maker using the direct weighting method. The alternative generation step produced three possible solutions to examine and grade in the alternative scoring process. The Deterministic Analysis and Sensitivity Analysis steps will be presented in Chapter 4.

IV. Analysis and Results

Chapter Overview

Chapter IV works up the right side of the VFT process "V" to analyze the results of the model inputs. A deterministic analysis will be performed to determine the suggested solution for the decision maker. This will be followed by a sensitivity analysis that will help verify the result of the deterministic analysis and will provide more insight to the decision maker about alternative dominance when subjected to changes in model parameters.

Step 8 : Deterministic Analysis

To calculate a global value score, '*HMD Value, Impact on O.E*', the metrics, value curves, and weights derived in the previous steps were populated into a spreadsheet, shown below in Figure 34.

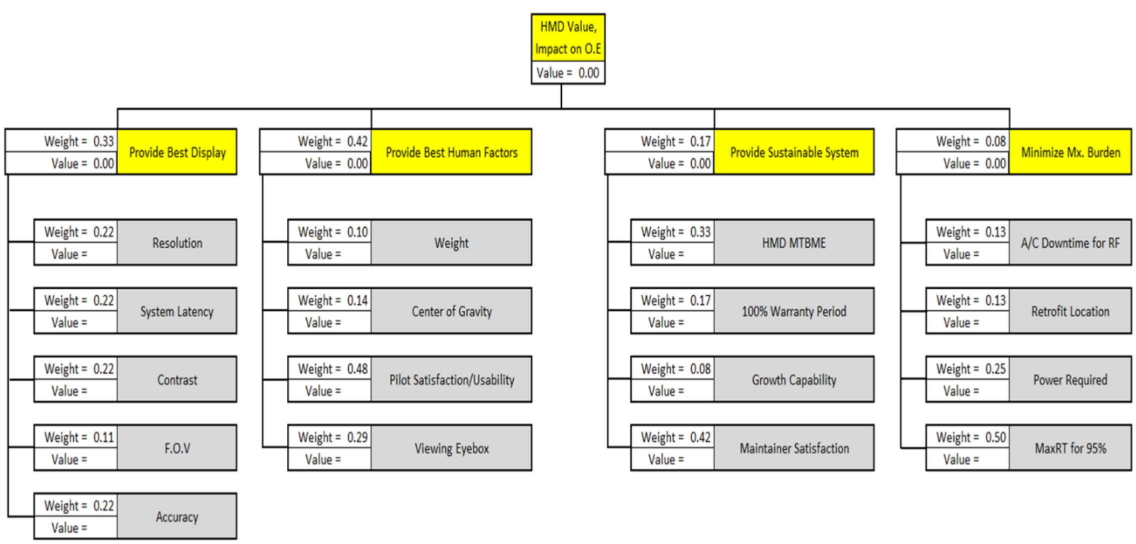

Figure 34 : Hierarchy used to determine HMD value

Using the direct weighting and additive methods, a value score for each alternative was output generated, shown in Table 5.

Table 5 : Weighted Value Scores

	HMD Value, Impact on Operational Effectiveness
Maximum Value	**1.000**
Alternative 1	**0.481**
Alternative 2	**0.436**

A graphical depiction of the global contribution each evaluation metric made to the total score is shown in Figure 35. The percentage value next to the metrics labels indicates the global weight of each evaluation measure. It can be seen that the resultant scores indicate Alternative 1 holds the most value for this decision situation. While Alternative 1 shows lower resolution, the better latency and center of gravity, make it the more valued alternative.

However, Alternative 2 sees only a 9.3% difference from Alternative 1. This can be attributed to the equalization required, due to lack of complete operational test data. For any missing data, because of releasability or access to information, the figures values came from the published HMD specifications. Not only did this technique result in similar values for each alternative, but for a few metrics, the specification value was the lower bound of the value function. It is expected, when populated with a full suite of actual test data, the framework would produce a resultant set of scores that would have more delineation between alternatives.

