MEASURE OF EFFECTIVENESS FOR JSTARS GROUND MOVING TARGET INDICATOR: A VALUE FOCUSED THINKING APPROACH

THESIS

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Abstract

As the nature of warfare has shifted from a conventional approach to more guerilla type warfare, intelligence has become more important than at any other time in the history of the United States Military. With the stochastic nature of intelligence gathering, it is almost impossible to know with any degree of certainty where and when the next piece of information that could possibly change the course of the battle or war will be obtained. US intelligence gathering assets have long been plagued with using useless measures of performance rather than measures of effectiveness to determine their worth. This research uses a value focused thinking approach to determine the effectiveness of a specific capability or asset. Specifically, it looks at Ground Moving Target Indicator onboard the E-8C Joint Surveillance Target Attack Radar System. This research attempts to provide a model to a decision maker so he or she will know in advance the approximate value of information they will receive from a particular asset or capability before the asset is ever deployed into the area of responsibility.

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Dedication

To Father and Mother

Acknowledgments

This program and project has definitely not been done in a vacuum. There are a host of people that I owe thanks for helping me to complete this project. Always first in my life I would like to thank my Lord and savior Jesus Christ who has been with me every step of the way. He has continually given me strength through the ups and downs of this program and I truly could not have completed this without him intervening many times during this program. I would also like to thank my wife who has sacrificed her career and at times her dignity to allow me to succeed not only in this program, but throughout my military career. She is the rock of our household, the glue that keeps everything together, and the primary care taker of our children. I would not be the man I am today without her love, guidance, and support.

I would also like to thank my advisor Dr. Jeffery Weir who has pushed me and given me guidance throughout my time at AFIT. The mentorship and wisdom he has bestowed upon me since I arrived here at AFIT has been invaluable. I truly could not have completed this project without him. Lieutenant Colonel Ahner has been instrumental in the writing of this document. Without his attention-to-detail in editing, this document would not have been half as good as its present configuration. I would also like to thank Dr Miller for his help, support and encouragement throughout this program. To the Defense Intelligence Agency, thank you for sponsoring my research and for providing subject matter experts to assist me along the way. I owe a big debt of gratitude to the men and women of the 116 Air Control Wing. From the Operations Group commander down to the airmen basic, they have been extremely hospitable and engaging throughout this process. The information they provided has been key in finishing this project.

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G. Jerell Joyner

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List of Acronyms

AC	Attack Control
AFT	Alternative Focused Thinking
AHP	Analytic Hierarchy Process
AIO/T	Airborne Intelligence Officer/Technician
AOR	Area of Responsibility
AOT	Airborne Operations Technician
ART	Airborne Radar Technician
ATSS	Airborne Target Surveillance Supervisor
AWO	Airborne Weapons Officer
CAOC	Combined Air Operations Center
COMINT	Communications Intelligence
CEO	Chief Executive Officer
CST	Communications Systems Technician
DA	Decision Analysis
DIA	Defense Intelligence Agency
DMCC	Deputy Mission Crew Commander
DOD	Department of Defense
ELINT	Electronic Intelligence
FTI	Fixed Target Indicator
GMTI	Ground Moving Target Indicator
GRCA	Ground Reference Coverage Area
ISR	Intelligence Surveillance and Reconnaissance
JSTARS	Joint Surveillance Target Attack Radar System
MCC	Mission Crew Commander
MOE	Measure of Effectiveness
MOO	Measures of Outcome
MOP	Measures of Performance
RRCA	Radar Reference Coverage Area
RSR	Radar Service Request
SAR	Synthetic Aperture Radar
SME	Subject Matter Expert
SOTAS	Stand-off Target Acquisition System
SS	Sector Search
SSM	Senior Surveillance Manager
TRADOC	Training Doctrine Command

Chapter 1. Introduction

Measure of Effectiveness for JSTARS Ground Moving Target Indicator: A Value Focused Thinking Approach

1.1 Background

"Electronic intelligence, valuable though it is in its own way, serves to augment the daunting volume of information which is directed at headquarters from satellite and aerial reconnaissance, intelligence-gathering ships, optical observation, Special Forces, armored reconnaissance teams, and the interrogation of prisoners. Nowadays the commander is confronted with too much information, rather than too little, and it is his informed judgment which ultimately decides what is relevant and important." (Farringdon)

The Department of Defense (DoD) has an enormous amount of assets that are dedicated to the intelligence gathering process. From satellites out in space to remotely piloted vehicles, there is a great amount of the DoD budget dedicated to gathering intelligence. In today's war environments where the fighting is mostly unconventional, we depend on our intelligence gathering platforms more than ever to provide timely and accurate information. A problem that has long since plagued the intelligence gathering systems is differentiating between measures of performance and measures of effectiveness. Measures of Effectiveness (MOEs) are quantitative measures that give some insight into how effectively a unit is performing, and Measures of Performance (MOPs) describes how well a system utilizes resources. For some of the systems it is as simple as taking a picture and then evaluating that picture to determine if it obtained the information you required. In this example it would be somewhat easy to determine some measure of effectiveness and then build a model to determine if the picture that was taken meets some threshold of satisfaction.

However, there are other intelligence gathering capabilities that are not as easy to determine a true measure of effectiveness. For example, how many hours does the RC-135 (Rivet Joint) have to orbit using its COMINT or ELINT capability to be considered effective? How long does the E-8 JSTARS (Joint Surveillance Target Attack Radar System) have to orbit to be considered effective? These are difficult questions to answer as who knows when either of these aircraft will gather that one piece of intelligence that could possibly change the course of the war. A piece of information that could be key in changing the course of the battle could come on the first intercepted transmission of the night, the last before they go off station, or not at all. Because of the sheer uncertainty of the intelligence gathering process, DoD has failed to place true measures of effectiveness on many of the platforms and/or their capabilities. Instead, in the absence of true measures of effectiveness, the effectiveness of these platforms is measured by a measure of performance. It's much easier and less complicated to assign a platform to go orbit for some duration of time and then measure its effectiveness by how long during that assigned station time they were actually on station. Measurements such as the previous example can lead to very high levels of effectiveness and look like a very attractive asset when doing an assessment of the best DoD intelligence assets. The problem however with these types of measurements is, if a detailed analysis where conducted you may find that the true effectiveness of these assets could be extremely low to almost zero.

1.2 Problem Statement

In sum, the security challenges we now face and will in the future have changed, and our thinking must likewise change. The old paradigm of looking at a potential conflict as *either regular or irregular war, conventional or unconventional, high-end or low-end is no longer relevant. And as a result, the Defense Department needs to think about and prepare for war in a profoundly different way than what we have been accustomed to throughout the better part of the last century. In truth, preparing for conflict in the 21st century means investing in truly new concepts and new technologies (Gates, US Department of Defense, 2010).*

It means taking into account all the assets and capabilities we can bring to the fight. It means measuring those capabilities against real threats posed by real world adversaries with real limitations, not threats conjured up from enemies with unlimited time, unlimited resources and unlimited technological acumen. (Gates, US Department of Defense, 2009)

In today's budget sensitive economy there is a battle waged over every dollar in the DoD budget. No more are the days of limitless and unchecked military spending. A growing chorus of politicians and citizens are calling for defense spending to be scrutinized as much as any other federal program when it comes time to tighten the nation's fiscal belt. At $689 billion this year, defense spending accounts for about 20% of the entire federal budget and it makes up 50% of the so-called discretionary budget, which pays for everything but entitlement programs and interest on the debt. (Sahadi, 2010). The DoD is now under scrutiny to find ways to cut useless and redundant equipment and systems. They have to justify ever piece of equipment it contends it requires to maintain the safety and security of the nation. With such tight constraints, every asset has to prove its worthiness or face possible crippling budget cuts.

The "shock and awe" strategy is a very popular one among senior officials, but the wars in Afghanistan and Iraqi show clearly that massive applications of force have done little more than kill the innocent and enrage their survivors (Arquilla, 2010). As the nature of warfare has changed so has the systems needed to fight successfully and win the changing and dynamic battlefield. The paradigm of always "fighting the last war" has been scrutinized severely and we can only afford to keep systems that will allow us to win the next war. Keeping and maintaining systems in the DoD arsenal because they have always been a part, no longer meets fiscal constraints. It has become imperative that every weapon system have measures of effectiveness that show that they can complete their mission in a manner that is cost effective to the tax-payer, and shows that it's contributing to the overall mission each and every time the asset is employed.

1.3 Research Objective

The value focused thinking (VFT) process has been used in several different applications over the years from determining force protection initiatives (Jurk, 2002) to determining security solutions for Homeland Security (Pruitt, 2003). This is not a new methodology. The goal of this research is to use the VFT methodology to model the collection of any intelligence gathering asset by developing a model that can consistently and accurately measure how effective an asset or capability will be in any given scenario. This will enable planners, collection managers, and flight crews to have a much better idea of the value of information they will receive prior to collection deck completion or pulling back on the yolk. This research will force all involved to look at the constraints of the mission and determine if there are any things they can change prior to the mission to improve the value of information they will receive. This research will also force commanders and decision makers to reanalyze whether they want to spend thousands of pounds of fuel, hundreds of man hours, and other coveted Air Force resources to fly missions that will potentially result in very low information value.

The remainder of this document will consist of a literature review section, a methodology section, a results and analysis section and finally conclusions and recommendations. The literature review section will discuss all information that is pertinent to intelligence, JSTARS, decision analysis and theory of measurement. The methodology section will discuss in detail the 10-step value-focused thinking methodology. Results and analysis will discuss how the model was created and what the results of the analysis of the output were. Finally, in section 5 the conclusions of the study will be documented along with some recommendations on how to proceed in the future will be presented.

Chapter 2. Literature Review

2.1 Introduction

To accurately model any process you must first understand what research has already taken place in the area of interest. Also there needs to be an understanding of other research and methodologies that do not directly relate to the area of interest, but could possibly be adapted to the issue or problem. This chapter provides background on the 4 main areas in which this research needs to be effective. Section 2 focuses on the intelligence process, the how and why we acquire and need certain types of intelligence. Section 3 will focus mainly on the E8-C Joint Surveillance Target Attack Radar System and the major capability it features which is Ground Moving Target Indicator (GMTI).

Section 4 will concentrate on the Theory of Measures of Effectiveness, the root on which we determine how well a system is or is not performing. Finally, section 5 will give a brief overview of decision analysis and the value focused thinking methodology which will be applied and explained in chapters 3 and 4 of this thesis in much greater detail.

2.2. Intelligence and Intelligence Capabilities

The purpose of collecting intelligence is to inform the commander, identify/define objectives, support planning and execution, counter the adversary, support friendly deception, and to assess the effects of the operation (Defense, Joint Intelligence, JP 2.0, 2007). Before you can do any of these things you have to understand what the true meaning of the word intelligence is. As with any popular word there are multiple ways in which intelligence is defined. Some of the more simplified definitions located in the dictionary state intelligence is the ability to learn or understand or deal with new or trying situations. It is also defined as the ability to apply knowledge to manipulate one's environment or to think abstractly as measured by objective criteria. The final Webster's definition of intelligence is information concerning an enemy or a possible enemy area (Merrian-Webster, 2011). Among the three different versions, a more hybrid approach is most appropriate for a military organization as it is concerned with the "ability to learn and understand", they are also interested in "knowledge", and finally they are concerned with information as it deals with their "enemies." In laymen's terms they need to have the ability to gather knowledge on our enemy so that we have the ability to learn and understand them and ultimately defeat them. In the joint environment, intelligence is defined as the product resulting from the collection, processing, integration, evaluation, analysis and interpretation of available information concerning foreign nations, hostiles or potentially hostile forces or elements, or areas of actual or potential operations (Defense, Joint Intelligence, JP 2.0, 2007). This definition goes far more in-depth on the processing, evaluation and analysis of the data. All types of information can be collected, but if there is no accurate well thought out procedure to exploit the data then the eight attributes of intelligence excellence that are located in appendix E will not be met.

A derivative of the intelligence process is ISR or Intelligence, Surveillance, and Reconnaissance. The goal of the ISR process is to provide accurate, relevant, and timely intelligence to decision makers (AFDD, 2007). ISR plays a crucial role in achieving decision superiority as it gives commanders a competitive advantage by ensuring he and his troops have the situational awareness to make better informed decisions. Of course ISR is broken down into the three components, of which intelligence has already been discussed. However surveillance is defined as "the systematic observation of aerospace, surface or subsurface areas, places, persons, or things, by visual, aura, electronic, photographic or other means." Reconnaissance is defined as "a mission undertaken, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy" (AFDD, 2007). The information derived from surveillance and reconnaissance is exploited and analyzed and turned into intelligence. The key principles of ISR are that it must be integrated, accurate, relevant, timely, fused, accessible, secure, survivable, sustainable and deployable. ISR is undoubtedly one of the most important aspects of the intelligence process and cannot be done effectively without some of the major ISR assets such as JSTARS, Rivet Joint, Global Hawk and other airborne and space assets.

2.3 The History of Ground Moving Target Indicator (GMTI) and Joint Surveillance Target Attack Radar System (JSTARS)

The development of GMTI dates back to the Arab-Israeli War in 1973. During a fact-finding tour, the US Army noted Arab and Israeli forces had lost more tanks in a six-day conflict than they had deployed in the entire European theater at the time (Dunn, Bingham, & Fowler, 2004). Noting the lethality of the new battlefield, General William DePuy, Commander of the Army's Training and Doctrine Command (TRADOC), recognized "field commanders would have to know the enemy's situation beyond the front line", to include his successive echelons, artillery, support troops, headquarters, and possible courses of action. In 1982 the new TRADOC commander, General Donn Starry, expanded the doctrine to include Soviet second-echelon forces which focused on the need to synchronize air and ground power at the operational level. Recognizing the need for a collaborative effort, the Army and Air Force entered into a joint agreement in 1983 to explore 31 specific initiatives supporting air and ground operations (Dunn, Bingham, & Fowler, 2004).

The Army's Stand-Off Target Acquisition System (SOTAS) along with the Air Force's Assault Breaker/Pave Mover were the precursors to the modern GMTI radar. The SOTAS was mounted onboard a helicopter and gained commanders support when they realized the value of seeing the opposing forces movement. Although there was strong support from field commanders for this program, due to cost overruns, the program was cancelled in 1980. While the Army was doing their research, the AF was also conducting significant research on adding the GMTI capability to fast-moving aircraft. In 1976 the Defense Science Board conducted a study that proposed an alternative to countering the Warsaw Pact by locating and attacking the second and third echelon forces with air and ground missiles (Dunn, Bingham, & Fowler, 2004). In support of this effort Grumman/Norden changed the emphasis of its Radar Guided Weapon System to a side looking GMTI system which gave them a head start in the Pave Mover. The Pave Mover system was initially installed on the F-111. The radar had the ability to switch rapidly from GMTI to Synthetic Aperture Radar (SAR) mode giving high resolution images of areas of interest. It became obvious that neither Congress nor the Office of the Secretary of Defense were going to fund two separate GMTI programs and urged the forces to combine their efforts. Selecting one aircraft to satisfy both services requirements was quite difficult because the Army wanted a dedicated intelligence Surveillance and Reconnaissance (ISR) asset, where as the AF wanted a Battle Management asset to guide aircraft and missiles and also provide ISR. Eventually both service chiefs signed a Memorandum of agreement that JSTARS would be the aircraft and the prioritization of its missions would be equitable easing Army tensions since the AF would be responsible for operating the aircraft. In 1985 Grumman/Norden was awarded the contract to build the 10 aircraft with 4 additional developmental aircraft.

JSTARS is a Boeing 707 aircraft that has several different missions which include Air Interdiction, Airborne Battlefield Command and Control Center, Close Air Support, Command and Control and ISR (Albers, 2001). The basic crew consists of 18 people which include a Pilot, Co-Pilot, Navigator, Engineer, Mission Crew Commander(MCC), Deputy Mission Crew Commander (DMCC, Army), Senior Director (SD), Airborne

Weapons Officer (AWO, 2), Senior Surveillance Manager (SSM), Airborne Operation Technicians (AOT, 2), Airborne Target Surveillance Supervisors (ATSS, Army, 2), Airborne Intelligence Officer/Technician (AIO/T), Communication Systems Technician (2) and an Airborne Radar Technician (2) (Vol 3, 2009). A more detailed description of the different jobs onboard the aircraft can be found in the appendix of this document. Figure 1 shows the hierarchy onboard the aircraft and how the positions interact with one another. The aircraft has 18 workstations in the back of the aircraft, but not all are used for ISR and battle management. Four of the consoles are obligated to airborne system maintenance as the CST's and ART's use these consoles. One more is used for the navigator to ensure they have total situational awareness of the actions that are taking place on both ends of the aircraft.

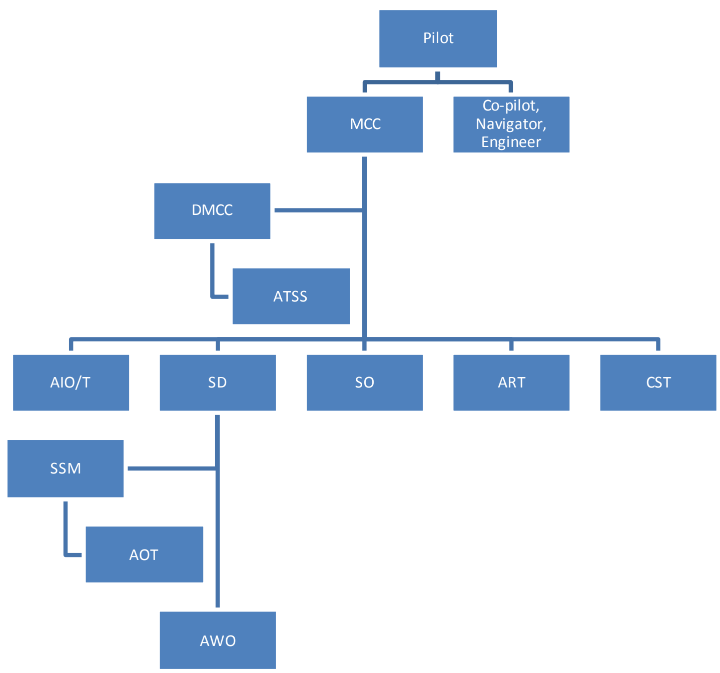


Figure 1: The JSTARS Crew Composition

The aircraft has a 24-foot, canoe shaped side-looking phased array radar in a dome underneath the aircraft. The crew conducts its operations by establishing a figure eight or race track orbit which is at least 50 kilometers away and no further than 250 kilometers away from the area of interest (Albers, 2001). The radar has two modes of operation, Moving Target Indicator (MTI) and Synthetic Aperture Radar (SAR) and has a 120 degree field of view that can detect targets up to 125 knots. The radar detects targets using a Doppler shift or a double Doppler shift. Track vehicles such as tanks are detected because the tracks on the vehicle are typically moving twice as fast as the vehicle itself. The tracks, or their direction of movement, are displayed on the operator's console. Magenta dots represent wheeled vehicles or Doppler shift and yellow dots represent track vechiles or double Doppler shift (Albers, 2001). In theory an operator should be able to tell what type of vehicle it is based on the color of the tracks, but in practice it has been shown that this is not a reliable way to identify the targets and there needs to be some type of cross-cue from another asset with video or eyes on the target to insure accuracy.

Prior to mission planning or during the mission, radar service request (RSRs) are received from supported agencies and establish the priorities for the radar. The radar sweeps the requested areas and provides the information to the on-board operators. The frequency or revisit rate in which these are looked at by the radar is based on the priority of the job. The radar has a limited amount of RSRs that it can process at any given time. The more RSRs that are requested affects the timeline of the radar which results in lower priority jobs not being processed in accordance with the agreed upon timeline.