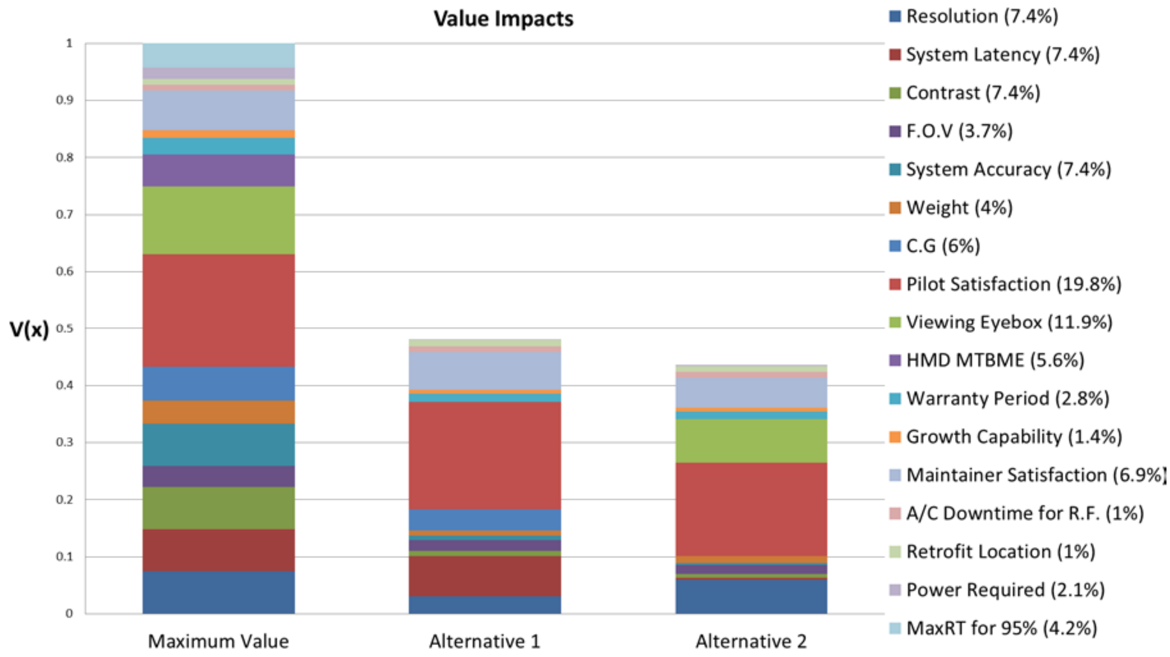

Figure 35: Contributions of Evaluation Metrics

Figure 36, shows another illustration of the contributing factors that account for the score differential between the two alternatives. This waterfall diagram contains the total value for each alternative, the green bars, and the evaluation measure deltas that created the total differential, in the blue and red bars. All other measures were of equal value. In this format it can be seen that Alternative 1 outscored or was equal in value for all measure except the three colored in red (resolution, weight, and viewing eyebox). These three scores accounted for 23.3% of the global weight, which means Alternative 1 holds as much or more value for over three quarters of all the evaluation measures.

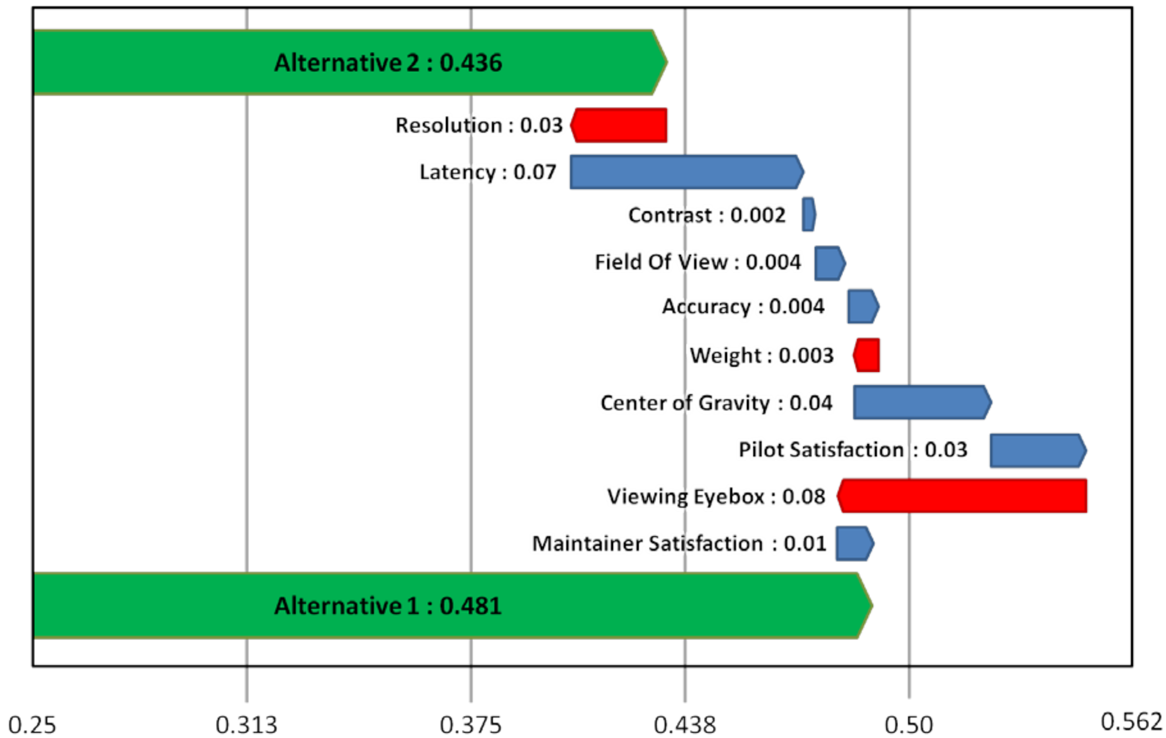

Figure 36 : Waterfall Diagram

Step 9 : Sensitivity Analysis

A sensitivity analysis is used to examine the global impact of changes to model inputs. For this study, a rank order sensitivity analysis was applied, which explored the possibility of a reverse in alternative's rank based upon a modification to the weighting schema. In Figure 37, the abscissa represents the preference weight of the *Provide Best Human Factors* objective, varying from 0 to 1 and proportionately adjusting the remaining three objective weights on the same level. The ordinate is the global value of the alternatives, which are represented as the red and blue trend lines. The green vertical line indicates the decision maker's original preference for this objective (0.42) and the intersection points correspond with the initial values found previously in Step 8.

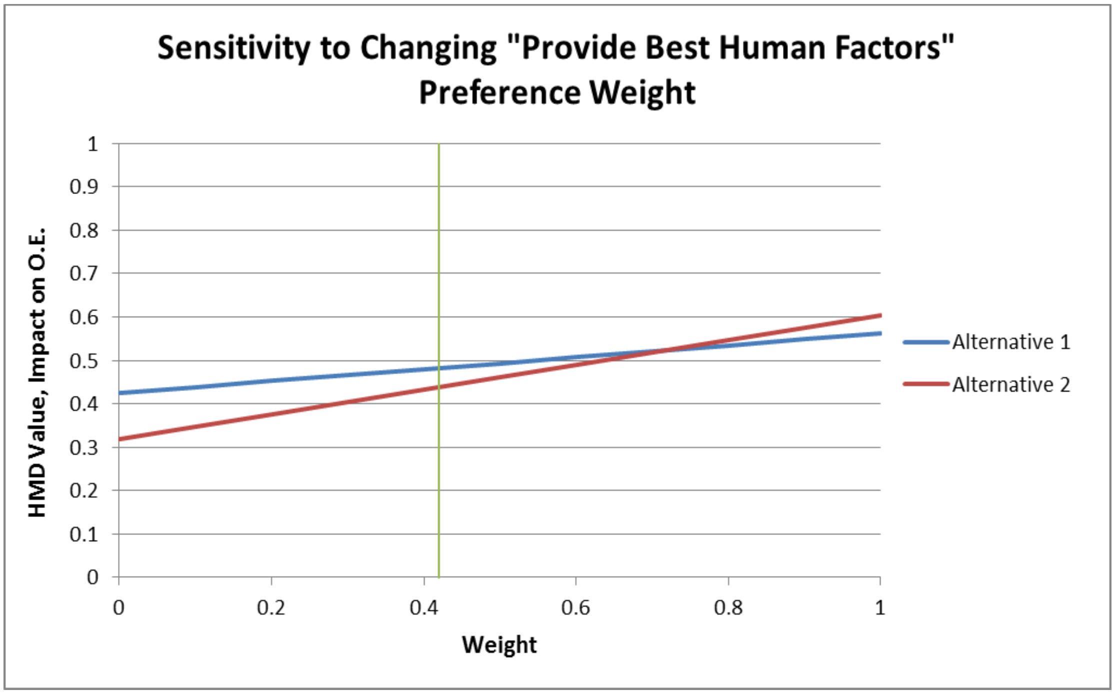

Figure 37 : Sensitivity Graph

Upon examination of the plot, it can be seen that Alternative 1 maintains a higher value until the weight is varied to equal 0.72, at which point Alternative 2 becomes the choice that brings the decision space the most value. In other words, if the decision maker were to reweight this objective higher than 0.72, the dominant alternative would change. However, this is a significant 71.4% change to the original assessed weight. The sensitivity to changes in the other three value hierarchy objective weights had even less of an effect on rank order, requiring a larger change from the original preference weights. Display Performance requires decrease by 91.5%, Sustainability never switches dominance, and Maintenance Burden requires increase by 92%.

Step 10 : Conclusions and Recommendations

This step should present the analytical findings to the decision maker and provide insight that will strive for clarity of action. While not incorporated into the framework itself, cost is an aspect of the decision space that cannot be overlooked. Based on literature review it was determined that presenting cost against value after the initial analysis would be the most efficient way to include the monetary factor. Figure 38 shows the two alternatives plotted on a Value vs. Cost graph. The cost is the estimated expense for a single HMD kit (unit cost or kit cost) and the value is the quantity calculated in Step 8, during the deterministic analysis.