There are at least five different RSRs that the radar can provide in the MTI mode. The first is the Ground Reference Coverage Area (GRCA) which is a wide area surveillance

(WAS) which has low resolution and low priority. The GRCA is the area in which the radar will attempt to continually keep in view no matter its position in the orbit and is generally an area of 160 x 180 kilometers. A standard revisit rate on the GRAC is sixty seconds, which means the radar will attempt to give an update of the MTI picture of the mission area every sixty seconds. The next one is the Radar Reference Coverage Area (RRCA) which is another low resolution and low priority job. The RRCA is fixed azimuth ninety degrees off the wing and does not have a defined search area. This mode is normally used enroute to the Area of Responsibility (AOR) to check the accuracy of the radar. The Sector Search (SS) is an RSR that is smaller in size than the GRCA and provides a higher resolution, higher revisit rate and is a higher priority job. The SS provides more accurate and timelier MTI data than the GRCA. The Attack Control (AC) is a high resolution, high priority RSR that has an even higher revisit rate than the SS. The AC is usually smaller than the SS and is the RSR that is most commonly used for targeting. The final MTI RSR is the Attack Planning (AP) which has high resolution, but its priority and revisit rate are lower than the AC. Since this mode is very similar to the AC it is rarely used during an operational mission (Albers, 2001).

The second mode the radar is operated in is SAR. In this mode the radar focuses on a specific area and creates a radar image of the area. SARs are high resolution RSRs and they use a much more of the radar time than any other RSR. SARs are also the highest priority RSR and once approved they are completed before any other job can be done. SARs can also be taken in the Fixed Target Indicator (FTI) Mode. When taken in this mode red dots are overlaid on the SAR picture signifying the area of the greatest returns. In general, SARs are used for battle damage assessments and in the FTI mode to indentify buildings, stationary vehicles, or assembly areas. The field of view in Figure 2 shows the special relationships between the aircraft and the different Radar Service Request.

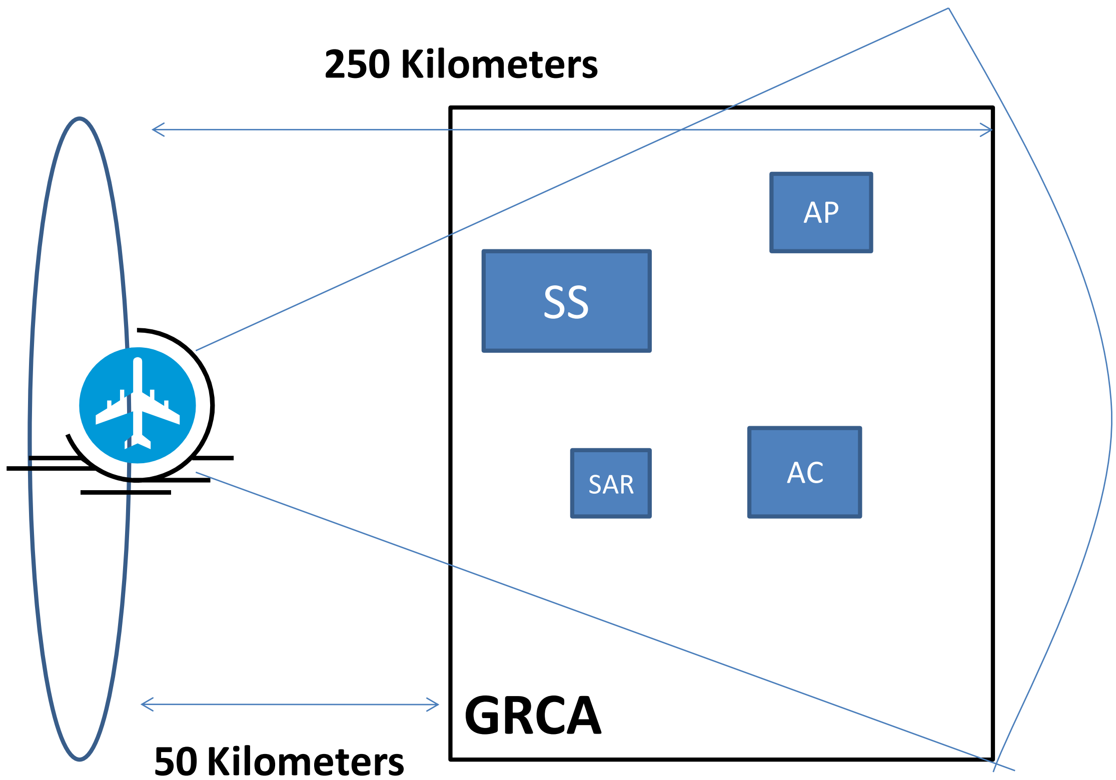


Figure 2: JSTARS Field of View

The JSTARS was given an opportunity to show the value of GMTI even before it was an operational aircraft.   Army Lieutenant General Fred Franks had been quite impressed with the capability of GMTI and convinced Army Senior leaders to insist on deploying the aircraft to the Gulf War while it was still in its developmental phase (Dunn, Bingham, & Fowler, 2004). With no operational experience and with civilian and military crews receiving on-the-job training, the crews quickly began to exploit the GMTI capabilities. The JSTARS crews were the first to locate advancing Iraqi forces that were moving into Saudi Arabia during the Battle of Khafji (Clevenger, 1996). GMTI played a role in assuring coalition leaders that the movement was indeed an attack and not military deception. The JSTARS proved GMTI was a unique and valuable capability that had changed the war. Brigadier General John F. Stewart, the Army's senior intelligence officer at the time stated "the JSTARS was the single most valuable intelligence and targeting collection system in Desert Storm" (Stewart, 1991).

During Operation Allied Force the JSTARS was called upon again to monitor the ground movement of the enemy from above. Unlike the wide open desert of Saudi Arabia, Kosovo terrain was rugged and full of foliage which increased the amount of radar screening dramatically. Another factor that limited the effectiveness of GMTI was the fact there were very few friendly ground troops, which allowed the Serb forces to disperse and escape from being targeted and attacked. The distance they had to fly to their orbits and the low number of aircraft (4) did not allow them to fly persistent 24 hour coverage which allowed Serb forces several opportunities to move without being detected. Finally, the orbits that they were assigned were not optimized to prevent radar screening. While some of these issues were mitigated once liaison officers were deployed to the Air Operations Center, it was clear that GMTI did not provide the earth shattering intelligence it did during Desert Storm (Dunn, Bingham, & Fowler, 2004).

JSTARS was once again called to duty in Operation Enduring Freedom. This environment also provided a myriad of challenges to JSTARS and the use of GMTI. Radar screening was a huge issue as the terrain in the AOR is quite mountainous;

however GMTI was more effective when the terrain channeled movement. While the vehicle movement was not as robust as in past scenarios, the fact that there was a much larger contingent of ground forces enhanced the effectiveness of GMTI. Orbit and altitude were also major issues as the aircraft was placed in orbits that were ineffective or the aircrafts could not reach altitudes that would decrease the radar screening. Another issue that was discovered was the time period that JSTARS arrived in the theater. Since JSTARS arrived after combat operations had already begun, much of the vehicular movement of the Taliban and al Qaeda was no longer occurring and valuable targeting opportunities for GMTI had been missed (Dunn, Bingham, & Fowler, 2004). One significant break though during this conflict was the cross cueing with remotely piloted vehicles which proved to enhance the intelligence capability.

During Operation Iraqi Freedom, the United States Military had the advantage of the lessons learned from recent wars and used that knowledge to do things much smarter. For the first time, several aircraft were to provide coverage and to collect baseline data before the conflict began. Once the conflict began, Iraqi forces had a dilemma. They could remain immobile and be easily defeated or they could move and risk being seen by GMTI and targeted by coalition forces. GMTI was also used in a new way to provide protective watch of coalition supply lines which allowed the forces to respond to Iraqi forces of significant size.

The JSTARS weapon system has had some great success and some extreme failures. Throughout these different conflicts however, a template of how to best employ the weapons system to maximize its effectiveness has emerged. Using this historical data along with knowledge of current employment strategies, this research develops measures of effectiveness used in a model to determine what scenarios maximize the effectiveness of this asset and capability.

2.4 Theory of Effectiveness Measurements

"Don't lower your expectations to meet your performance. Raise your level of performance to meet your expectations. Expect the best of yourself, and then do what is necessary to make it a reality." (Marston, 2009)

Measurement is an integral part of our daily lives. Measurement is closely aligned with physical science and is deterministic in nature. Unfortunately some fields such as the social and behavioral sciences have events and processes that are difficult to understand and very difficult to measure. Military intelligence gathering is another example where it is extremely difficult to measure effectiveness because of the dynamics and unpredictability of when, where and even how it is obtained. The challenge in gathering intelligence is the nature of intelligence is stochastic and dynamic and really does not exhibit any deterministic traits.

Effectiveness measures provide the critical link between strategy and execution, essentially translating strategy into reality (Melenyk, Stewart, & Swink, 2004). Measures of effectiveness directly influence how decision makers assess the impact of deliberate actions and affect critical issues such as resource allocation as well as whether to maintain or change the existing strategy (Gartner, 1997). The lack of a foundation and framework can lead to erroneous measures that really don't accurately measure what they are intended to measure. Measurements in military environments can contain error yielding uncertainty concerning the true state of the system resulting from deliberate actions.

Measurement is needed to capture information about the system through their attributes which can be directly or indirectly observable (Bullock, 2006). Measurement is an abstraction because it does not directly measure the system, but only addresses the attributes about the system (Pfanzagl, 1971). In other words measurement can be thought of as a process that assigns symbols to attributes that reflect the underlying nature of the system (Bullock, 2006). However, attribute selection is crucial since the validity of the system measurement is influenced by the number of attributes used in the measurement. While a small number of attributes can simplify the measurement process, too few can lead to poor or misleading insights about a system.

Once attributes are identified, observations or data collection on the system can begin. There may be several different ways to measure, but whatever measurement is used it is just a raw symbol derived from the observation while an indicator, or index, is a measure for a complex attribute (Bullock, 2006). Good measures are generally characterized as being valid, reliable, and have some type of amplitude. The validity of any measure is affected by its attribute, because validity characterizes how well a measure reflects the system attributes it was supposed to represent. Reliability addresses the consistency or repeatability of the measure, and amplitude demonstrates how well the measure represents high order constructs and complex attributes (Geisler, 2000).

Typically when something is measured, it is done with some type of instrument. That instrument can be as simple as a ruler or as complicated as a mathematical model (Bullock, 2006). Regardless of the form, the underlying relationship between the instrument and the attribute being measured must be the same. The problem is that scales themselves can be a source of error, since most measures have some type of inherent error. The primary source of measurement error comes from random, systemic, and observational error. Random error is the stochastic variation that can be generated from anywhere. Systemic error is derived from the construction of the measure or definition of the measurement bias. Observational error is the oversight of key systems attributes requiring measurement or using the wrong measures for the indentified system attributes (Bullock, 2006). Error is inescapable, but through statistics we can make inferences on the data that is either input or output.

To measure a system properly, it is imperative that something is known about the system. Unfortunately, the reason measurement is required is because there is a need to get a better understanding of the system (Geisler, 2000). For complex systems the attributes of the system may be unknown and require a proxy or indirect method of measurement such as a mathematical model or some type of approximation. There is really no easy way to derive the proxies of the systems and usually requires breaking complex systems down into understandable, measurable components.

The most widely accepted form of a measure is the representational view which is built upon their representation, uniqueness, and meaningfulness. For a system to be measureable, it must somehow map a formal domain into an empirical domain. Simply stated, there must be some rational way to turn the attribute of the systems into an applicable measure.

There are at least nine different scale types, but the most common are Nominal, Ordinal, Interval, Ration and Absolute. Nominal scales only have equivalence meaning, where ordinal scales have both equivalence and rank meaning. Interval scales have both equivalence and rank meaning, but also have some meaning in the intervals between values. Ratio scales have all of the preceding meanings but add a ratio value meaning and absolute scales are ratios with no units attached, but are often interpreted as a measurement by counting. Each higher level scale can always be converted to a lower level scale, but a lower level scale cannot be converted in to a higher level scale.

To create good measures you must first have a measurement plan. The measurement plan should address the information to be derived from the measurement activity (Park, Goethert, & Florac, 1996) and how the system will be measured. This should include how measures will be determined and how measures will be collected, as well as allocation of resources for the measurement activities to include training and tools. The plan should be a living document which serves to guide the measurement process, document the process, and provide an audit trail for the system measurement process (Sproles, 1997). A good measure can also yield information on when and why a system is deviating from its normal behavior, but in order to receive maximum benefit the measurement must be an explicit and objective activity.

Measures of effectiveness (MOE), measures of performance (MOP), and measures of outcome (MOO) are the three types of measures typically used to measure a system. MOEs provide insights on how well a system tracks against its purpose and MOPs describe how well a systems utilizes its resources. In other words, MOEs determine if the right things are being done and MOPs determine if things are being done right. The key difference between the two is a MOP alone does not provide indication of normative behavior. The final measurement, MOOs gauge indirect conditions created by the system.

The key to a successful measurement is ensuring the right measures are being used to gauge the system purpose. The challenge however, is differing between what one would like to measure and what is actually measurable. Generally a vertical framework is used for effectiveness measures where all measures are a derivative of the systems strategic purpose. A real problem in understanding which inputs lead to which outcomes is identifying and articulating the cause and effect linkage between strategic, operational, and tactical levels (Kaplan & Norton, 1996). The cause and effect relationship can be difficult to discern because the output of one system could very well be the input of another. Some systems can even change overtime or adapt to being measured. The primary goal is to develop system measures that yield the most insight while imposing the least burden on the system and the person or persons conducting the measurement.

Modeling large complex systems can result in numerous measures, with each only providing a narrow view of the system. Having so many different views can make it difficult to assess the overall system. If this is the case, aggregation is a tool that can help, but can be difficult because most of the measurements are usually not the same. Combining dissimilar measurements requires an understanding of the scale types being used in order to ensure the aggregated measurement is meaningful and preserves the original scale (Antony, et al., 1998). One method commonly used to combine measures is the aggregation process which can be additive or multiplicative. The easiest and most obvious is the additive:

Equation 1: Additive Aggregation

where is some type of predetermined weight and is the measures. If the relationship is known to be non-linear you can aggregate using the multiplicative normalization process:

Equation 2: Multiplicative Aggregation

The last is a higher order polynomial aggregation which closely captures the systems underlying nature:

Equation 3: Polynomial Aggregation

Good measures share six distinct characteristics which are timely, objective, economical, complete, measurable, and strategically linked (Bullock, 2006). A timely measure is one that is collected in a time frame that is relevant. Objective measures are measures that meet the clairvoyance test, are repeatable, and have “face value” and or credibility that they actually represent the system. They should also be economical in the sense that the data or information gained from creating the measure is of more value and requires less effort than the burden of the measurement activities themselves. The completeness characteristic is defined by a measure or set of measures spanning the entire system. A complete measure addresses both breadth and depth of the attributes of the systems and the system itself. There is no easy way to achieve completeness; this requires creative and critical thinking and exceptional knowledge of the system. For a measure to be measurable implies that the measure can be feasibly obtained and the collected measures are accurate and can be verified (Jordan, Prevette, & Woodward, 2001).

For years now senior executives in a broad range of fields have begun rethinking how to measure performance of their businesses. They have all recognized that new strategies and competiveness require new measurement systems. They have all come to the understanding that treating financial figures as their only source of performance measurement is a flawed theory (Eccles, 1991). Many mangers have been tracking things such as quality, market share, and other nonfinancial measures for years, but not using them as measures of performance. Changing the status quo has been difficult because when conflicts arise, financial considerations always win out.

Chief Executive Officer’s now feel they have initiated a change in their business practices in how their managers think about business performance. Executives have come to the conclusion that what gets measured gets attention especially if there is some type of reward tied to it. They also understand that they cannot simply add new measures to the old accounting-driven performance and expect significant results. Instead they have to identify key corporate performance measures such as productivity, employee attitude and public responsibility along with managing short and long term goals. Many in the business community blame the short-term thinking of most CEO’s as a major concern when it comes to change. The blame has been cast on a relentless desire for rising quarterly earnings, while others fault senior executives and their short terms as the leader of the companies as the reason for the shortsightedness. This short-term thinking puts tons of pressure on the managers themselves and they have a strong incentive to manipulate the earnings reports (Eccles, 1991). This is a game that few in management deny takes place and calls in question the very measures that the markets uses to determine stock price.

Measures of Effectiveness for governmental organizations are much more difficult because their objective is not necessarily financial gain. The accounting systems and economic and financial methods in use in these organizations neither satisfy the large information needs for measuring how effectively they achieve their objectives nor provide the information feedback required for high-level decision making about allocation of budgets and resources (Gawande & Wheeler, 1999). However the need for such measures of effectiveness is imperative because of the Chief Financial Officers Act of 1990 and the Governmental Performance Act of 1990 which implement performance based management across all sections of the government. The government is increasingly trying to become more efficient and maximize its total returns from its spending allocations.

2.5 Decision Analysis

There are multiple times in our lives when we will be faced with tough decisions. Most of us make those tough decision based on a hunch or gut feeling, but most of us wish we had some way to make those decisions in a much easier systematic way. Decision analysis (DA) provides a systematic structure and guidance for thinking about hard decisions (Clemen & Reilly, 2001). There are four basic sources of difficulty to any decision which are complexity, uncertainty, multiple objectives, and different perspectives. Complex problems are tough, but decision analysis provides effective methods for organizing a complex problem into a structure that can be analyzed. That structure includes possible courses of action, possible outcomes, the likelihood of those outcomes, and the eventual consequences (good or bad). In turn this structure helps answer the "what if" questions of complex problems. Usually there is no hard decision made with one hundred percent certainty. DA helps identify important sources of uncertainty and represents that uncertainty in a systematic logical way (Clemen & Reilly, 2001). Many decisions have multiple objectives such as maximizing square footage, while minimizing cost. Clearly, these objectives conflict with each other, but DA gives us tools to make trade-offs when dealing with multiple objectives. Finally, when there are multiple decision makers, they rarely come to the same conclusion on any decision. Most individuals will look at a problem from different perspectives which lead to different choices, but DA once again helps sort through and resolve these differences.

Applying DA techniques correctly will help make better decisions, and over time produce better outcomes. As stated above there is uncertainty in any tough decision, which means no matter which decision that is chosen there is some probability that a negative outcome could be the result. Additionally, just as there is a chance of the negative outcome, there is also a possibility that you could be lucky and have a positive outcome when choosing a bad alternative. However, using DA consistently will improve your chances of enjoying positive outcomes and lessen the probability of those negative outcomes. Psychology has shown that people generally do not process information and make decisions that are consistent (Clemen & Reilly, 2001). DA does not provide solutions to problems, instead it is an information source that provides insight about a situation, uncertainty, objectives, and trade-offs, which will yield some recommended course of action. DA is a tool in decision making and is not meant to replace the decision maker's intuition, relieve him or her of the obligations in facing the problem, or to be a competitor to the decision maker's personal style of analysis, instead it is meant to complement, augment, and generally work alongside the decision maker in exemplifying the nature of the problem (Bunn, 1984).

Many managers and decision makers frequently complain that most analytical processes from management science ignore subjective judgment which is the beauty of DA because it requires subjective judgment (Clemen & Reilly, 2001). Clemen & Reilly define their DA process as seven step process that begins with identifying the decision situation and concludes with implementation of the chosen alternative (see figure 3). As stated, the first step is for the decision maker to identify the decision situation and to understand his or her objectives in the situation. While there are plenty of problems to solve, you should avoid making a type III statistical error in which you do a great job solving the wrong problem. Once the problem has been identified, it's time to discover and create alternatives. The next step in the process modeling is the most critical in DA modeling because it enables users to create quantitative and analytical approaches to their problems. This is a key advantage to the DA process because the mathematical representation of the decision can be subjected to analysis. Choosing the best alternative, sensitivity analysis, further analysis if needed, and implementation of the chosen alternative complete the DA process. During these steps users are attempting to answer the "what if" questions about a certain alternative and determining if slight changes in one or more aspects changes the recommended alternative. If small changes do indeed change the alternative, the decision maker may want to redefine certain objectives, include other objectives or identify new alternatives. As seen, the DA process not only provides a structured way to think about decisions, but also fundamentally provides structure which allows a decision maker to develop beliefs, feelings, and those subjective judgments that are critical for good decision making.