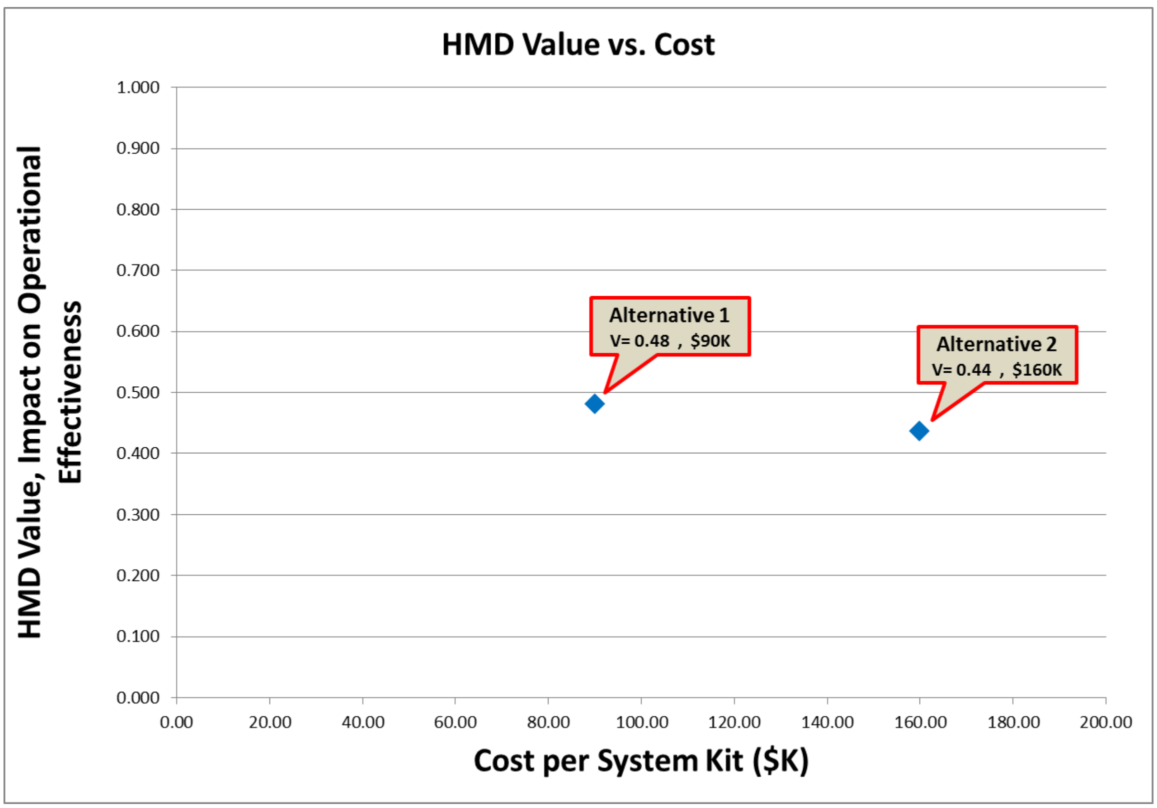

Figure 38 : HMD Value vs. Cost

Figure 38 clearly indicates Alternative 1 has the slightly higher value and less cost, both are desired attributes for a solution. If this was the only relevant data, the analyst would recommend Alternative 1 be selected for integration on the decision maker's aircraft. Naturally other cost factors could be included such as estimated operations and support (O&S) cost or total lifecycle cost (LCC).

Summary

This chapter has provided an analysis of the results gained from the decision model created in Chapter III. An initial ranking was determined based upon original decision maker preferences and HMD metrics, determining that for this particular set of alternatives and senior decision maker, Alternative X was deemed to provide more value. The individual contributions of each evaluation metric on the global score were examined. A sensitivity analysis was performed on the model to examine any possibilities of rank order switching based upon a change in weighting preference or evaluation measure.

V. Conclusions and Recommendations

Chapter Overview

The purpose of this research was to develop and present an evaluation framework that could provide the basis for a tool usable by program office decision makers. The framework was to incorporate Human Systems Integration principles in order to assist in the identification of a COTS HMD solution that would best optimize performance and minimize total life cycle costs of the system. The VFT decision analysis method was applied to a theoretical decision context of a fighter platform needing an HMD system. Proceeding through the process, objectives relevant to the context were elicited and evaluation measures developed. Existing HMD technology alternatives with readily available information were examined and scored within the framework.