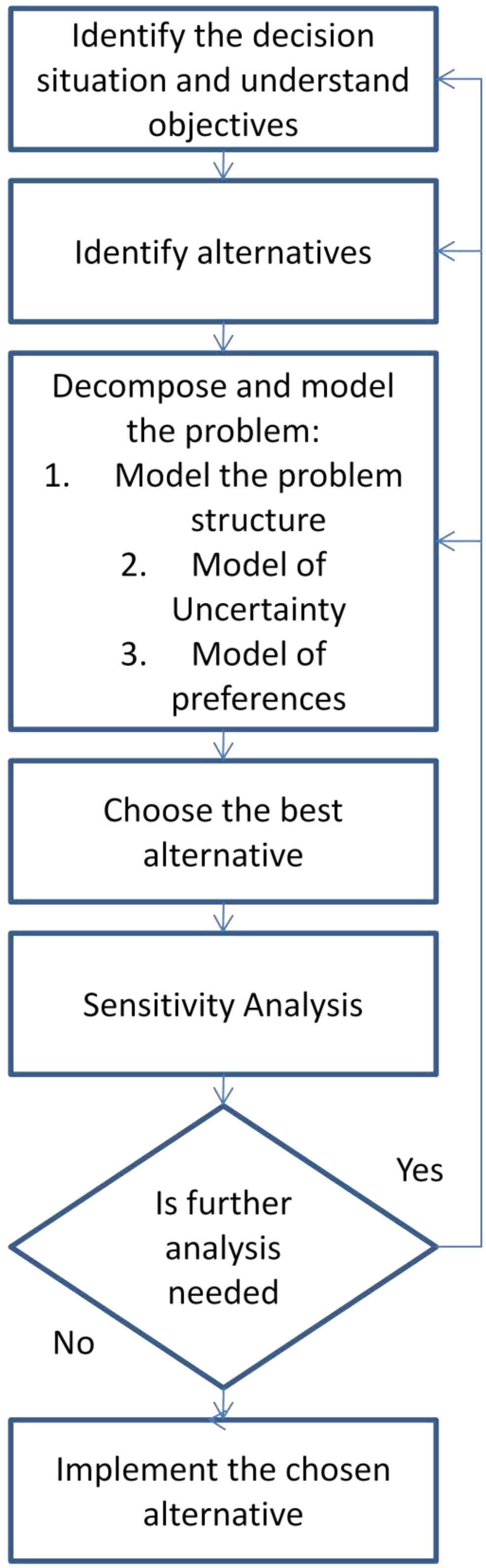


Figure 3: Decision Analysis 7 Step Process (Clemen & Reilly, 2001)

2. 6 Value Focused Thinking

Values are what we care about and thus should be the driving force for decision making (Keeney, 1992). Value focused thinking; a decision-making methodology is used to ensure that decisions are made in the most beneficial manner (Pruitt, 2003). Focusing early and deeply on values when facing difficult problems will lead to more desirable consequences, and even to more appealing problems than the ones we currently face (Keeney, 1992). Value-focused thinking involves starting at the best possible alterative and working to make it reality, while alternative-focused thinking involves starting with what is readily available and taking the best of the lot. Alternative-focused is the “natural” way we have learned to make decisions and is deeply engrained in us to make our choice out of the options available to us. Value-focused thinking can be thought of as constraint–free thinking, because we focus on what we want to achieve rather than the selecting from alternatives. Value-focused thinking should lead both to more appealing decision problems and to choices among better alternatives than those generated by happenstance or conventional approaches (Keeney, 1992) .

Any decision that is a real decision, is important to a person or organization, and is complex and there is no clear “solution” is ideal for VFT. When faced with a difficult decision start first by thinking about your values by writing down a list of your objectives. The principal of thinking about values is to discover the reasoning of each objective and how it relates to other objectives (Keeney, 1992).

The purpose of thinking about values is to pinpoint the values that are the drivers in a decision situation. Sometimes you may have a gut feeling about what values are relevant, but find them hard to articulate while other times you may have a difficult time determining what values are needed in a complicated decision. Figure 4 gives an overview of nine reasons why VFT could and would be effective in any business, government, or even personal decision making.

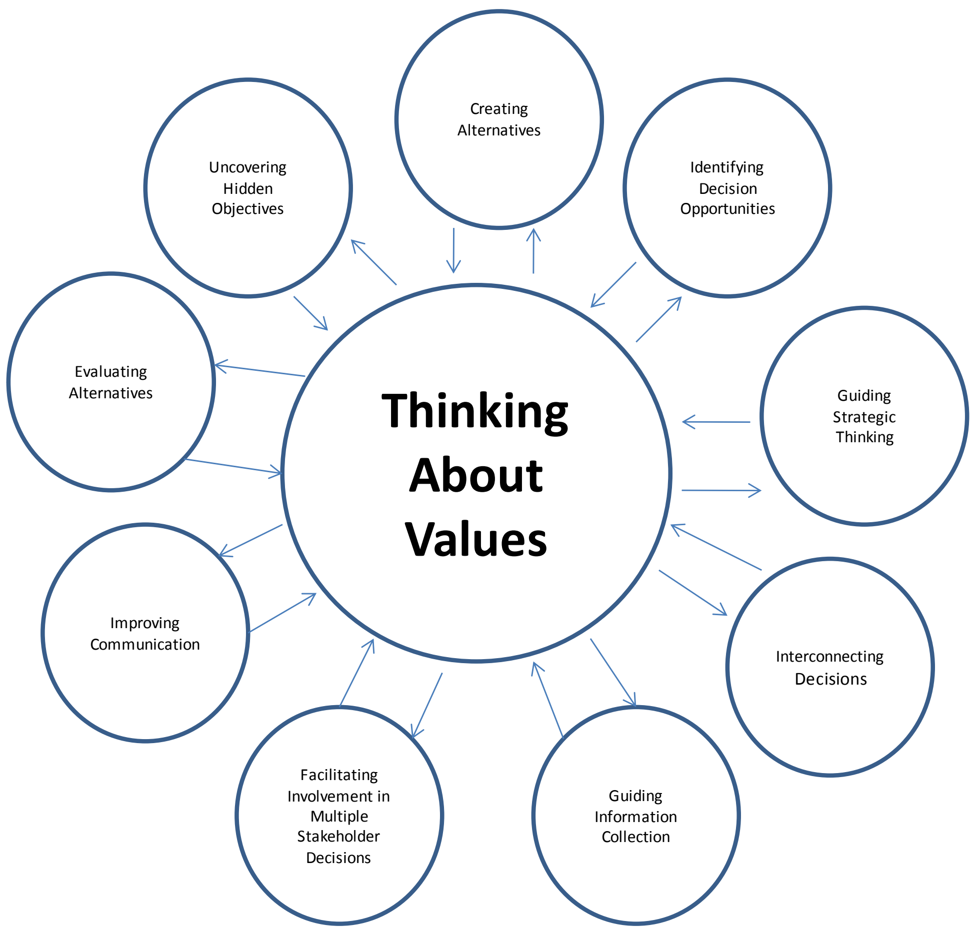


Figure 4: Overview of VFT (Keeney, 1992)

Before you can get into the steps or methodology of VFT, you must first understand the frame work of the process. The decision context and the fundamental objectives together provide the decision frame (Keeney, 1992). The decision context defines the set of alternatives appropriate for consideration, while the fundamental objectives determine the values in which one cares about and the class of consequence of concern. Better stated, fundamental objectives are the ends objectives of a given decision context. Fundamental objectives are the basis of interest in the decision being considered and qualitatively state all that is of concern in the decision context. For example, the decision context for a real estate investor could be what property to purchase. The fundamental objectives in this context could be price, square footage, neighborhood and property taxes

Strategic decision context requires that you have strategic objectives. All organizations have strategic objectives, whether written down or not, that help provide common guidance to all decisions and decision opportunities. They also serve as the mechanism by which management can guide decisions by individuals or groups (Keeney, 1992). Structuring strategic objectives can aid tremendously in decision making as it establishes a sound basis that can be repeatedly used and provides a reference point for even turbulent decision situations.

As stated above, most if not all of us, are alternative focused thinkers versus value focused thinkers. When a decision opportunity presents itself, the first thing we do is begin sorting through the alternatives we have versus focusing on our values and allowing those to shape our alternatives. There are major short comings to this method of decision making such as viable superior alternatives not being indentified. The objectives that are identified are often only means to the consequence that are of fundamental concern and there is no logical match between alternatives and objectives (Keeney, 1992). Fortunately, value focused thinking can significantly alleviate these shortcomings by allowing us to broaden the decision situation and define it more carefully. This is done by not thinking about means objectives until fundamental objectives are found and then from the opposite direction work back from strategic objectives to generate fundamental objectives. This new set of fundamental objectives will be much broader than the means objectives, but much narrower than the strategic objectives, giving you a well-defined decision frame.

Solving decision problems is the sole aim of alternative-focused thinking and is typically a reactive process. However you can think of value-focused thinking as not only a problem solving methodology, but as a proactive process that helps with the identification of decision opportunities.

Table 1: Comparing sequences of AFT & VFT

Alternative-Focused Thinking		
1. Recognize a decision problem		
2. Identify Alternatives		
3. Specify values		
4. Evaluate alternatives		
5. Select an alternative		
Value-Focused Thinking		
For Decision Problems	For Decision Opportunities	
	Before specifying strategic objectives	After specifying strategic objectives
1. Recognize a decision problem	1. Identify a decision opportunity	1. Specify values
2. Specify values	2. Specify values	2. Create a decision opportunity
3. Create alternatives	3. Create alternatives	3. Create alternatives
4. Evaluate alternatives	4. Evaluate alternatives	4. Evaluate alternatives
5. Select alternatives	5. Select an alternative	5. Select an alternative

There are five major steps that are associated with Alternative-Focused Thinking that are depicted in Table 1. The first three steps are the big difference between VFT and AFT. Step one of AFT "Recognize a decision problem" usually takes place as a result of actions out of the control of the decision maker and is generally a plea for something to be done. Step two is to "identify the alternatives." Sometimes this can be as easy as turning the light on or leaving it off. Regardless of the decision context all the alternatives are almost always already known prior to making the decision. In some instances decision makers attempt to search for additional alternatives, but the stated alternatives anchor the thought process and stifle creativity and innovation. The third step of AFT is typically done with much less thought than one would expect with the VFT process. Since alternatives are already identified, values are selected based on the alternatives available and no real thought about the fundamental objectives take place during this stage.

2.7 Summary

Intelligence is a stochastic process and it is difficult to know with any sort of certainty when a valuable piece of information will present itself. Commanders are and have been aware of this fact for years but still thrust their assets into situations that are less than optimal to try gain an edge in intelligence. GMTI onboard JSTARS is one of those capabilities that has been used in optimal and less than optimal conditions.

Through its' successes and failures intelligence analyst have gained valuable knowledge on how to successfully employ JSTARS. Using this knowledge and the knowledge of how to create MOEs that can effectively measure a system, this research will help decision makers use their dwindling assets more effectively and increase the value of information they receive.

AFT is the decision making process that most people undertake when a decision problem is presented. The previous material has shown how there are numerous short comings with making decisions in this manner. This research will help move decision makers from AFT to VFT in order to help them make decisions that are quantifiable, repeatable, and take into consideration the values of the objectives they are trying to achieve. Chapter 3 will further define and develop the VFT process and demonstrate how this methodology can help all involved make better decisions when it comes to using intelligence assets.

Chapter 3. Methodology

As stated, JSTARS has had many success and many failures over the years. In each situation there were key factors that enabled the system to fail or succeed. Using the VFT methodology we will be able to generate scenarios that will almost always produce positive results. If a decision maker decides to fly missions that don't perform well in the model, they will know before the mission is ever flown that the probability of getting high values information on said mission will be exceptionally low. In this chapter the VFT process will be described in greater detail. Specifically, the 10 steps of the VFT process will be expounded upon. Terms that will be important to know in this chapter and referenced often are listed below in Table 2.

Table 2: VFT Key Terms

Evaluation Consideration	Any matter that is significant enough to be taken into account while evaluating alternatives.
Objective	The preferred direction of movement with respect to an evaluation consideration. Assumes that preference displays a monotonic behavior which means either "more is better" or "less is better" with respect to each evaluation consideration.
Goal	The threshold of achievement with respect to an evaluation consideration which is either attained or not by any alternative that is being evaluated.
Evaluation Measure	A measuring scale for the degree of attainment of an objective. Example "annual salary in dollars"
Level or Score	A numerical rating for a particular alternative.
Value Structure	The entire set of evaluation considerations, objectives, and evaluation measures for a particular decision analysis.
Value Hierarchy or Tree	A value structure with hierarchal a "treelike" structure.
Layer or Tier	The evaluation consideration at the same distance from the top of a value hierarchy.

3.1 Introduction

The current value model process was created and compiled by Shovaik (Shoviak, 2001) and is broken down into 10 steps which is depicted in Table 3. The first and probably most crucial part of the VFT process is identifying the problem. Once the correct problem has been identified, it is now time to create the value hierarchy. This step entails sitting down with the decision maker or decision makers and finding out what are the things that they value or what is important about the particular decisions. For example, if you were purchasing a new home one of the things that would be of value to most people would be price. Section 3.3 will discuss the procedures for developing a value hierarchy.

Once the decision maker is satisfied they have captured everything that is important with the objective of the decision it's time to move on to step 3 of the process which is creating evaluation measures. Using the house example again, assume location was in the value hierarchy, what things about the location are important. Is it being close to your child's, school, being close to work or shopping malls, having sidewalks, high property values, or is it all of the above. Section 3.4 will go into greater detail on how to determine effective measures. The creation of value functions is the next step in the process. During this step a single dimensional value functions will be assigned to each measure which will assign a score to each alternative and will be discussed in-depth in section 3.5.

The weighting of the hierarchy is the next step in the process. In this step the decision maker will have to determine how much weight to give to each value in the hierarchy. This is an important step because it is when the DM determines which measures are most important and which are least important. It is important to note that steps 1 -5 all require input from your decision maker and/or subject matter experts. The remaining steps can and should be completed by the analyst without any input from the decision maker.

Generating alternatives is the next step in the process and is completed by populating the model with a fully exhaustive list of alternatives. Once the alternatives have been generated it's time to score each alternative. This process is done by scoring each alternative against every measure in the hierarchy. Once the scoring has been completed, the deterministic analysis takes place by multiplying the score in the particular measure against the weight that was given by the DM to come up with an overall raw score for each alternative. Sensitivity analysis is then done on the model to determine if small changes in the weight values will cause the ranking of the alternatives to change. The final step is to communicate the conclusions of the analysis and recommend a course of action to the decision maker.

Table 3: 10 Step VFT Process (Shoviak, 2001)

Step 1.	Problem Identification
Step 2.	Create the Value Hierarchy
Step 3.	Develop the Evaluation Measures
Step 4.	Create the Value Functions
Step 5.	Weight the Hierarchy
Step 6.	Generate Alternatives
Step 7.	Alternative Scoring
Step 8.	Deterministic Analysis
Step 9.	Sensitivity Analysis
Step 10.	Conclusions and Recommendations

3.2 Step 1: Problem Identification

The problem identification step is one of the most important steps in this entire process. It would be a shame to go through this entire process to learn at the out brief to your decision maker that you have committed a type III error and solved the wrong problem. Sometimes problem identification can be quite evident when deciding which car to purchase or which house to buy. At other times, it may take a little time to get down to the root cause of the problem. This is why it is imperative to take the time up front to determine what the true problem is, because if not, the resulting solution will have no value and be considered a wasted effort (Jurk, 2002).

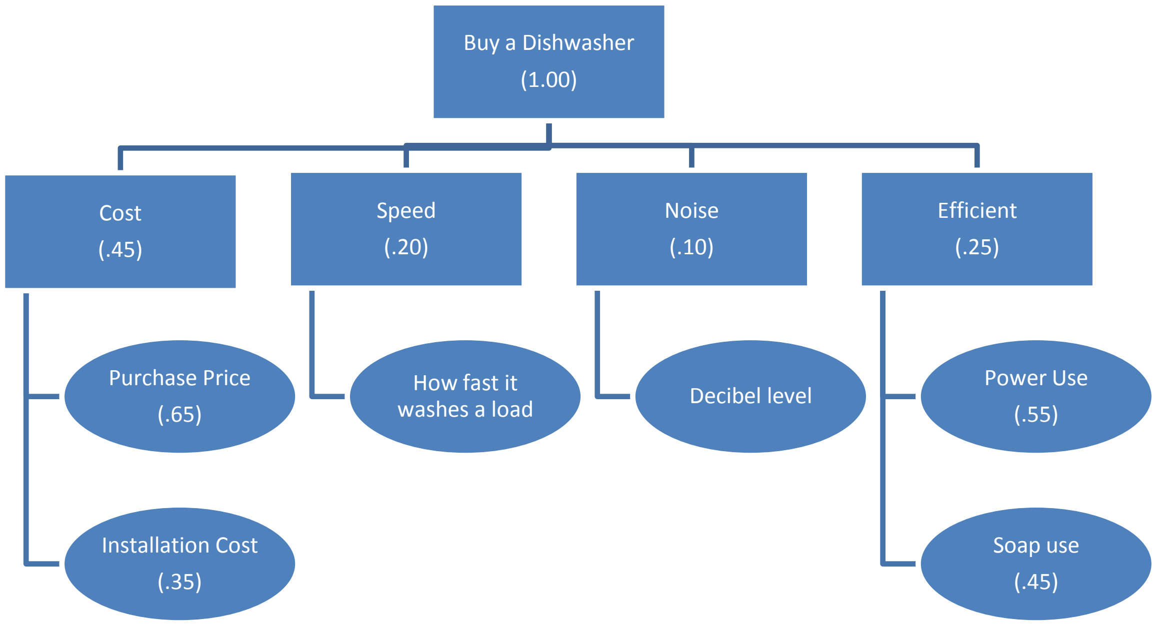


Figure 4: Dishwasher Example Hierarchy

3.3 Step 2: Creation of the Value Hierarchy

The value hierarchy serves as the apparatus that allows the decision maker to evaluate each alternative. The model structures the values that the decision maker has concluded to be important in context to their decision and uses some type of measure process to evaluate how each alternative scores. The hierarchy gives decision makers a repeatable and defendable decision making support and enables them to identify possible missing values. The hierarchy should without a doubt be collectively exhaustive and mutually exclusive, or in other words every value that is important should be explored and no two values or measures should represent the same thing.

3.3.2 Properties of the Hierarchy

The desirable properties of a hierarchy are completeness, non-redundancy, decomposability, operability, and small size (Kirkwood, 1997). A complete hierarchy is one that adequately covers all concerns necessary to evaluate the overall objective of the decision. Completeness ensures that the alternatives are adequately evaluated and ranked accordingly.

A non-redundant hierarchy is one where no two evaluation considerations in the same layer or tier of the hierarchy overlap. For example, in Figure 4 the cost of the dishwasher is divided into purchase price and installation cost. For this hierarchy to be non-redundant every cost associated with the dishwasher should fit one of these two categories.

Decomposability which is better known as Independence means that the score an alternative receives should not influence its score in another measure. This property is easier explained with an example illustrated by Kirkwood. Assume a "value of economics" issue with lower tier values of "salary", "pension benefits" and "medical coverage." Note that for the lower tier values, the "value attached to the variations in scores depends on the levels of the other two lower tier values." Simple stated, if the salary were $250,000 a year, there would be no value to a slight increase in "pension benefits" and "medical coverage." Therefore, the values are not independent (Kirkwood, 1997).