This chapter will discuss the significance of this research, primarily its possible implications on assisting the DoD acquisition community during the analysis of alternatives phase of the product life cycle. Recognizing limitations in resources and scope, recommendations will be made for future follow-on actions and research efforts in order to increase the effectiveness of the demonstrated framework.

Investigative Questions Answered

What are the major objectives for HMD use in a fighter aircraft?

The objectives elicited and derived in Step 2 of this framework were based upon literature review, discussions with members of the user community and technical experts, and the author's experience with HMD technology. The top down approach used to define the objectives was based upon the principles of Value-Focused Thinking decision analysis, uniquely applied to the operational combat aircraft environment.

What HMD factors/attributes, with an emphasis on HSI principles, are important when comparing technology solutions?

Step 3, Develop Evaluation Measures, facilitated the collection of an exhaustive list of HMD attributes. This compilation was paired down to accommodate analysis by examining each factor for their contribution to the decision space and relevance to modern technology capabilities. Those that were deemed to be sufficiently defined in a requirements documents were also removed as a continued gradation after meeting the minimum was not value added to the decision. The final list of 17 metrics was used through the rest of the assessment and analysis process.

How should the factors be weighted?

As is required in the VFT methodology, decision maker's preference was represented by developing a weighting schema for the factors. This process is key to tailoring the results for the unique decision space. In a case such as this, weighting can be used to adapt the framework for individual aircraft program offices, military environments, and decision maker personalities.

What are the value metrics for those factors?

Values were calculated using value function curves that determined a score based on an evaluation measure input. The shape and bounds of the curves were created based upon human performance characteristics and decision maker preferences, which shows another way this framework can be tailored for use in a variety of manners.

How sensitive is the preferred solution to framework parameters?

One sensitivity analysis was performed on this framework, which showed a rank order sensitivity to changes in weight of a top level objective. It is expected that with further analysis more value sensitivity could be found.

Significance of Research

Though directed by military handbooks and instructions, the incorporation of human systems integration (HSI) principles is still a struggle in DoD acquisition programs. While they are finding a foothold during requirements writing, no quantitative analysis of COTS equipment against the HSI domains has been applied in a mainstream forum. Furthermore, selection of COTS solutions is often performed in a manner that could miss influences on fundamental objectives, which has been shown to have an impact later in the system's life cycle. The evaluation framework presented in this thesis incorporates many HSI principles in a repeatable, objective manner. Tailorable to specific platforms and needs of the user, a model of this nature could be used to assist in consistent and justified decision making for a variety of programs.

Recommendations for Action

The following are recommendations for actions that will immediately bring added utility to the framework presented in this study.

Apply Weighting to Questionnaires

To improve the accuracy of the pilot and maintainer questionnaires and value metric, each individual prompt can be weighted. This weight would be assigned by the subject completing the feedback form and would represent their preference on specific characteristics on the examined HMD system. Similar to weighting the hierarchy, this would add additional aircraft specificity, as pilots and maintainers from different platforms may have different views on what is important based upon their environment and mission.

Additional Value Function Curves

As mentioned in Step 4, Create Value Function Curves, some evaluation metrics such as display resolution, contrast, and latency can have completely different value curves based upon what is being displayed or the intended environment (Day vs. Night usage). To enhance the completeness and ensure a robust decision framework, these additional value functions can be integrated into the model. Supplementary literature reviews and input from technical experts would occur to ensure accurate curves that account for physiological capabilities and decision maker's viewpoint on the attributes.

Evaluate More Alternatives

Due to time and resource constraints, this effort could only apply the evaluation framework on two example alternatives, with some limitations on metric availability. While this was enough to demonstrate feasibility and usability of the model, it is desired to gather information and metrics on additional HMD systems for examination and comparison. Working with an aircraft System Program Office in need for this type of evaluation would also add to the validity of the framework, as complete tailoring could be performed for the needs of the customer.

Apply Life Cycle Cost vs. Value Comparison

Step 10 of this research presented a basic way to communicate two important metrics in the acquisition community, Performance (value) and Cost. However, the cost figure available at the time of authorship was the cost per unit of the HMD systems. While this is important to the decision space, a more desirable data point would be the estimated life cycle cost of owning the system. As the goal of HSI is to maximize performance while minimizing total life cycle cost, a graph that presents both of these metrics on one medium would be extremely valuable to the decision maker.

Recommendations for Future Research

The following are suggestions for future research to enhance framework fidelity and application.