Operability means that the hierarchy is understandable for the person or persons that are using it. Operability generally becomes a problem when technical specialists have to interact with the general public. A great example of this is when technical experts had to interact with the public during the Three Mile Island nuclear power plant incident. During the analysis of the event, experts had a very difficult time presenting an assessment of risk to journalist and the general public. In general, it is better to compromise on some aspects of the hierarchy in order to create evaluation measures that are operable and easy to understand.

The final desirable property of a hierarchy is that it be of small size. A smaller value hierarchy can be communicated more easily to interested parties and requires fewer resources to estimate the performance of alternatives with respect to the various evaluation measures (Kirkwood, 1997). Many business, government, and not-for-profit groups have a tendency to keep adding evaluation considerations until the hierarchy becomes so complex that it becomes difficult for an analyst to conduct and interpret. The quest for completeness and detail must be balanced against the need to finish the analysis in a manageable time frame and budget. When faced with this issue analyst should use the “test of importance.” This test states that an evaluation measure should be included only if possible variations among the alternatives with respect to the proposed evaluation could change the preferred alternative (Kirkwood, 1997). For example, if you were purchasing a hat and all colors but red were acceptable, it probably would not be prudent to add color to the hierarchy since hats come in multiple colors.

3.3.2 Hierarchy Structure

There are a couple different approaches to developing or structuring a hierarchy. The method for developing a hierarchy is dependent on whether the alternatives are known at the time the hierarchy is being developed. If the alternatives are known, then a bottom up approach is appropriate, if not the top-down strategy is more appropriate. Most of the time it is necessary to build a specific hierarchy to solve your problem because creating a general-purpose hierarchy which would solve a wide range of problems is complex and impractical. However, since value modeling has been around for several decades, you can sometimes find and use a previously used hierarchy that fits your problem instead of starting from scratch.

In “bottom-up” or “alternative driven” alternatives are examined to determine the ways in which they differ. The evaluation measures are then developed to evaluate things in which the alternatives differ. This approach develops the bottom layer of the hierarchy, and then constructs the remainder of the hierarchy on top of this layer.

The “top-down” or “objective-driven” is used when alternatives are not as well known. The process starts with an overall objective and subdivides as appropriate to develop the bottom tiers. One of the main purposes of this method is to identify potential alternatives. Also by starting with an overall objective and subdividing it helps develop the evaluation considerations in greater detail. This is also the preferred method of most VFT modelers.

3.3.3 Standards of Information

In soliciting information about the hierarchy from decision makers and stake holders there are three standards, Gold, Silver and Platinum (Weir, 2010). The gold standard is the lowest of the three and entails using the decision maker’s strategic vision or plan to deductively develop the value hierarchy. The next standard, the silver standard, entails having meetings with a large group of stakeholders to inductively develop the value hierarchy using affinity diagrams. The final and best way to solicit information is the Platinum standard. This includes interviewing senior leaders and key technical personnel to again inductively develop the value hierarchy via affinity diagrams (Weir, 2010). This is the best way to get the information, but also the most difficult since senior leaders do not usually have time to sit down with an analysis and describe exactly what he or she wants multiple times.

3.3.4 Affinity Diagrams

An affinity diagram is a tool that gathers large amounts of data (ideas, opinions, issues) and organizes them into groups based on the nature of their relationships (Defense, Basic Tools for Process Improvement: Module 4 Affinity Diagram, 2007). The affinity process is a proven way to get people to work on creative level to address difficult issues. The process is extremely useful when sifting though large volumes of data because it allows team members to organize the data into groups. It is also useful when attempting to encourage new patterns of thinking. Since brainstorming is the first step in the process the team considers all ideas from all members without criticism. This often stimulates a creative list of ideas and allows members to break away from the traditional entrenched thinking.

When creating affinity diagrams there are three basic tenets that discussion leaders should always abide by. The first is “Do it silently.” The most effective way to work is to have everyone move items at will, without talking. This helps encourage unconventional thinking, discourages semantic battles and prevents one person from steering the affinity. The second tenet is “Go for the Gut Reactions.” This tenet encourages team members to react quickly as speed rather than deliberation is most important to keep the process moving. The final tenet is “Handle Disagreements Simply.” When a team member does not agree where an idea is grouped allow them to move it. If consensus still cannot be reached, create a duplicate and place one in each group. This creates an environment where it is okay to disagree.

Table 4: Steps to Creating an Affinity Diagram (Defense, Basic Tools for Process Improvement: Module 4 Affinity Diagram, 2007)

Creating an Affinity Diagram	
Step 1	Generate Ideas
Step 2	Display Ideas
Step 3	Sort Ideas Into Groups
Step 4	Create Header Cards
Step 5	Draw Finished Diagram

Creating affinity diagrams involves a five step process (See Table 4). The first step “Generate Ideas” is the brain storming session where all ideas are written on post-its. Step 2 “Display the Ideas” simply post all the ideas generated in a random order on a board or table. “Sorting the Ideas into Groups” is when team members do so without talking. They do this by looking for two ideas that seem related and placing them together. This process is repeated until all ideas have been placed in a group. (If there are ideas that don’t fit into any group, let them stand alone under their own headers (Defense, Basic Tools for Process Improvement: Module 4 Affinity Diagram, 2007).) Next is to “Create header cards for the groups.” A header is an idea that captures the essential link among the ideas contained in the group. The final step in the process is to “Draw the finished Affinity Diagram.” Write down the problem statement, place headers and super header cards above the groups, review and clarify groupings and document the finished affinity diagram.

3.4 Step 3: Develop Evaluation Measures

Evaluation measures, also called “measures of effectiveness,” “attributes” or “metrics” allow an unambiguous rating of how well an alternative does with respect to each objective.

3.4.1 Types of Evaluation Measure Scales

Table 5: Types of Evaluation Measure Scales

	Natural	Constructed
Direct	Commonly understood measures directly linked to strategic objectives - Example: Profit	Measures directly linked to the strategic objective but developed for a specific purpose - Example: Figure Skating
Proxy	In general use the measure focused on an objective correlated with the strategic objective - Example: Gross National Product	Measures developed for a specific purpose focused on an objective correlated to the strategic objective - Example: Student Grades

Evaluation measures can be classified as either natural or constructed and direct or proxy (see table 5). A natural scale is in general use with a common interpretation by everyone. A good example would be “number of fatalities” which is a natural scale for evaluating death. A constructed scale is one that is developed for a particular decision problem to measure the degree of attainment of an objective. These are typically used when natural scales are not appropriate. A direct scale is one that directly measures the degree of attainment of an objective, while a proxy scale reflects the degree of attainment of its associated objective, but does not directly measure this (Kirkwood, 1997). There are many questions that arise when developing evaluation measures such as should the scale be a natural proxy or a constructed direct? Should the scales be subdivided to provide further detail, or how carefully should you specify the scale definition of a constructed scale? Whatever scale you choose, the goal is to make sure that it is not ambiguous. The best scales always pass the clairvoyance test in that if there were a clairvoyant that could foresee the future with no uncertainty; they would be able to unambiguously assign a score to the outcome from each alternative. Most natural measures easily pass the clairvoyance test, but constructed scales can be more difficult to develop to do this.

3.5 Step 4: Creating Value Functions

Each measure that was created in the previous step has to have some mechanism to properly analyze each alternative and give it a score. The mechanism that is used to do this is the Single Dimensional Value Function. The SDVF enables a combination of multiple evaluation measures into a single index of the overall desirability of an alternative (Kirkwood, 1997). This is done by having the SDVF vary between zero and one over the range of the scores of interest. This allows an alternative with the most preferred option to have a score of one and the alternative with the least preferred option to have a score of zero.

3.5.1Types of Singe Dimensional Value Functions

There are two different types of SDVF's that will be discussed in the section. The first is the piecewise linear function which is made up of segments of straight lines that are joined together. The second is the exponential that uses a specific mathematical form.

The piecewise linear function is most practical when the evaluation measure being considered has a small number of possible scoring levels. In order to determine the piecewise linear function it requires that the relative value increments be specified between each of the possible evaluation measure scores (Kirkwood). Since all values are between 0 and 1, Figure 5 shows an example of a piecewise linear function. In the example, notice that if the alternative x-axis score falls under “choice 1” it receives no points and for that same measure if the x-axis score falls under “choice 5” the alternative receives all the points for that particular measure.

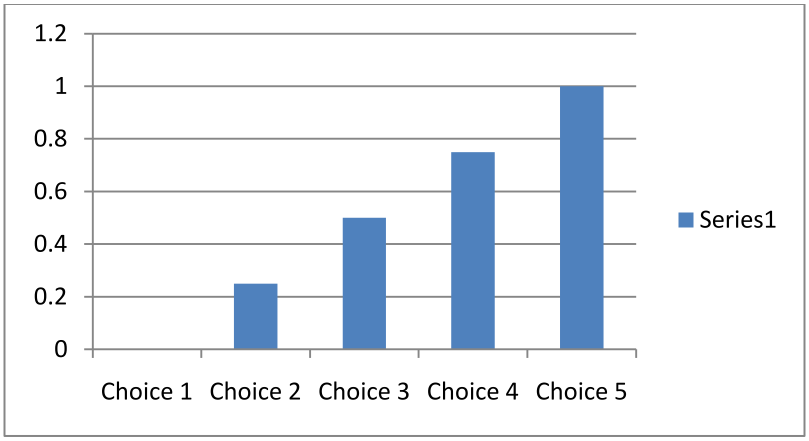


Figure 5: Monotonically Increasing Piecewise Linear Function

Sometimes it is extremely impractical to use a piecewise linear SDVF because of the large number of value increments that would have to be found. In these cases, it’s more appropriate to use an exponential SDVF .The exponential SDVF is used when the evaluation measure being considered can take on an infinite number of possible scoring levels as depicted in Figure 6. The exponential function has a particular form that depends on the range of the evaluation measure and an exponential constant denoted by the Greek letter ρ (rho). The shape of the exponential SDVF is dependent upon the value of ρ.

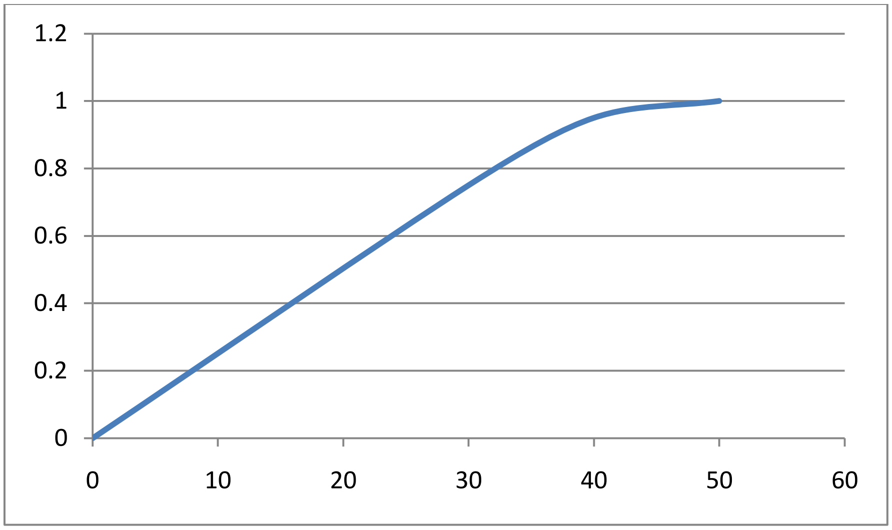


Figure 6: Monotonically Increasing Exponential SDVF

As ρ increases the shape of the graph becomes less curved until it becomes a straight line with infinitely large values. If the preferences are monotonically increasing over an evaluation measure x (that is, higher amounts of x are preferred to lower amounts) then use the equation in (Equation 4).

Equation 4: Monotonically Increasing Equation

If preferences are monotonically decreasing over x (that is, lower amounts of x are preferred to higher amounts) then use the equation in (Equation 5) where "Low" is the lowest level of x of interest , "High" is the highest level and ρ is the exponential constant

(Kirkwood, 1997). In a monotonically increasing function the *v*(Low) = 0 and the *v*(High) = 1. In a monotonically decreasing function the *v*(Low) = 1 and the *v*(High) = 0.

Equation 5: Monotonically Decreasing Equation

The appropriate value of ρ depends on the range of the possible scores for the evaluation measure. In particular, realistic values of ρ will generally have a magnitude greater than one-tenth of the range of the possible scores (Kirkwood, 1997). For instance, if the possible values range from 0 to 10 a realistic value of ρ would be 1 or greater if positive and -1 or less if negative. There is no upper limit for the magnitude, but once again as ρ grows infinitely large the value function curve will be straight.

3.6 Step 5: Weighting the Value Hierarchy

The final step of the value model that requires DM or stakeholder input are the weights. The weights are especially important in determining which alternatives will score the best. It is crucial to work closely with the DM to get the best set of weights possible. If the DM is unsure about some of their weights they will have an opportunity during sensitivity analysis to find out how sensitivity their choices are and what changes can lead to different decisions. During this step the DM determines the relative importance of each value and measure in their hierarchy. When weighting the hierarchy there are a few terms that one should be familiar before beginning. Those terms are branches, tiers, local weights and global weights. Below in Figure 7 the oval labeled as "Branch" depicts a branch of the hierarchy. Each value in a hierarchy should have a branch associated with it that goes down to the lowest tier of the branch which should be the evaluation measures. The next word is tier.

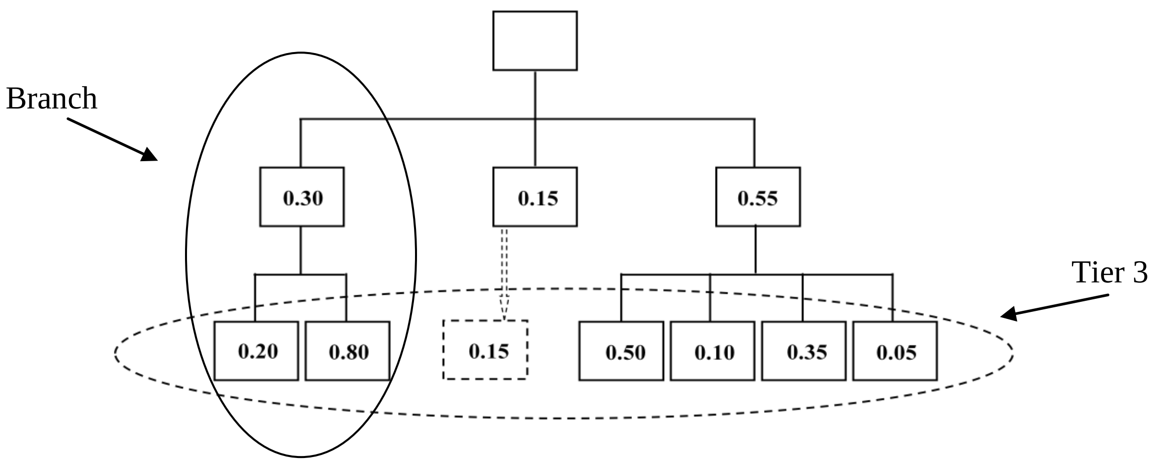


Figure 7: Tiers & Branches of a Hierarchy (Weir, 2010)

The evaluation considerations at the same distance from the top of a value hierarchy constitute a "layer" or "tier" (Kirkwood, 1997). Global weights sum to 1 across an entire tier and are calculated from the local weights (Weir, 2010). In Figure 8 below notice that the numbers across the bottom sum to 1. They are calculated by multiplying the local weight in the 2nd tier above times the local weight in the tier 3rd. For example, in the first branch multiple *.30 * .20* and you will get *.06*, its global weight. Global weights are used when using a bottom-up approach.

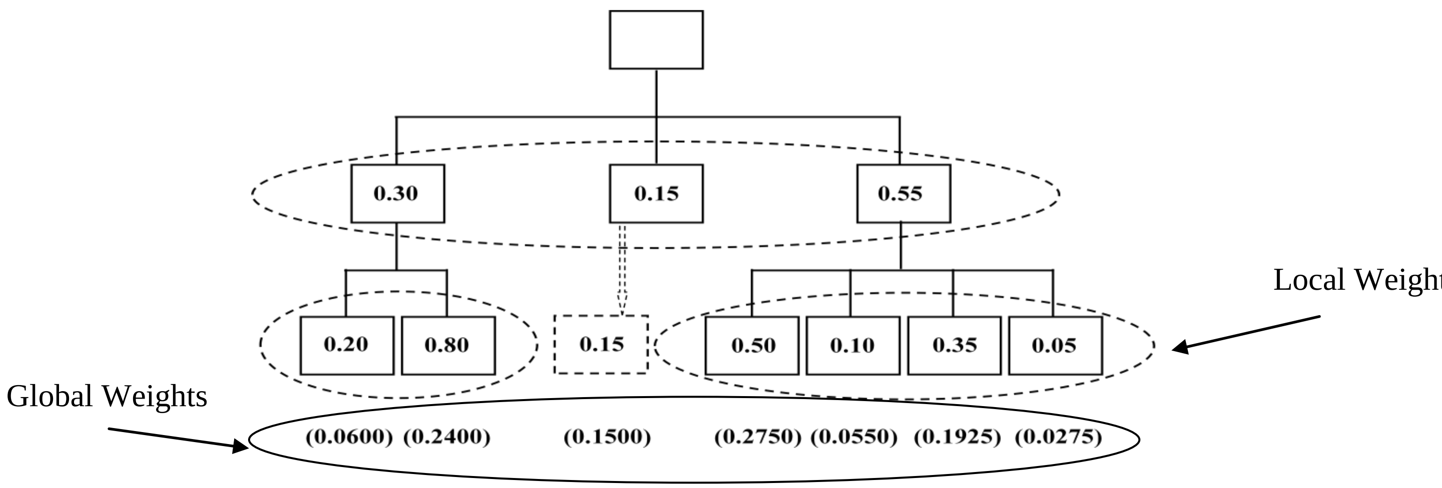


Figure 8: Global & Local Weights (Weir, 2010)

Local weights sum to 1 on a tier within a branch and are calculated from the global weights (Weir, 2010). For instances, in the first branch of the hierarchy in figure 8 .2 + .8 sum to1 and are the local weights of this particular branch.

3.6.1 Techniques to Determine the Weights

There are several techniques used to solicit the weights for the hierarchy. One way is the “group weight assessment procedure” or “direct assessment.” In many situations the weights are accessed using a group of people. In this process each person spreads 100 points (can be poker chips, pennies, etc) which equates to 100% of the weight among the different evaluation considerations. Once everyone has allocated their weight to the hierarchy, the discussion leader calculates the average weights. After calculation, discussion takes place of any significant differences. Once discussion is complete, a revote is taken and if there are no major differences then these are the weights for the hierarchy.

A second method is to build a Swing Weight Matrix. In this method a swing weight matrix like in Figure 9 is built. Next, with DM or stakeholder input, the values of each row are filled in with a number which indicates its importance. Next, each measure is placed in its appropriate box. After all measures are in their correct position the weights are calculated as a ratio of box_{ij}/sum of all boxes used.

		Level of Importance of Value Measure			
		Extremely Important	Very Important	Important	Less Important
Variation in Measure Range	Very High	1000	440	230	100
	High	750	380	210	90
	Medium	500	300	170	70
	Low	250	170	100	50

Figure 9: Swing Weight Matrix

A final way to calculates weights is via the Analytic Hierarchy Process or AHP. In order successfully complete this process a pair wise comparison of the measures to be weighted must be built. The next step is to judge the relative importance of each measure within a pair. Then, a comparison matrix is built and the max Eigen-value and Eigenvector is calculated. Once the Eigenvector is normalized you have the weights. This process seems more difficult than it really is. Today there are software packages that can help do this process. An example of what one of these software packages would look like is in figure 10. Here it shows that two measures can be compared to each other one at a time. Figure 10 reads as measure 1 is more important than measure 2, measure 1 is more important than measure 3, and measure 3 is more important than measure 2.

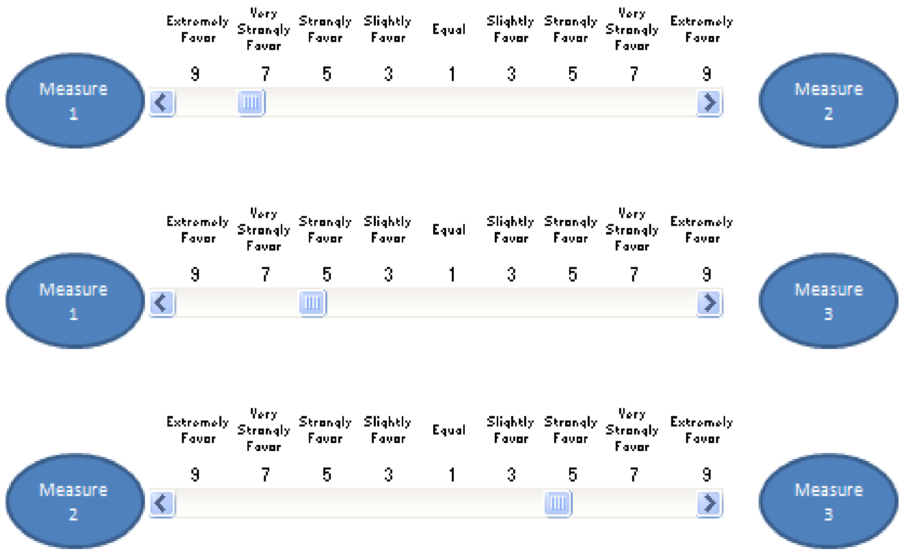


Figure 10: AHP Example

3.7 Step 6: Alternative Generation

Keeney states "The range of alternatives people identify for a given decision situation is often unnecessarily narrow (Keeney, 1992)." This is mostly caused by a need to feel progress toward reaching a solution to the decision problem. The genius of VFT is that it is considered to be constraint-free thinking. This method allows freedom to consider options that normally would not, and then allow the model to determine which one objectively does the best in meeting the objectives.

Often in decision making opportunities there is always the "do nothing" option or "status quo." Regardless if this is the best option or not, most of the time this is the anchor point for creating more alternatives which limits the search to similar alternatives.

This tendency can be counteracted by beginning the search for alternatives at the “ideal point” or best hypothetical alternative and then down grading that alternative until it reaches the feasibility region. There are usually several different anchors in terms of consequences that can be used in a given problem (Keeney, 1992). Each anchor should search different places in the mind for alternatives.

Kirkwood suggests that thought is an “associative process” and people think about a new situation by making mental associations with previous situations that seem relevant. These associations occur with relative little conscious control an ideas “pop into our minds” and they are used as a basis for structuring our consideration of the new situation (Kirkwood, 1997).

3.7.1 Method for Generating Alternatives

There are a few different ways to develop good alternatives. One way is to develop them based off the lowest tier of the hierarchy one at a time (Kirkwood, 1997). This is done by developing alternatives that do well in one of the evaluation criteria while not considering the others. The alternatives generated are typically too one-dimensional to be feasible, but they allow a combination of the strong points of each to make better alternatives.

A hybrid approach to the first option is to consider multiple objectives. This approach is started by considering two objectives at a time. The alternatives created now are likely to be refinements or combinations of those created using single objectives (Keeney, 1992). Then take three objectives at a time, then four and so on, until all objectives have been considered together. The final step is to examine the alternatives that have been generated to see if it is possible to combine any of them into a single alternative. Again, these alternatives may not be feasible either.

Another method is to maximize objectives at a higher tier in the hierarchy (Kirkwood, 1997). This method is likely to generate alternatives that are more balanced than ones generated by focusing on the lower tiered objectives.

3.7.2 Number of Alternatives

In some cases there are far too many alternatives and in others there may be far too few. In this section we will briefly discuss some methods to increase or decrease the number of alternatives generated.

Having a large number of alternatives generally presents two problems. Primarily, it is difficult to organize/evaluate information about the alternatives and secondly it is extremely difficult in some situations to collect the required information about the potential alternatives (Kirkwood, 1997). In some situations there are literally an infinite number of alternatives. For instances, if there was a value hierarchy that composed of several exponential single dimensional value functions it would be virtually impossible to enumerate every possible combination as each exponential SDVF has an infinite amount of choices. In many portfolio problems combinational growth can grow rapidly. The number of -combinations of a set with elements is represented by

Equation 6

Having only 10 different alternatives will generate 1023 possible combinations. A method to reduce the number of alternatives is to use screening criteria. Screening the list of alternatives to marginally reduce the size of the alternative pool can greatly reduce the number of combinations and thereby the time and costs associated with evaluation (Cote, 2010). Using the dishwasher hierarchy in Figure 5, a good example of screening criteria will be illustrated. Say for instances you only had $500 to purchase the new dishwasher. It would be feasible to screen out dishwashers over $550 as you probably will not be able to afford any above this price. Don't make the mistake of screening exactly at $500 because there may be better options right above $500 in which you may be able to negotiate or get discounts which will make them affordable. It is important to select screening criteria that is relatively loose so not to exclude alternatives that would be most preferred.

When there are too few alternatives, associative reasoning can both help and hinder the process. The reasoning process can help because they may generate ideas that do not seem at first to be relevant, but turn out to be useful. However it can also hinder the process because it allows you to quickly build a "good story" to why you already have all the alternatives you need. Therefore, there is a tendency to "rush to judgment" and select an alternative before giving careful consideration to other possibilities (Kirkwood, 1997). There are several methods for developing more alternatives but most of them center on using the existing list of alternatives and creating more attractive alternatives from those.

3.8 Step 7: Score the Alternatives

Once the alternatives and the SDVF's are in place the scoring part is pretty easy. It's simply a matter of determining the *x*-axis value and then reading the value off the *y*-axis. The most important part of the step is ensuring that the x-axis has been "clearly" defined. You want to ensure that if someone was analyzing your model with the same alternatives 10 years from now that they would come to the same conclusions.

Years ago the scoring process was a tedious one done by subject matter experts considering each alternative for a particular measure before advancing to the next. This allowed SME's to maintain clarity for each measure definition and its associated categories along the *x*-axis and ensured each alternative was scored consistently (Jurk, 2002) . Today finding the overall values for the alternatives using the value functions is pretty simple as the calculations are generally done by an electronic spreadsheet or special program.

3.9 Step 8: Deterministic Analysis

Deterministic analysis is simply the process of taking the score of the alternative that was achieved in step 7 and multiplying it times the weight the decision maker decided upon for the specific measure in step 5. There are two value functions that are primarily used, the additive value function and the multiplicative value function. The additive value function is the simplest and easiest to use and is commonly used among value modelers. The additive value model is depicted below in Equation 7

Equation 7

where *w* represents the weight of the particular measure and *v* represents the value given of the particular alternative for all alternatives. These values are added up and each alternative is given a score from 0 to 100 based on how it scored on each measure in the model. At this point there is a list of alternatives that are ranked from 1 to n and sensitivity analysis can begin.

3.10 Sensitivity Analysis

Sensitivity analysis is the process of taking the ranked list of alternatives and determining if small changes in weights would cause the rank order to change. During this process typically the weights of one of the measures are changed within some specified range while holding the weights on the other measures constant. Sensitivity analysis can also be completed on SDVF's but it's really not a feasible technique as you don't see a great deal of change by doing this (Weir, 2010). This process shows the DM how important his weights are and if they changed their mind on what was important, which alternative would be the most attractive. Sensitivity analysis can be performed on the local or global weights.

The current strategy for sensitivity analysis and changing weights is depicted below in Equation 8

Equation 8

where w_i represents all changing weights in the sensitivity analysis, w_s represents the weight under consideration w_i^o represents all changing weights' original values in the first model and m represents the number of dependent weights (Weir, 2010). This analysis is single dimensional and only allows one weight manipulation for analysis.

There are several ways to do sensitivity analysis, but the two main ways that are commonly used are global and local proportional. Global proportional is used to determine how much weight would have to be taken from the entire model to change the preferred alternative. This method is mostly used when there is one DM making all the decisions about the weights. If there is one DM weights at the top of the hierarchy, but the branches are controlled by other personnel, then local proportional weighting is used. This method allows sensitivity analysis to take place at lower levels of the hierarchy without changing the weights on the top values. It depends on what type of analysis is being done which technique would be best to use.

3.11 Recommendations and Presentation

Once sensitivity analysis has been completed it's time to present the DM with the results. The DM may or may not have a strong math background so instead of boring them with information on how the results were attained, get straight to the point and let them know what their best alternatives are. This is also an opportunity to give them some insight on their weight sets and how sensitivity some of them are. This information will be extremely beneficial and enlightening, especially if they were not too sure on their weights in the first place.

3.12 Summary

VFT is a ten step process that begins with determining what the true problem is and ends with briefing the recommendations from the analysis. Within those steps, 1-5 require plenty of DM or stakeholder input and steps 6-10 are done at the discretion of the analyst. The overall purpose of the process is to have a decision making process that is defendable, repeatable and allows sensitivity analysis to identify areas where a small change in the weights can change the desired or preferred alternative.

Using these steps, a real world example will be performed on the JSTARS in chapter 4 to determine which environments maximize the GMTI capability. Through this analysis, it will illuminate some of the good and bad elements of how this capability is currently being used.

Chapter 4 Results and Analysis

In chapter 3 a great deal of attention was taken to explain the ten step value focused thinking process. In this chapter, a brief explanation of the specific steps that were taken for this particular thesis work will be given. The majority of this chapter will focus on the deterministic and sensitivity analysis, steps 8 and 9 of the value-focused thinking process. This section will focus mainly on how and why the preferred alternative rose to the top and others did not.   Additionally, the results of the sensitivity analysis on the local and global weights are examined to see how changes in weights would influence the ranking of the most preferred alternative.

4.1 Problem Identification

The sponsoring agency of this work (DIA) presented the problem of having no way to model or measures the effectiveness of an asset with the GMTI capability. It was decided to use the JSTARS as the test case since it is the premier GMTI asset in the AF inventory even though there are other assets with this capability. Specifically, they wanted to know "how do you determine the effectiveness of GMTI when there is no amount of traffic that makes this capability more or less effective?" As stated previously, they currently use MOP's to measure their effectiveness. Unfortunately, the MOP's they use do not translate into usable information when trying to model how many GMTI assets are required or how well they are doing collectively when modeling the intelligence process.

4.2 Creation of the Hierarchy

The intent was to use intelligence analyst from the United States Central Command as the subject matter experts, since the aircraft is currently deployed in its' AOR. However, after multiple attempts to meet and subsequent cancellations, it became obvious that there was a need to use an alternative subject matter expert (SME). The decision was made to use the men and women of the 116 ACW as the SME's. Specifically, the SME's consisted of Senior Directors, Surveillance Officers, Mission Crew Commanders, Deputy Mission Crew Commanders, and Senior Surveillance Mangers. A list of the crew duties can be found in appendix A along with the names and duty titles in appendix D.

The value hierarchy was created over two 4 hours periods using the affinity diagram method. During this time the SME's named all the values that were key in the successful implementation of GMTI. After some lively discussion, grouping and regrouping they came up with the hierarchy that is depicted in Figure 11.

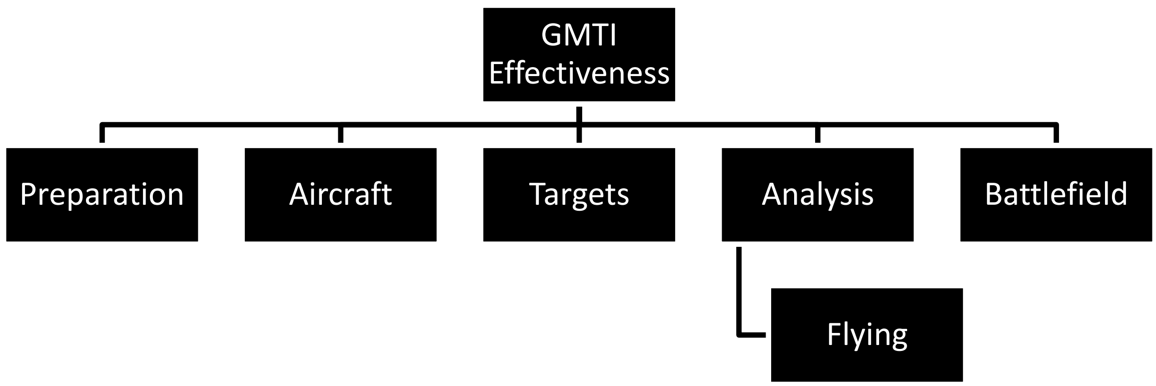


Figure 11: Values of GMTI Hierarchy

In Table 6 below are definitions of what each value means and how each value affects the effectiveness of GMTI.

Table 6: Definition of Values

Values	Definitions
Preparation	Deals with the pre-analysis that takes place prior to the engagement beginning
Aircraft	Deals with things that can be directly controlled by the crew or planners of the missions.
Targets	Deals with things that directly deal with the environment of the targets
Analysis	Deals with the during mission and post mission analysis of the information being provided
Battlefield	Deals with things that are not target related and concerns other aircraft and locality of JSTARS

4.3 Develop Measures

During the same period, the SME's went ahead and developed the evaluation measures for the hierarchy. If you recall, measures are either natural or constructed and direct or proxy. (See section 3.4 if you need a reminder of what this means.) In Table 7 it shows the name of the measure and its definition. This information was used to build the second tier of the value hierarchy structure that is depicted in Figure 12.

Table 7: Measure Definitions

Value	Measure Name	Definition
Preparation	Intelligence Preparation of the Battlefield (IPB)	Categorical (yes or no) measure. Where the crews able to get in country before the engagement began to get an idea of what the steady-state traffic flow was like. JSTARS specific.
Aircraft	Surveillance Area	Categorical Measure with 4 or less being the best and 9 or more being the worst. The trackers onboard the aircraft can only track about 4-15X15 areas at any one time with a high degree of accuracy. Once the tracking areas get larger in size or more than 4 the tracking accuracy goes down.
	Altitude	Decreasing Single Dimensional Value Function with 10,000 being the worst and 28,000 being the best. The aircraft has an optimal AGL altitude that maximizes radar performance, as you get below that altitude the radar performance degrades.
	Distance	Decreasing and increasing SDVF. Is the distance the aircraft is from the area of interest the optimal distance for radar performance? The optimal distance is the distance located in the Jane's manual. Measure is penalized for the aircraft for being too close & too far away.
Targets	Terrain	Categorical Measure with 5 different categories. The categories from best to worst are Water, Desert, Light Vegetation/Grasslands, Urban/Mountainous Environment, and Ice. The type of terrain that the aircraft is operating in plays a significant role on how well the radar performs.
	Weather	Categorical Measure 4 different categories. The categories from best to worst are Dry, Light Precipitation, Heavy Precipitation, and Snow/Ice. The weather the targets are operating in plays a major role in radar performance.
	Type	Categorical Measure with 5 different categories. The categories from best to worst are Large Boats, Tanks, Car/Truck, Human, and Birds. The category size of the target helps identify the target easier; therefore this measure will be defined by the radar cross section of the target.

	Number	Increasing SDVF with 1 being the worst and 15 or more being the best. The total number of targets in each in the particular area that are being tracked on the particular target helps great increase the fidelity of the targets.
Analysis	Positive Identification (PID)	Categorical (yes or no) measure. Do you have a "proper" positive identification asset? For example it would not be a proper PID asset for a human walking to ID a vehicle driving down the road.
	Communication	Categorical (yes or no) measure. Are you directly working with an agency that is prosecuting the particular target?
	Feedback	Categorical (yes or no) measure. After the mission is complete are you getting any type of feedback from the agencies that you are supporting on how helpful the information was that you provided. Also what you can do on the next mission to enhance the value of the information you are providing. This is not the agency that you were working with to prosecute the target.
Battlefield	Location	Categorical (yes or no) measure. Is the orbit that is provided in the best location to see the particular target.
	De-Confliction	Categorical (yes or no) measure. Has the airspace been de-conflicted so that the radar and communications are not being jammed by another asset?

It is extremely important to note that an independent study done by the MITRE Corporation showed some of the same things to be important factors when attempting to optimize the GMTI capability. The factors they found important in optimizing GMTI were mission, target, environment and sensor selection (Bonaceto, Mooers, Theophanis, & Wrick, 2010). Target and environment were already captured in the model. Mission is captured as well as the model in Figure 12 is the High Value Target model, when prosecuting a forensics only mission the "Analysis" value would be deleted along with everything beneath it. The final thing they thought to be important, sensor selection, is not a factor in this study as there is only one to choose. Thus there independent study helped validate the working model.

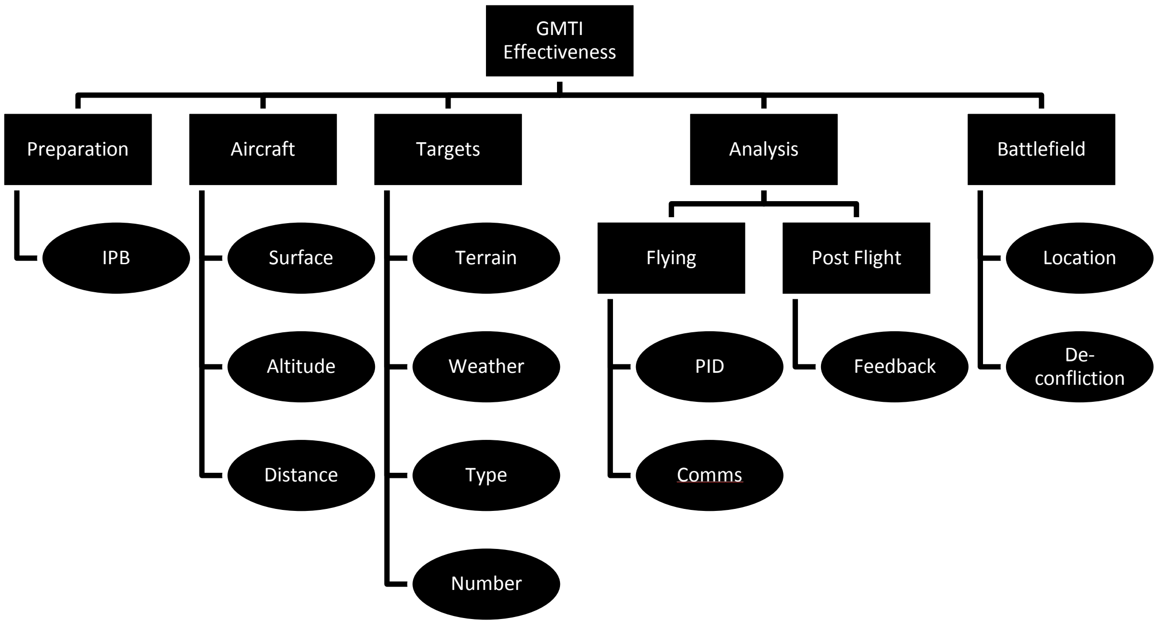


Figure 12: GMTI Hierarchy with Measures

4.4 Create Value Functions

Armed with the measures and their definitions the SME's next proceeded to create the value functions for each measure. There were 13 measures and of those 13, ten were given piecewise linear or categorical SDVF's and the other three were given exponential SDVF's. The 10 categorical measures were designated as such because there were only a small amount of vales that each category could possibly be. The measures distance, altitude, and number were all given exponential SDVF's because they could take on 10 or more values.   All of the SDVF's are located in appendix 3. The only thing remarkable about any of the functions was the one for distance. Since this measure penalized the aircraft for being too close and too far away, there had to be two exponential functions created. In figure 13, the exponential SDVF “Distance I” measures when the aircraft is between 0 to 50 miles.