Incorporate Additional Acquisition Objectives

Discussions with Senior Decision makers and other acquisition professionals have clarified that in reality there are 4 overarching objectives for an acquisition program that must be carefully examined and balanced; Cost, Schedule, Performance and Risk. During an analysis of HMD alternatives, these objectives would all play a part in which solution is chosen. As illustrated in Figure 39, the evaluation framework presented in this thesis effort has encompassed the Performance aspects of the system, and the value an alternative brings to that objective. To maximize the framework's utility in the military acquisition community, it would be ideal to integrate the other three objectives as part of an analysis. For example, Performance or the *HMD Value, Impact on Operational Effectiveness* metric could be plotted against Cost and also Schedule so as to allow for comparison of often competing objectives. Risk could possibly be incorporated as a multiplier of the value score, i.e. a high risk alternative would have a risk multiplier less than one which would then lower the value score when multiplied on *HMD Value, Impact on Operation Effectiveness.* Future research efforts could determine the optimum way to integrate these acquisition objectives.

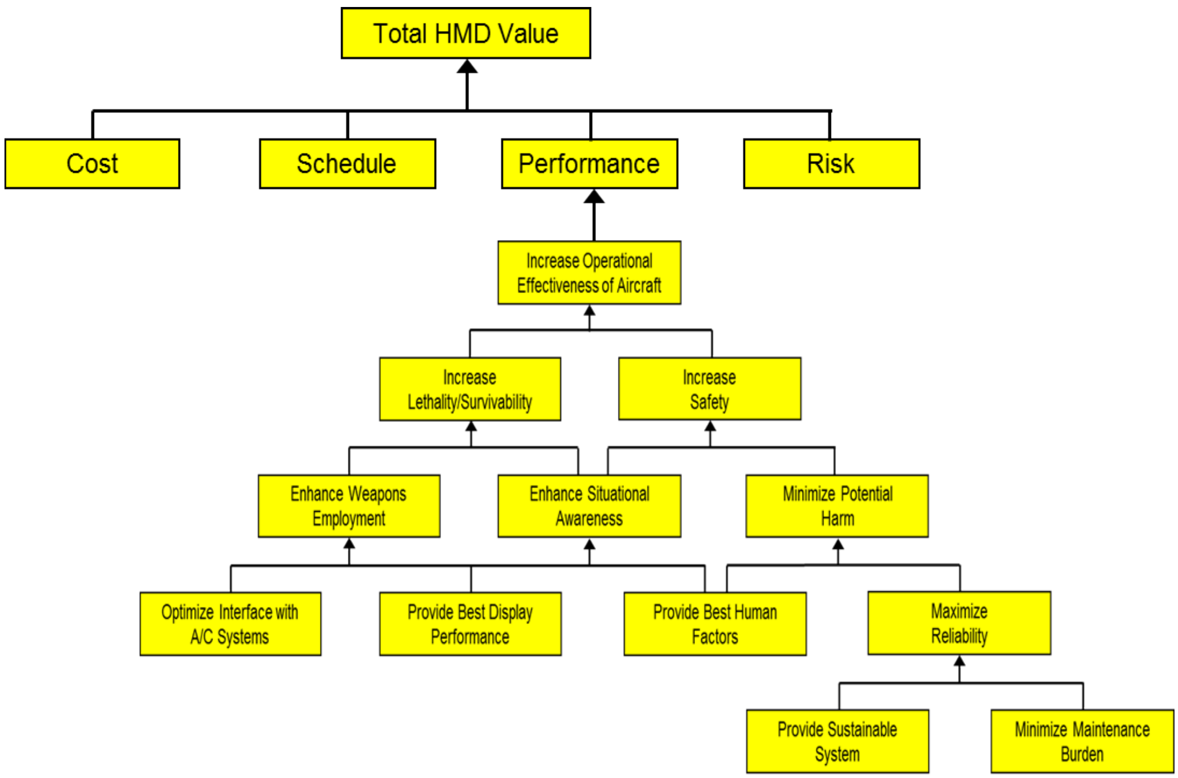

Figure 39 : Acquisition Objective Hierarchy

Integrate Additional HSI Domains

As described in Chapter II, Human Systems Integration (HSI) is broken out into 9 domains that when holistically applied can increase performance and decrease total life cycle costs. It is recognized, not all 9 domains were represented in the framework for this effort, as many have a more direct impact on the cost, schedule, and risk objectives described above. Further evaluation and investigation could be performed to more fully incorporate additional HSI impacts into a larger HMD evaluation framework applied across all the acquisition objectives.

Account for Unique HMD Capabilities

As with most technology options, each HMD system brings their own unique integration approach and capabilities. For example, some systems have full color symbology while others produce monochrome displays. One solution may feature a biodynamic sensor that measures the pilot's blood oxygen levels, and another may incorporate an ambient light sensor that automatically drives a change in display brightness as the environment changes. For this effort, it was assumed that the pilot/maintainer feedback forms may account for some of the additional capabilities not defined in requirements as they would likely add to the usability or satisfaction of the system. However, it is recognized and desired that future research should determine a means of quantitatively incorporating unique capabilities into the value metrics. This would allow for added system value with an increase in capabilities and therefore a more thorough assessment of alternatives.