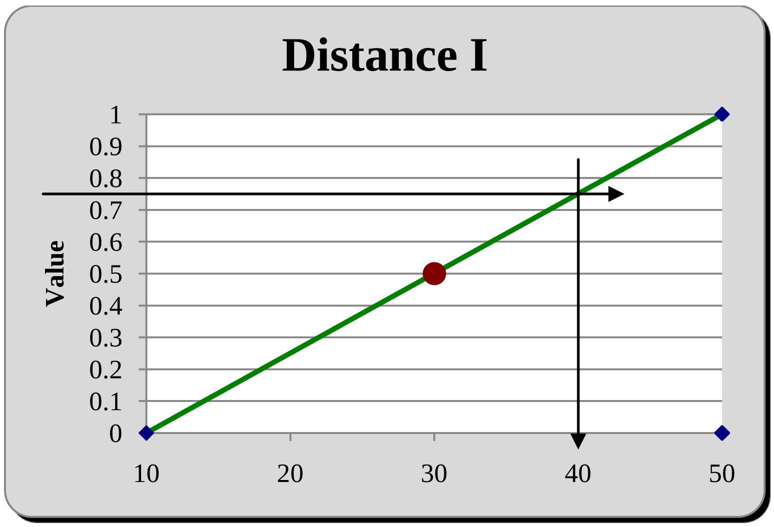


Figure 13: Distance Measure I SDVF

The second exponential SDVF “Distance II” in Figure 14 measures when the aircraft is between 60 miles away or greater. Anything between 50 and 60 automatically gets a score of 1. Since the software (Hierarchy Builder) only allows one SDVF per measure, if the aircraft distance was located in “distance II” then it required the user to interpret the data and place it in “distance I” For example, if the aircraft was 70 miles away the user would have to interpret where 70 was located on the y-axis in Figure 14 (.76) then take that information and put it into the y-axis in “distance I” in Figure 13 and determine the x-axis value (40) which is the number that would go into the model.

Figure 14: Distance Measure II SDVF

4.5 Weight the Hierarchy

The weighting of the hierarchy was done using the direct assessment method. Each SME was explained how the weighting process worked. After, they were all given a sheet with the entire hierarchy and told to independently determine what they thought the weights should be for each measure & each value. Once complete, all weights were put on the board. Any weights that were significantly different were discussed and a re-reweighting process was done on the measures independently. Remarkably, the weights on the first try were very similar and there were only a few differences that needed to be discussed and reweighed. The final weighted Hierarchy is located below in Figure 15.

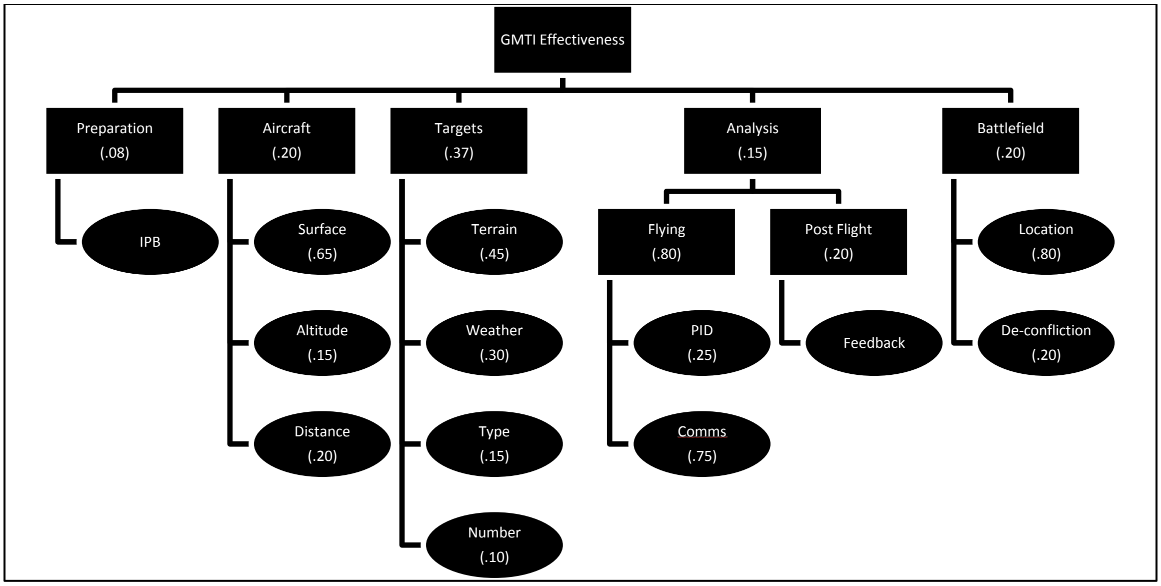


Figure 15: Final Weighted Hierarchy

4.6 Alternative Generation

The alternative generation stage required some thought and resourcefulness to get the alternatives down to a manageable number. At first glance it was thought to enumerate every possible combination. With 13 measures and 10 of them being categorical, enumerating the 10 categorical would be 25,600 alternatives. If the 3 exponential SDVF's that can take on an infinite amount of possibilities were added, there would be an intractable number of alternatives. Even if the exponential SDVF's were broken into 4 different quadrants there would still be 1.6 million possible alternatives.

To arrive at a manageable number of alternatives it was decided to use a preponderance of the weight to derive the alternatives. Using the measures *IPB*, *Sur Area*, *Terrain*, *Weather*, *Type*, *Location*, *De-confliction*, and *Communication* comprised of 83.3% of the total hierarchy as seen in Table 8. Any alternative that rose to the top of this modified hierarchy will also be in the top of the overall hierarchy. For example, the measure “Weather” which was included in the modified hierarchy was enumerated by its four different categories of ice/scow, heavy precipitation, light precipitation, and dry where as the measure “Number” was simple given the value that would achieve a score of one in that measure which was 15. Table 8 depicts the global weight of each measure. The measures that are highlighted are the measures that were optimized to their max performance during the scoring of the alternatives. These measures were chosen not to be included because they had the lowest global weights and because many of them are controlled by the planners and crews. By doing this, each alternative score was artificially inflated 17% before the scoring process ever began.

Table 8: Measure Order by Global Weight

Measure Ranking	
Measure	**Global Weight**
Terrain	0.1665
Location	0.16
Surface Area	0.13
Weather	0.111
Communication	0.09
IPB	0.08
Target Type	0.0555
Distance	0.04
DeConfliction	0.04
Number	0.037
Altitude	0.03
PID	0.03
Feedback	0.03

Using the 8 remaining measures (all categorical) 9600 alternatives were generated. Even though this number was far less than the 1.6 million or more that could have been generated, it was still far too many. To get an acceptable number of alternatives, the 9600 alternatives were input into the model and once they were ranked the top, middle, and bottom 400 alternatives would be used for analysis. 1200 alternatives still made it difficult to perform good analysis, so those 1200 were broken down even further. Using the *weather* measure, each or the 3 groups were broken down into 4 categories of *dry*, *heavy precipitation*, *light precipitation*, and *snow/ ice*. Within the groups they were separated into 4 groups of 100. Finally, a random draw was taken from each of the 16 groups to come up with the alternatives used for analysis.

Table 9: Top 400 Alternatives Broken into Weather Categories

Top 400 Alternatives				
	Top 100	101-200	201-300	301-400
Dry	56	50	45	44
Heavy Precip	8	18	16	20
Light Precip	36	32	31	31
Snow/Ice	0	0	8	5

For example, Table 9 represents the break-out of the top 400 alternatives. One alternative was randomly selected from each group providing 14 alternatives for analysis since there is no *snow/ice* alternative in the top 200 alternatives. Completing this exercise for the middle and bottom alternatives produced 46 alternatives that could be easily manipulated to conduct deterministic and sensitivity analysis. There was also some analysis done on any alternative that scored 75% or better in the model of which there was 1758.

4.7 Score the Alternatives

Once a manageable number of alternatives was reached, the alternatives were rescored and used for analysis. The scores of the 46 alternatives used are located in Table

11. The measures that were not used in the final scoring of the alternatives are not depicted in the Table 10 nor are they depicted in Figure 16, the graphical depiction of the scored measures.

Table 10: Alternative Scores

Possible Score	0.1665	0.16	0.13	0.111	0.09	0.08	0.0555	0.04	1
Measure	**Terrain**	**Location**	**Sur Areas**	**Weather**	**Comms**	**IPB**	**Type**	**Deconflict**	**Score**
light 2244 0.969	0.1582	0.16	0.130	0.089	0.09	0.08	0.0555	0.04	0.9695
Dry 2242 0.959	0.1582	0.16	0.098	0.111	0.09	0.08	0.0555	0.04	0.9592
Heavy2184 0.922	0.1582	0.16	0.130	0.050	0.09	0.08	0.0472	0.04	0.9223
light 1013 0.914	0.1582	0.16	0.117	0.089	0.09	0.08	0.0527	0.00	0.9137
Heavy2218 0.904	0.1665	0.16	0.098	0.050	0.09	0.08	0.0527	0.04	0.9037
Dry 929 0.892	0.1665	0.16	0.117	0.111	0.09	0.08	0.0000	0.00	0.8915
light 1650 0.888	0.1665	0.16	0.130	0.089	0.00	0.08	0.0555	0.04	0.8878
Heavy1013 0.875	0.1582	0.16	0.117	0.050	0.09	0.08	0.0527	0.00	0.8749
Snow2184 0.872	0.1582	0.16	0.130	0.000	0.09	0.08	0.0472	0.04	0.8724
Dry 981 0.872	0.1582	0.16	0.059	0.111	0.09	0.08	0.0472	0.00	0.8719
Snow2189 0.868	0.1665	0.16	0.117	0.000	0.09	0.08	0.0472	0.04	0.8677
Heavy1048 0.866	0.1665	0.16	0.098	0.050	0.09	0.08	0.0555	0.00	0.8665
light 1036 0.864	0.1249	0.16	0.098	0.089	0.09	0.08	0.0555	0.00	0.8637
Dry 1582 0.861	0.1582	0.16	0.098	0.111	0.00	0.08	0.0472	0.04	0.8609
Heavy2289 0.627	0.0333	0.16	0.059	0.050	0.09	0.00	0.0278	0.04	0.6265
light 2288 0.626	0.0333	0.16	0.020	0.089	0.09	0.00	0.0278	0.04	0.6264
Snow432 0.626	0.0333	0.16	0.130	0.000	0.00	0.08	0.0555	0.00	0.6258
Dry 398 0.624	0.0333	0.16	0.020	0.111	0.00	0.08	0.0527	0.00	0.6235
Dry 2006 0.622	0.1665	0.00	0.020	0.111	0.09	0.00	0.0278	0.04	0.6218
Heavy365 0.621	0.0000	0.16	0.117	0.050	0.00	0.08	0.0472	0.00	0.6211
light 856 0.621	0.1249	0.00	0.098	0.089	0.09	0.00	0.0527	0.00	0.6209
Snow1625 0.620	0.0000	0.16	0.117	0.000	0.00	0.08	0.0555	0.04	0.6195
light 1924 0.619	0.0000	0.00	0.098	0.089	0.09	0.08	0.0555	0.04	0.6188
Heavy1842 0.618	0.0333	0.00	0.130	0.050	0.09	0.08	0.0278	0.04	0.6180
Dry 368 0.618	0.0333	0.16	0.020	0.111	0.00	0.08	0.0472	0.00	0.6180
Snow2290 0.616	0.0333	0.16	0.098	0.000	0.09	0.00	0.0278	0.04	0.6156
Heavy2131 0.615	0.0000	0.16	0.000	0.050	0.09	0.08	0.0278	0.04	0.6147
Dry 1221 0.615	0.1582	0.00	0.059	0.111	0.00	0.08	0.0000	0.04	0.6147
light 136 0.614	0.1249	0.00	0.098	0.089	0.00	0.08	0.0555	0.00	0.6137
Snow1905 0.613	0.1249	0.00	0.059	0.000	0.09	0.08	0.0527	0.04	0.6131
Snow229 0.372	0.1582	0.00	0.000	0.000	0.00	0.00	0.0472	0.00	0.3724
light 273 0.370	0.0000	0.00	0.059	0.089	0.00	0.00	0.0555	0.00	0.3698
Dry 247 0.364	0.0333	0.00	0.000	0.111	0.00	0.00	0.0527	0.00	0.3640
Heavy758 0.360	0.0333	0.00	0.020	0.050	0.09	0.00	0.0000	0.00	0.3598
Snow481 0.355	0.0000	0.16	0.000	0.000	0.00	0.00	0.0278	0.00	0.3548
Heavy1383 0.343	0.0000	0.00	0.059	0.050	0.00	0.00	0.0278	0.04	0.3432
light 247 0.342	0.0333	0.00	0.000	0.089	0.00	0.00	0.0527	0.00	0.3418
Dry 1352 0.338	0.0000	0.00	0.020	0.111	0.00	0.00	0.0000	0.04	0.3375
Snow1981 0.325	0.0000	0.00	0.000	0.000	0.09	0.00	0.0278	0.04	0.3248
Heavy1412 0.324	0.0000	0.00	0.020	0.050	0.00	0.00	0.0472	0.04	0.3236
light 187 0.317	0.0333	0.00	0.000	0.089	0.00	0.00	0.0278	0.00	0.3169
Dry 157 0.311	0.0333	0.00	0.000	0.111	0.00	0.00	0.0000	0.00	0.3113
Dry 151 0.278	0.0000	0.00	0.000	0.111	0.00	0.00	0.0000	0.00	0.2780
light 152 0.275	0.0000	0.00	0.020	0.089	0.00	0.00	0.0000	0.00	0.2753
Snow1353 0.266	0.0000	0.00	0.059	0.000	0.00	0.00	0.0000	0.04	0.2655
Heavy182 0.264	0.0000	0.00	0.020	0.050	0.00	0.00	0.0278	0.00	0.2642

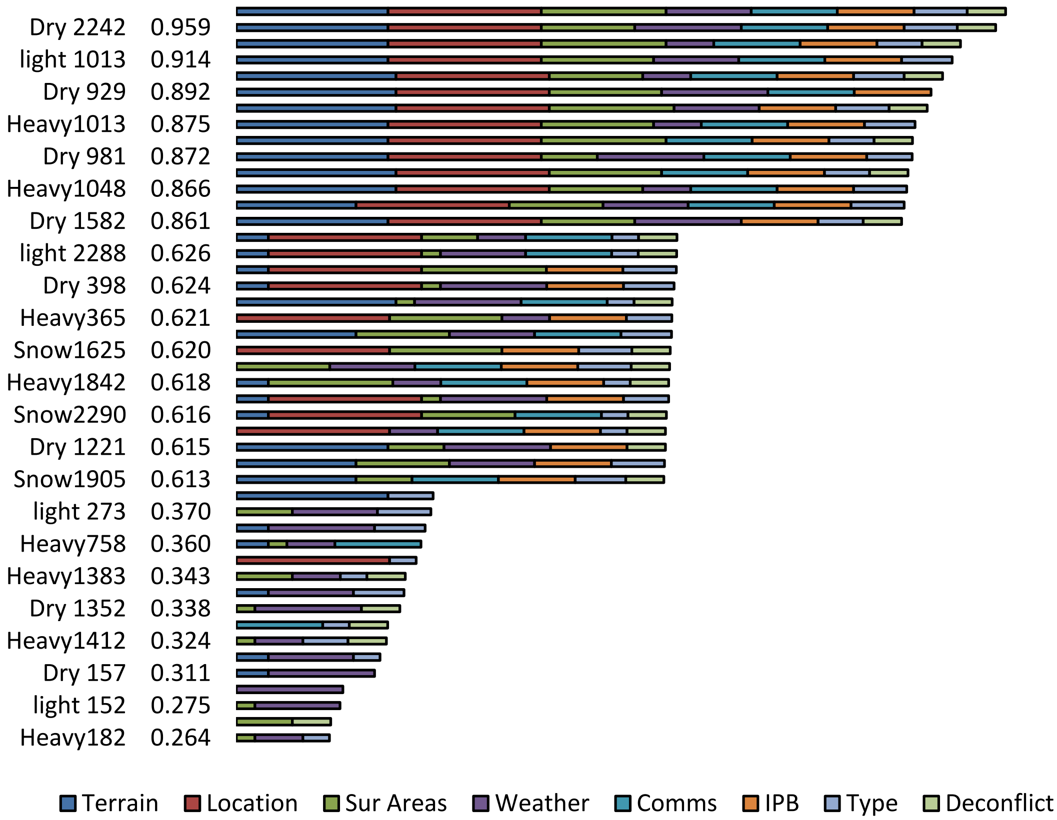


Figure 16: Breakout of Alternative Scores by Measure

4.8 Deterministic Analysis

In beginning the deterministic analysis, it was pretty evident that the alternatives that performed well in *terrain, location, surface areas* and *weather* would also perform well in this model as these four measures account for 56.75% of the total model. In Figure 16 the measures are arranged in order of their weight. Here you can visually see that the top alternatives are dominated by alternatives that perform well in these categories.

Before the alternatives were narrowed down there were some observations that need to be mentioned about the 9600 alternative set. Among the top 400 alternatives the top 10 all included alternatives that included *dry* weather. The top alternative that included *heavy precipitation* was not observed until #54 and there was no alternative that included *snow/ice* until #209. The assumption was made that any mission that scored 75% or above in the model would be considered an effective mission and as stated before there were 1758 combinations of missions that meet this criteria.

Table 11: Alternatives That Met the 75% Cutoff Score by Weather

Snow/Ice	181	0.103
Light	545	0.310
Heavy	360	0.205
Dry	672	0.382

Among the 1758 alternatives, 69% include *light precipitation* or *dry* weather and only 10% are in *snow/ice* conditions as seen in Table 11.

In order to conduct a thorough analysis of the data the data was broken down by measure in order of the weight of the measure. The first measure analyzed was *terrain*.

Table 12: Top, Middle & Bottom Alternatives 400 broken out by Terrain

Terrain					
Top		**Middle**		**Bottom**	
Category	**Number**	**Category**	**Number**	**Category**	**Number**
Water	170	Water	76	Water	3
Desert	149	Desert	81	Desert	6
Light Veg	76	Light Veg	84	Light Veg	18
Urban/Mount	3	Urban/Mount	83	Urban/Mount	139
Ice	0	Ice	75	Ice	234

Terrain is the measure that has the most weight in the entire model at16.5%. Of the 1758 alternatives that scored 75% or better in the model, 1599 included *water*, *desert*, or *light vegetation* as its *terrain* option. Table 12 shows the top, middle and bottom 400 alternatives broken out by the Terrain measure. In the top 400 there are no alternatives that include *ice* as its *terrain* option and there were only 3 that include *urban/mountainous* terrain. In the top 1758 there were only 159 or 9% that contained *ice* or *urban/mountainous* terrain as its environments. Conversely, even though water provides the best conditions to track, there were 3 alternatives that put tracking in a *water* environment in the bottom 400 alternatives of the model. The bottom 400 alternatives are dominated by alternatives that consist of tracking in *urban/mountainous* or *ice* terrain. In looking at Table 12, 373 of the 400 or 93.25% of the alternatives consist of *urban/mountainous* or *ice* terrain environments. The alternatives in the middle of the model show an even distribution of each the terrain categories. In looking at the data, this will be a common theme for each of the measures.

The next measure that was analyzed was *location* with 16% of the model weight. The raw data in Table 13 shows that there are no alternatives in the top 400 that do not score well in this category. Furthermore, of the alternatives that meet the 75% cut off, there are only 130 that do not score a *yes* in this category. That means 93% of the alternatives scored well in this category. This demonstrates that mission success is highly dependent on the aircraft being in the correct location.

Table 13: Top, Middle and Bottom 400 broken out by the Location Measure

Location					
Top		Middle		Bottom	
Category	Number	Category	Number	Category	Number
Yes	400	Yes	192	Yes	5
No	0	No	207	No	395

The *number of areas* each tracker has to monitor was the next measure with 13% of the overall model. Figure 17 illustrates the 400 alternatives in this category. The numbers *four*, *five*, and *six* consisted of 84% of the alternatives. Even when the alternative set was expanded out to top the 18% of the 9600 alternatives, Table 14 shows that categories *four*, *five* and *six* consisted of almost 75% of the alternatives. This shows that the correct location is a critical component to mission success.

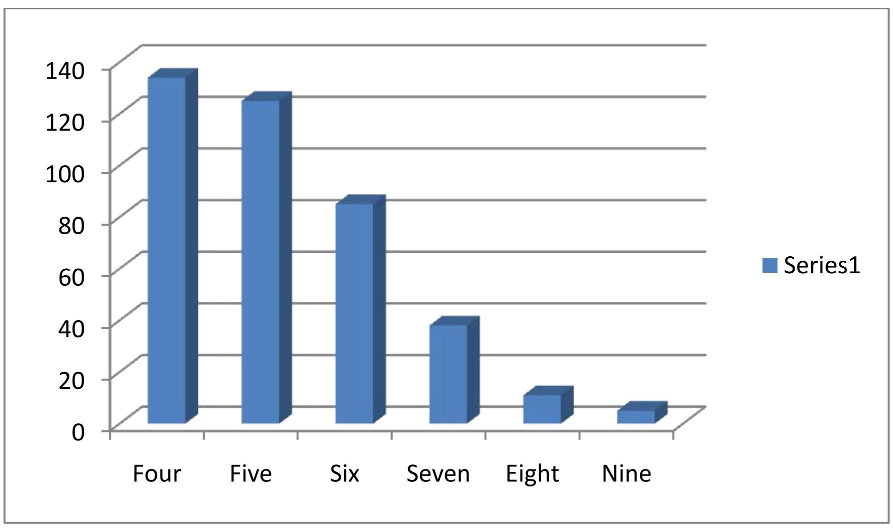


Figure 17: Top 400 Surface Area Alternatives

Table 14: Top 1758 Surface Area Alternatives

Surface Area	
Category	**Number**
Four	471
Five	451
Six	362
Seven	236
Eight	136
Nine	102

Figure 18 clearly shows that when the trackers are over tasked and have to look at seven or more areas that these alternatives perform poorly as 342 of the 400 alternatives are found in categories where they are tracking in more than seven areas. Therefore, keeping the numbers of areas they track in the area of six or less dramatically increase the probability of having a successful mission.

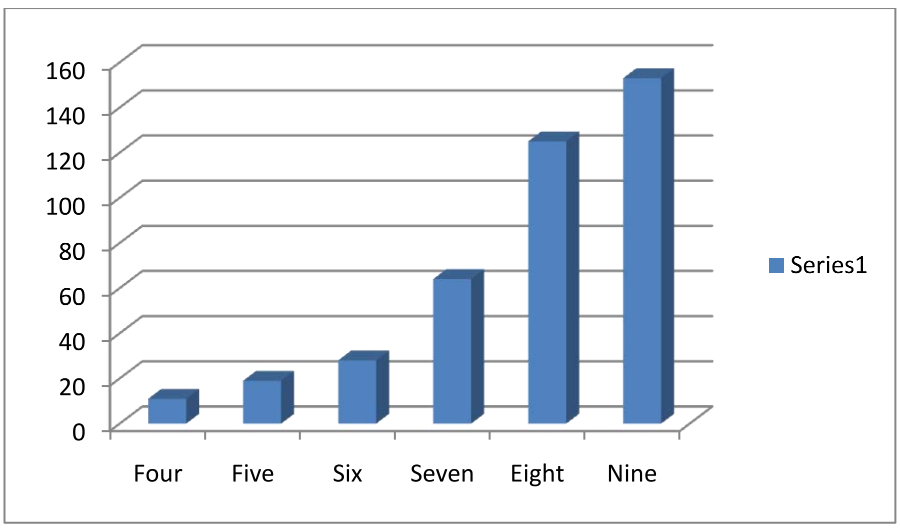


Figure 18: Bottom 400 Surface Area Alternatives

The *weather* measure completes the measures with double digits percentages as it comes in at 11.1% of the overall model. *Dry* weather and *light precipitation* dominated the majority of alternatives in the top 400 consisting of over 82% of the total alternatives (see Figure 19). There were only 13 *snow /ice* alternatives in the top 400, less than 4% of the total, and none in the top 200. Just as the top alternatives were dominated by two categories, the bottom was dominated by *heavy precipitation* and *snow/ice* with a little over 81% consisting of these two weather conditions as seen in Figure 20. However, unlike the top 400 alternatives in this measure 2 of the bottom 100 were Dry alternatives and 10 of the bottom 200. This provided clear evidence that even in the best tracking conditions weather wise, there could still be poor mission results.

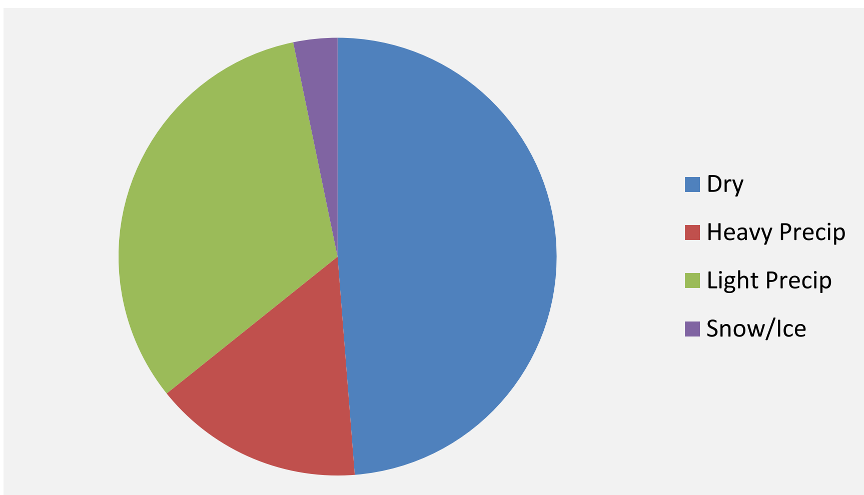


Figure 19: Top 400 Weather Alternatives

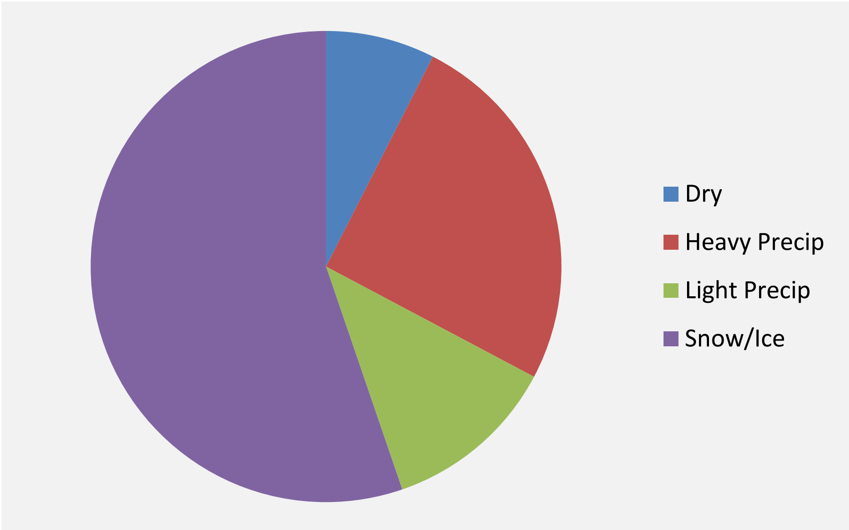


Figure 20: Bottom 400 Weather Alternatives

When it came to *communication*, 9% of the overall model, the data remained pretty consistent. Table 15 revealed that of the top 400 alternatives 89% of the alternatives had a *yes* response in communication measure. Even when expanded out to the 75% cut off score, 74% of the alternatives still maintained a *yes* response in this particular measure. When looking at the bottom of the alternative list, only 15% of those alternatives had a *yes* response in this measure which is pretty consistent with the top alternatives with a small difference of 4%.

Table 15: Top, Middle & Bottom 400 Communication Measure Data

Communication					
Top		**Middle**		**Bottpm**	
Category	**Number**	**Category**	**Number**	**Category**	**Number**
Yes	355	Yes	207	Yes	61
No	45	No	192	No	339

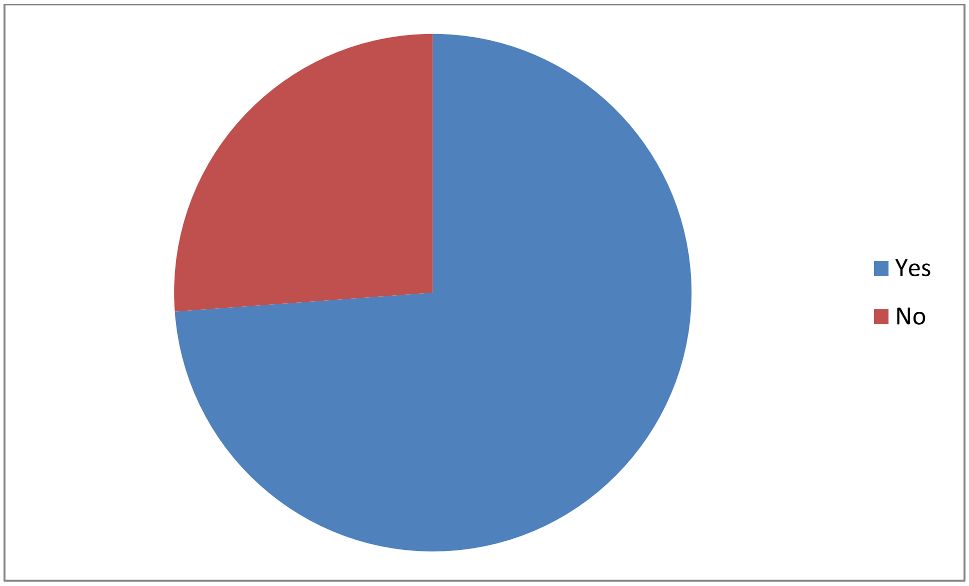


Figure 21: Top 1758 Alternatives in Communication Measure

Like the *communications* measure, *Intelligence Preparation of the Battle Space* remained fairly consistent as well. Referencing Table 16, there were just as many *no* responses in the top alternatives as there were *yes* in the bottom alternatives. Additionally, taking a look at the middle responses they had virtually the same amount of *no* and *yes* responses which made this particular measure linear. This indicated that among the alternatives, the amount of *yes* to *no* responses changed equally from the best to the worst alternatives.

Table 16: IPB Measure Data

Intelliegnce Preparation of the Battle Space					
Top		Middle		Bottom	
Category	Number	Category	Number	Category	Number
Yes	337	Yes	198	Yes	61
No	61	No	201	No	339

The final measure that was used to analyze the data was the *type of target* they were tracking which garnered 5.55% of the overall model. This measure showed in Figure 22 that the top alternatives did best when tracking the best targets, and in Figure 24 the bottom alternatives did worst when tracking the worst targets. However, it also showed that these obstacles could be overcome for any target type if provided with the right mix of the other measures. Figure 23 shows that there is no consistency in the middle alternatives on which target type is more preferred.

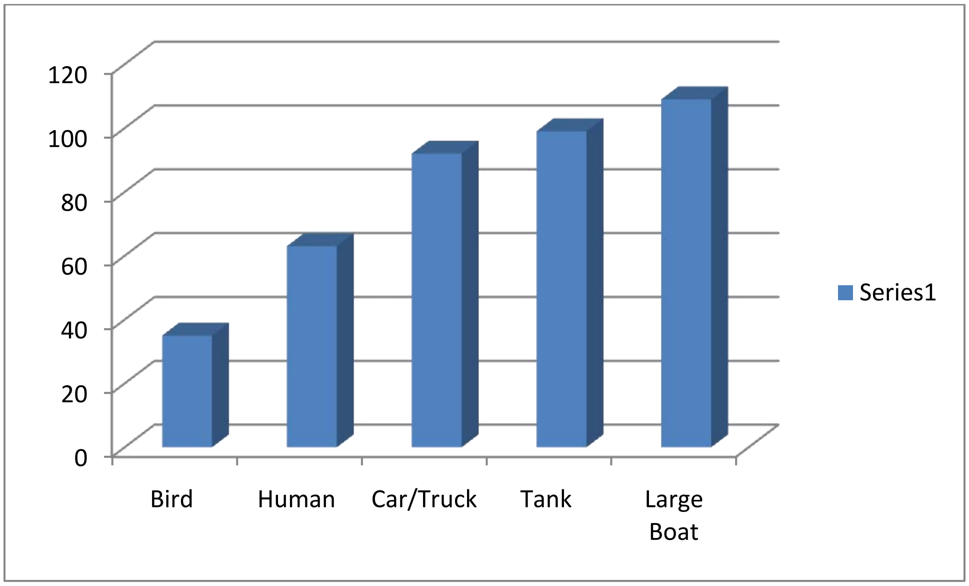


Figure 22: Top 400 Target Type Alternatives

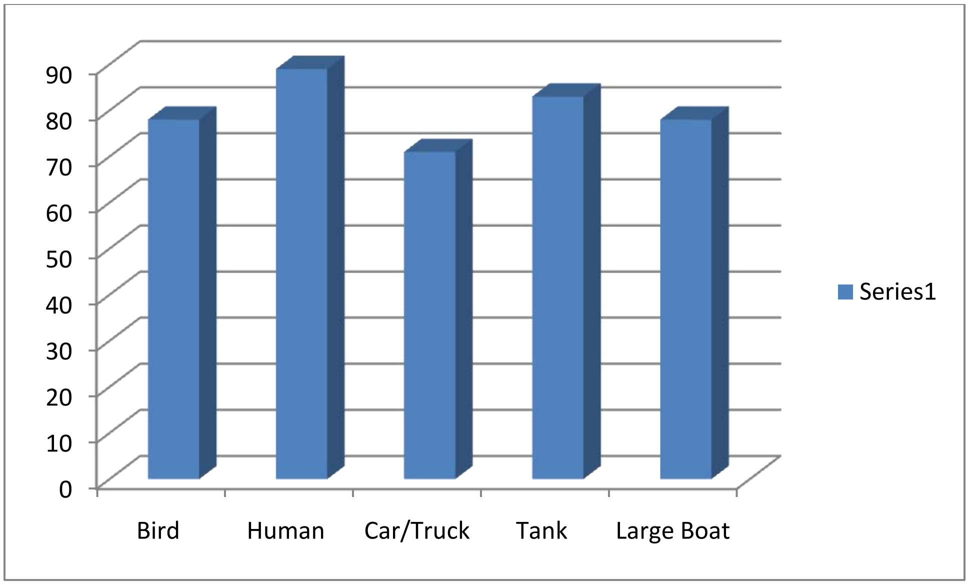


Figure 23: Middle 400 Target Type Alternatives

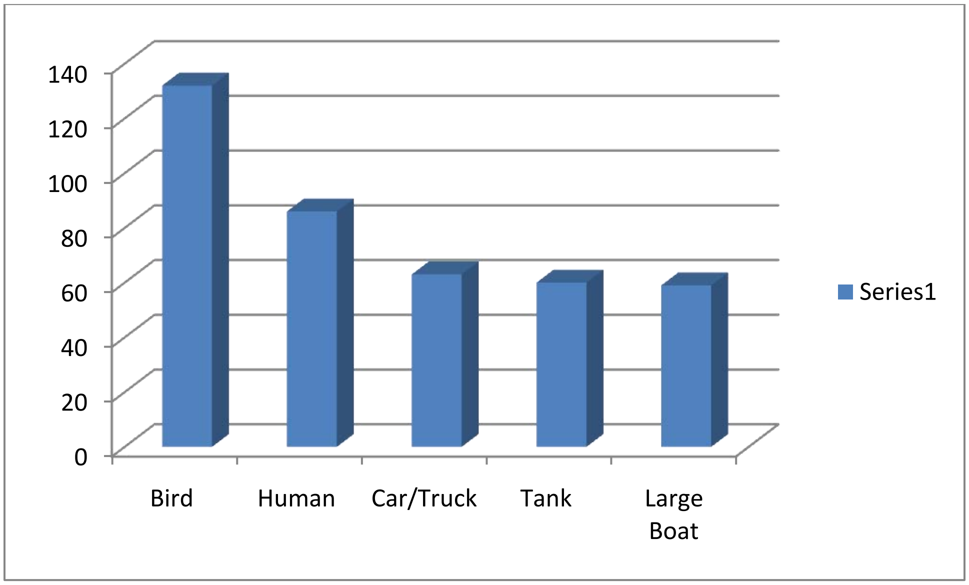


Figure 24: Bottom 400 Target Type Alternatives

4.9 Sensitivity Analysis

As a reminder, the sensitivity analysis phase deals with determining if small changes in the weights would cause the user to make a different decision. There are two ways to do sensitivity analysis, global and local sensitivity analysis. Since many of the alternatives were deleted so to achieve a manageable alternative set, it was impossible to do true sensitivity analysis. Therefore the focus was on showing examples of sensitive and non-sensitive weights and or measures.

Figure 25 shows an example of a non-sensitive measure. In this example, the alternative *Heavy 1048* deterministically dominates all other alternatives.

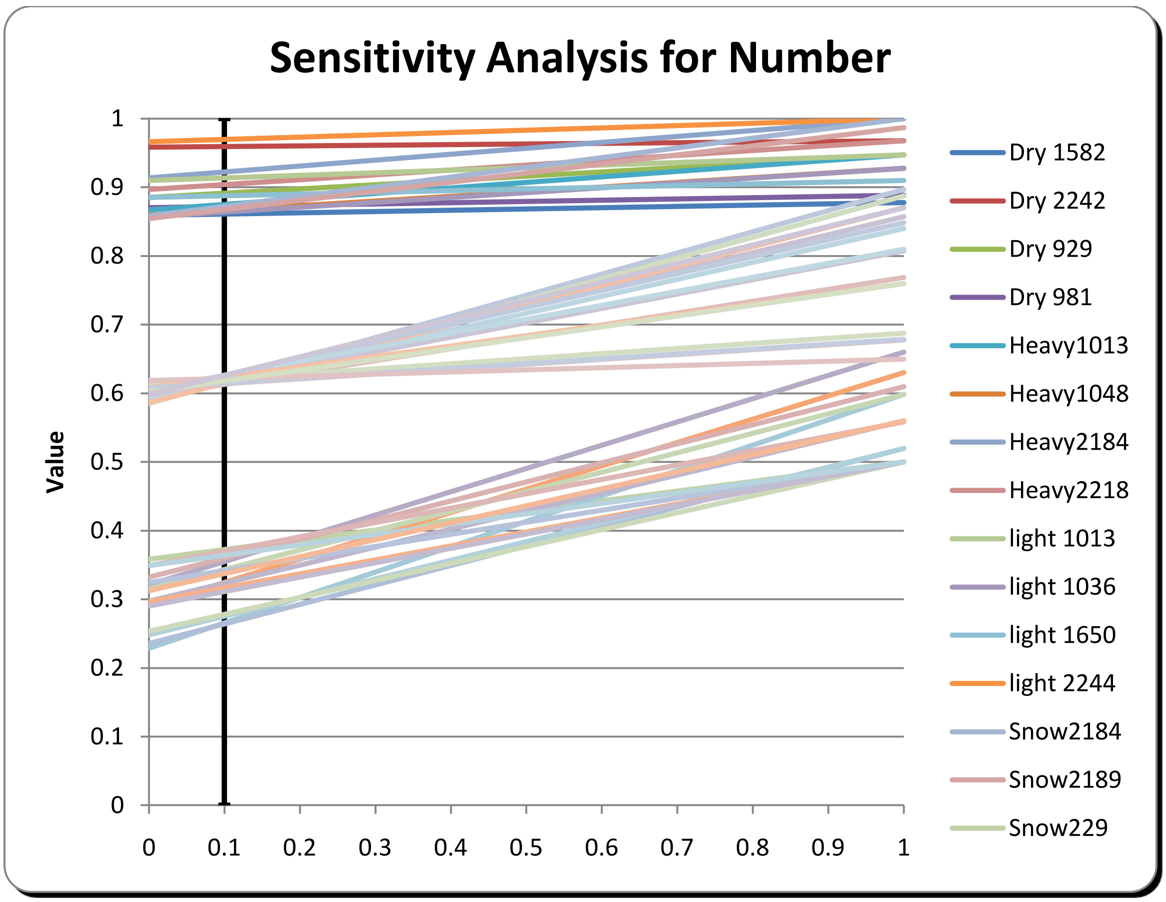


Figure 25: Non Sensitive Measure (Target Type)

At no point, no matter what the value of the weight of the measure, will any other alternative perform better than *Heavy 1048*. An example of a sensitive measure can be seen in Figure 26. In this example at the current global weight of 11.1% *heavy 1048* is the clear #1 choice for this measure. However, if the global weight of this measure changed to 18% or greater, the DM would make a different decision and chose alternative *Dry 2242* as its preferred alternative. This is a global analysis, which means that DM would have to convert 7% of the entire model weight to weather for the preferred alternative to change.