Breakout Mission Tasks and Environments

Another opportunity for adding tailorability to this framework would be to delineate Task/Environment bins based upon the multiple mission types flow by the aircraft. A night mission would likely have different objectives needs and consequently HMD capability requirements than a day mission. Therefore, each can be broken out as its own value hierarchy. This could create multiple performance type hierarchies (such as

Day, Night, Air-to-Air, and Air-to-Ground) under the *HMD Value, Impact on Operational Effectiveness* score. The evaluation measure collection itself may not change, but the value function curves and preference weights may vary based on mission type. Each hierarchy would have its own weight to represent either importance of the task/environment type or the proportion at which that mission type is flown over the others.

Conclusions of Research

This research effort has shown the development and utility of a value based quantitative assessment framework for helmet mounted display system alternatives that incorporates critical Human System Integration principles. The usability of this model comes from its structure and inherent tailorability, which can allow for different types of technology to be evaluated on varying aircraft platforms. The insight offered by performing an analysis such as this can provide decision makers with defendable, subjective information for alternative selection. Future research can enhance the basic framework by refining evaluation metrics and expanding the Value Focused Thinking methodology across the crosscutting military acquisition priorities.

Appendix A : Initial HMD Factor List

Weight	Anthropometric Accommodation
C.G.	User adjustability
Display Resolution	Growth Capability
Contrast at worst ambient condition	Mx Impacts
Total System/Display Refresh Rate	MTBF
Display Luminance	MTBR
Display Color	MTBME
Symbology Sets	Availability
Ocularity	training required
Potential for optical issues (jitter, ghosting, etc.)	support equipment required
F.O.V	facilities/tooling required
NVIS/LEP compatibility	service life
Latency	cleaning
Accuracy	aircrew flight equipment compatibility
Drift	dimming range
Noise Attenuation	reflections
Sound Usage	power required
Mx Burden/Reliability	Ocular Rivalry
Ease of Use/Pilot Interface	Pilot Control Interface
User Fit/Comfort	Ease of Calibration
A/C Integration	Built in Test
Additional Capabilities	Environmental compatibility
Escape Impact	Amount of symbology
Vibration	Display tailoring
Effect on External Viewing	Display Blanking/Declutter
Angular Resolution	Dimming Range
Graphics Processing	Display uniformity
Stability (symb, tracking)	Display Recording
Display Distortion	Compatibility with A/C and environment lighting
Exit Pupil	Helmet/visor protection
Eye Relief	Failure risks
Modular Transfer Function	Personnel required for maintenance
Volume of Space Required (size)	Security
Frangibility	Technology Readiness Level

Appendix B : Questionnaires

HMD Analysis Questionnaire - Pilot

Organization:________________ Pilot:_________ Date:_________ HMD System:_________

1	2	3	4
Completely Unacceptable, Needs Major Improvements	Unacceptable, Needs Minor Improvements	Minimally Acceptable	Completely Acceptable

While wearing one of the Helmet Mounted Display alternatives, please rate the following features.

Note: Please add comments or observations for system improvements.

1. Fit and Comfort:

a) The ability to Don/Doff the HMD 1 2 3 4

b) The ability to change between DAY and NIGHT HMD configurations 1 2 3 4

c) Overall weight 1 2 3 4

d) Center of Gravity – ability to move head as necessary, impact on fatigue, etc. 1 2 3 4

e) Comfort compared to legacy helmet 1 2 3 4

f) The ability to perform normal aircrew duties with DAY configuration, i.e. checklists, check-6 1 2 3 4

g) The ability to perform normal aircrew duties with NIGHT configuration, i.e. checklists, check-6 1 2 3 4

Comments:____

2. Observe the HMD display and provide a rating:

a) Readability and usability of the display symbology 1 2 3 4

b) Maximum brightness of display 1 2 3 4

c) Size of display 1 2 3 4

d) The ability of the HMD to be confidently used as required for safety of flight and mission completion 1 2 3 4

Comments:____

3. Observe color, contrast, and visibility of surfaces throughout the cockpit and provide a rating. These include; switches, dials, printed words and symbols, as well as kneeboards, manuals, and other applicable materials:

a) Readability and usability of symbology on surfaces 1 2 3 4

b) Distinguishing contrast or color changes of surfaces 1 2 3 4

c) The ability to confidently use commands and instructions on surfaces for safety of flight and mission completion 1 2 3 4

Comments:____

5. Observe interior aircraft lighting and provide a rating:

a) Distinguishing illumination of controls and displays 1 2 3 4
b) The visibility of interior lighting for safety of flight and mission completion 1 2 3 4

Comments:____

6. Observe exterior aircraft lights and airfield lighting and provide a rating:

a) The visibility and discernibility of exterior lights 1 2 3 4
b) Distinguishing color or brightness changes of exterior lights 1 2 3 4
c) The visibility of exterior lighting for safety of flight and mission completion 1 2 3 4

Comments:____

7. Observe the visibility of the scene outside the aircraft and provide a rating:

a) Discernibility of objects and geography in the external scene 1 2 3 4
b) Visibility through canopy 1 2 3 4
i.e. No abnormal reflections, glare, or image distortion that would interfere with safety of flight and mission completion
c) Effect on expected field of view 1 2 3 4

Comments:____

8. Integration:

a) The ability to adjust HMD display brightness to an appropriate night level 1 2 3 4
b) The ability to turn off the HMD display 1 2 3 4
c) The ability to align/calibrate HMD symbology 1 2 3 4

Comments:____

Additional Feedback:

HMD Analysis Questionnaire

Aircraft Maintainer:__________ Life Support Back shop Maintainer:__________ Date:________

HMD System:________

1	2	3	4
Completely Unacceptable, Needs Major Improvements	Unacceptable, Needs Minor Improvements	Minimally Acceptable	Completely Acceptable

While evaluating one of the Helmet Mounted Display alternatives, please rate the following features.

Note: Please add comments or observations for system improvements.

1. **Deconstruction: (8)**

a) The amount of steps required to deconstruct HMD components 1 2 3 4

b) The amount of tooling required to deconstruct HMD 1 2 3 4

Comments:____

2. **Construction: (8)**

a) The amount of steps required to construct HMD components 1 2 3 4

b) The amount of tooling required to deconstruct HMD 1 2 3 4

Comments:____

3. **Pre-flight: (8)**

a) The amount of steps required to fit and check HMD 1 2 3 4

b) The complication of pre-flight tasks 1 2 3 4

Comments:____

5. **Post-flight: (8)**

a) The amount of steps required for storage of HMD 1 2 3 4

b) The complication of storage tasks 1 2 3 4

Comments:____

6. **On-Aircraft Servicing: (12)**

a) The amount of tooling required 1 2 3 4

b) The amount of steps required to completely remove and replace HMD components 1 2 3 4

c) The amount of cockpit hardware to be removed for regular maintenance 1 2 3 4

5. Observe interior aircraft lighting and provide a rating:

a) Distinguishing illumination of controls and displays 1 2 3 4
b) The visibility of interior lighting for safety of flight and mission completion 1 2 3 4

Comments:____

6. Observe exterior aircraft lights and airfield lighting and provide a rating:

a) The visibility and discernibility of exterior lights 1 2 3 4
b) Distinguishing color or brightness changes of exterior lights 1 2 3 4
c) The visibility of exterior lighting for safety of flight and mission completion 1 2 3 4

Comments:____

7. Observe the visibility of the scene outside the aircraft and provide a rating:

a) Discernibility of objects and geography in the external scene 1 2 3 4
b) Visibility through canopy 1 2 3 4
i.e. No abnormal reflections, glare, or image distortion that would interfere with safety of flight and mission completion
c) Effect on expected field of view 1 2 3 4

Comments:____

8. Integration:

a) The ability to adjust HMD display brightness to an appropriate night level 1 2 3 4
b) The ability to turn off the HMD display 1 2 3 4
c) The ability to align/calibrate HMD symbology 1 2 3 4

Comments:____

Additional Feedback:

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The promise of providing an intuitive and efficient information interface, while allowing the warfighter to perform other critical tasks such as targeting or aircraft control, has led to the growing popularity of Helmet Mounted Displays (HMDs) across the military landscape, especially combat aircraft. Though design and selection of competing systems is critical to optimized performance and safety, structured methods for the evaluation of HMDs are not often used in the acquisition community, leaving selection among alternative designs to the judgment of subject matter experts. However, technical decision-making has been shown to be flawed without the use of a structured decision analysis framework, which can help to overcome narrow focus, potential bias, and human error. This thesis proposes a HMD design evaluation framework that derives system metrics from fundamental multi-level performance objectives and employs a robust, analytical approach to assess the alternative's ability to bring value to these objectives. Supported by principles of Human Systems Integration (HSI) and Value-Focused Thinking, the framework can be used by decision makers to craft informed, defendable judgments that strive to increase system performance while decreasing maintenance and integration resource. The 17-factor framework is illustrated through application on two possible solutions for a fixed-wing fighter platform.

15. SUBJECT TERMS

Helmet mounted displays (HMD), decision analysis, Value Focused Thinking (VFT)

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