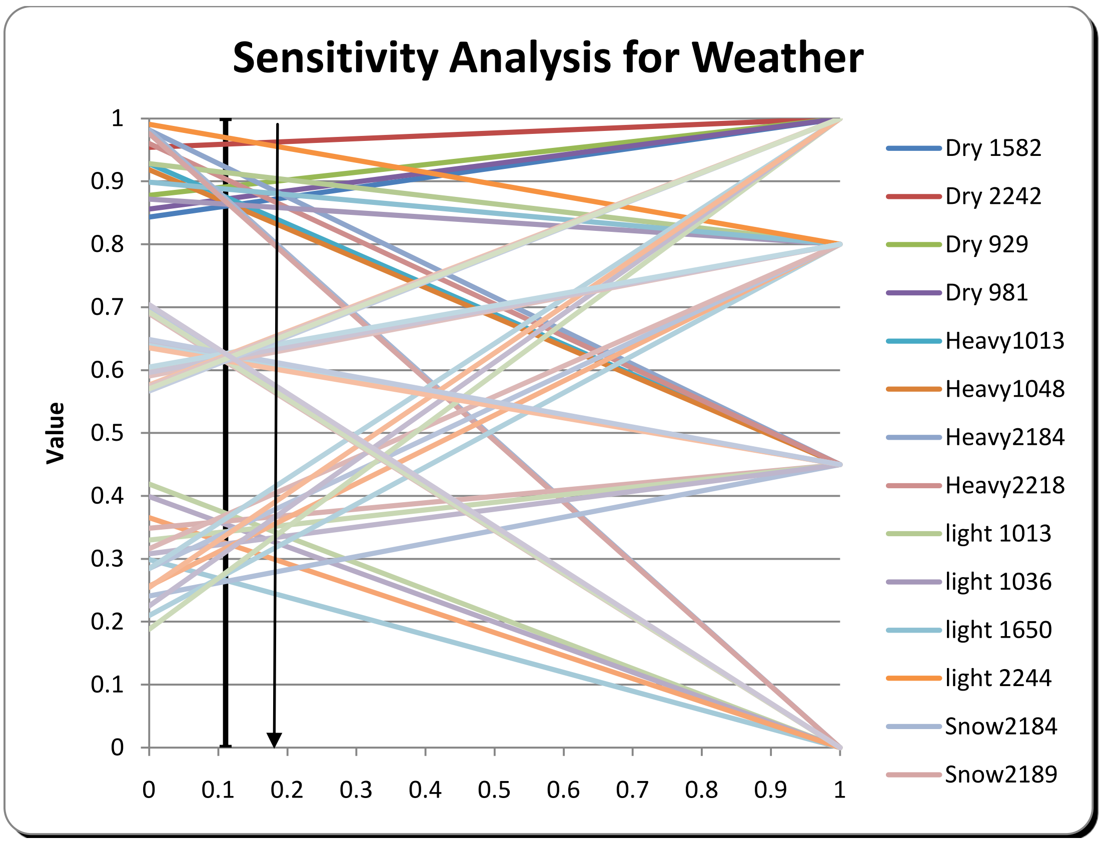


Figure 26: Global Sensitive Measure (Weather)

If the DM is happy with their weights on the values, it may be better to do local sensitivity analysis. Figure 27 shows an example of local sensitivity analysis on the same measure *weather*. In this example, the blue arrow shows that the DM would have to give over half of the weight in the value *targets* to change the preferred alternative which would only leave .48 percent for the three remaining measures. So while this measure seemed sensitive under global sensitivity analysis, under local sensitivity analysis, this measure is not sensitive at all. If the DM did a decent job in determining the weights during the building of the hierarchy, it would seem infeasible that they would change any local weight by more than 70% of its original weight.

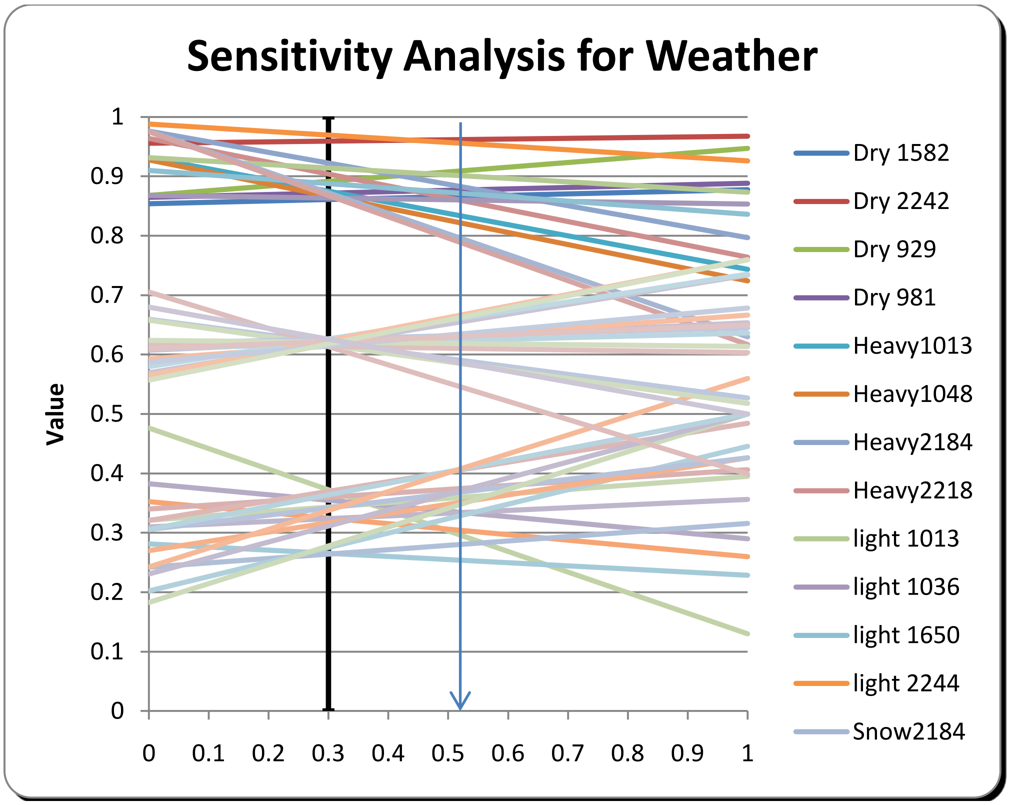


Figure 27: Local Sensitivity Analysis (Weather)

It is impossible to determine the true sensitivity of this model without all the alternatives inserted. Based on the 46 alternatives that was chosen, this model is pretty insensitive to the weights. However, it has been shown that small changes in weights can change the preferred alternative. If in a situation where a small change does change the preferred alternative, it is best to notify the DM as they may want to redefine their objectives or include other objectives.

4.10 Summary

Chapter 4 reviewed the steps that were taken in creating the JSTARS GMTI value model and the results of the model including sensitivity analysis. The deterministic analysis showed for example that there are some environments that GMTI does very well in such as *water*, *desert* and *light vegetation*, but other environments such as *mountainous* or *urban or icy terrain* it can be extremely difficult, but not impossible to overcome these obstacles and achieve a mission that receives a score of 75% or better. In the final section of this chapter the focus was on sensitivity analysis and how to determine when a measure is sensitive using local and global sensitivity analysis.

Chapter 5 Findings and Conclusions

Chapter 5 is the culmination of the thesis effort. It draws conclusions to the application of the value-focused thinking model on JSTARS and GMTI. Here the focus the overall conclusions of this particular study, recommendations to increase the likelihood of having a successful mission and some future research that could or should be done in this area.

5.1 Study Conclusions

One of the first observations discovered during this research was that using the measures that the crew or planners have direct control over; they can only achieve a score of .47. Table 17 shows the controllable and uncontrollable measures. Since the score of the controllable measures is so low, it is imperative the crew and planners spend the appropriate amount of time studying the terrain, location, and weather of the planned area to ensure that they can reach an acceptable mission score.

Table 17: GMTI Measures: Controllable & Uncontrollable

GMTI Measures	
Controllable (.47)	**Uncontrollable (.53)**
Surface Areas (.13)	Terrain (.1665)
Communications (.09)	Location (.16)
IPB (.08)	Weather (.111)
Distance (.04)	Type (.0555)
De-Confliction (.04)	Number (.037)
Altitude (.03)	
Positive Identification (.03)	
Feedback (.03)	

The next conclusion pertained to the terrain measure. It was very hard and almost impossible to have a measure that falls in the mountainous or urban or ice terrain categories to do well in this model. Only 3 *mountainous* or *urban* terrain alternatives were in the top 400 and no *ice* alternatives. Even when using the top 1758 there were only 9% of the alternatives that include these categories. Remember that each alternative had an artificial 17% inflation which means there could possibly have been even less than 9% in the top alternatives.

It was also impossible to score well in the model if the aircraft was not in the correct location. 400 of the top 400 all received a *yes* response when determining if they were in the correct location. When it came to the amount of surveillance areas the trackers had to monitor, *four*, *five,* or *six* dominated the top alternatives. Once they got above *six,* the possibility of scoring well in the model decreased dramatically.

Most of the top alternatives did well in *communications* and *Intelligence Preparation of the Battle Space*, but the data showed that even if they did not; either of these measures could be overcome. Communication had 44 *no* response in the top 400, but also had 61 *yes* responses in the bottom 400. Additionally, IPB had 61 *no* responses in the top 400 and 74 *yes* responses in the bottom 400. This data indicated that an alternative could score well in these measure and easily be in the top or bottom of the alternatives. It is important to note, that even if IPB was not accomplished prior to arriving in theater, if the aircraft remains operational in theater long enough, at some point IPB can be considered to be accomplished.

The final conclusion that was gleaned from this research was about the targets. While the best targets such as *boats* and *tanks* rise to the top, there is no huge disparity in tracking the other targets. *Tanks* and *large boats* can only be tracked 1.3 to 1 better than *humans*, *cars* and *boats*. Out of the top 400 alternatives, 208 consisted of *tanks* and *large boats*, and 155 consisted of *humans, cars and trucks*.

5.2 Current Operational Data

Since JSTARS in currently operating in the Afghanistan AOR, this model was presented to the crews to see how their current missions would score. While the true score is classified, it can be seen in Figure 28 that they are operating in the middle scores of the model and below the 75% that was assumed to be an acceptable mission score.

Some of the issues that lowered their score were altitude, terrain, type of target, positive identification, communications, and feedback.

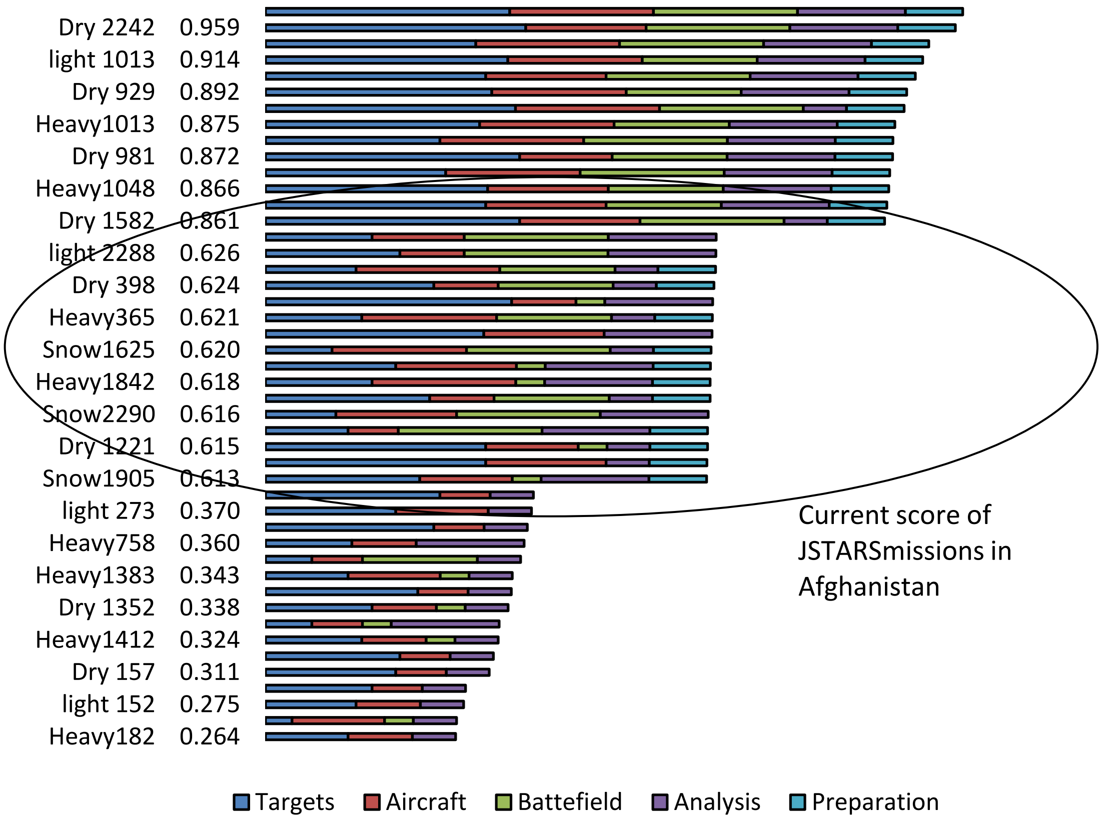


Figure 28: GMTI Effectiveness Alternative Scores

5.3 Recommendations

There were several recommendations that came out of this analysis. The first was to always have the trackers monitoring six areas or less. The scores of the mission rose considerably when monitoring in six or less. The can do this in one of two ways. The first is by adding an additional tracker to the crew and have them take over one of the technicians consoles when on-station. This would spread the number of areas amongst a greater number of people there by lowering the number of surveillance areas monitored by any single tracker. The other option is to simply accept a lower number of areas to monitor from the collection manager. By showing the collection manager how much better they do when not having to monitor so many areas should entice the collection manger to focus their efforts to receive a higher value of information.

The next recommendation is to simply fly higher. They can do this by taking on less fuel during their air refuelings. This would give them the ability to fly higher for greater amounts of their on-station time. However, taking less fuel also comes at price because more tankers would be required to get the same amount of coverage. The other issue it creates is more time will be spent air refueling which results in less time on-station. The tradeoff here comes when determining if it is more important to have more time on-station at less than optimal altitudes or is it better to forgo some on-station time to be at optimal altitudes for longer periods of time.

Other recommendations are to create relationships with outside agencies so to increase the time they have a positive identification and an on the ground communications asset. By creating these relationships, they will also help with fostering better feedback during and after the mission. They could also use this model with the Combined Air Operations Center (CAOC) to show the leaders there how much better there information would be if provided with the correct cross-cue assets. The final recommendations are to track in low areas and not in mountainous areas and attempt if at all possible to fly in dry conditions. It was shown that tracking in mountainous areas provides low values of information. It would be much better to reject these missions and request missions where the probability of a successful mission is much higher. By doing some or all of these things it is possible to increase the value of a mission by as much as 30%.

5.4 Verification and Validation

The model verification process determines if the model meets identified specification and ensures the model is doing what you expect it is doing or the mathematical calculations that the model is computing are indeed correct. To verify this model, the output data of three of the alternatives were compared against a manual calculation of the same alternatives. After comparing the calculations, it was noted that the manual calculations derived the same scores for the alternatives as the model which verified that the model was working in the manner in which it was intended.

The model validation process is much harder and is a way of evaluating if the model meets the overall project objectives. This process confirms that a model can effectively be applied to a given task. This particular model was validated in two ways. The first validation took place when comparing the data the MITRE Corporation compiled to the data that was compiled for this model (Bonaceto, Mooers, Theophanis, & Wrick, 2010). Both independent studies the same factors to be important when modeling the GMTI process. The second validation process came from the crews of the JSTARS themselves. This model was presented to crewmembers other than the ones who actually helped build the model to determine if the scores of the current missions they were flying accurately represented their mission results. The crewmembers felt that the scores there missions were receiving was extremely close to the mission results they were seeing on their flights.

5.5 Conclusion

This thesis began by asking how can the effectiveness of a GMTI asset be measured when there is no magic number of tanks, boats, cars or people that will make this capability more or less effective. Understanding that intelligence is a stochastic process, determining the true answer to this question is probably impossible. By understanding how and when GMTI and JSTARS have been effective allowed the JSTARS intelligence gathering process to be modeled using the VFT 10 step process. This process enabled some valuable insights to be gained on the process and identified ways to optimize the use of the GMTI capability. Specifically, this research identified environments or situations when using this capability will and will not provide values of information that are adequate enough for it to be used. Hopefully DM will use this model to make better decision about when and where to deploy JSTARS. This template of value-focused thinking can be used to determine the effectives of other intelligence assets in the DoD arsenal.

Appendix A: JSTARS Mission Crew Duties & Responsibilities

Mission Crew Commander (MCC).
Responsible authority for assigned BM-C2ISR mission tasks and coordinates with the AC to ensure effective sortie and mission accomplishment. Supervise execution of HHQ assigned tasks. Ensure crewmember adherence to Rules of Engagement (ROE) and SPINS. During decentralized operations the MCC is the onboard authority for determining mission tasking. Declare operations normal/on-station/off-station and advise external agencies about the aircraft status. Collate and compile mission reports and summaries. Responsible for accounting and safeguarding of classified materials and proper destruction. Tailor mission crew and positional responsibilities based upon mission requirements and operations.

Deputy Mission Crew Commander (DMCC).
Act as Army liaison to MCC and mission crew. Ensure that the Ground Commander's intent is understood and that JSTARS crewmembers understand how ground operations will be executed. Ensure the ground commander and common ground stations (CGSs) are aware of on-station/off-station and aircraft status. Manage Information flow to supported ground units via radios and all available data links (FBCB2, IDM, SCDL, DATASAT, & AIRNET/INMARSAT). Coordinate with the ground Fire Support Officer when required.

Airborne Intelligence Officer/Technician (AOI/T).
Analyze incoming reports from external intelligence collection agencies and determine the impact on mission execution. Ensures amplifying intelligence data is fused as applicable to enhance the BM-C2ISR mission. Verify and update the order of battle data. Operation of the Broadcast Intelligence system. Report radar tracks both internally/externally to intelligence collection agencies for further collection and amplification.

Senior Director (SD).
Monitor and assess current air/ground situation; coordinate mission changes with appropriate agencies. Direct BM-C2 mission execution with regard to Find, Fix, Track, Target, Engage and Assess (F2T2EA). Coordinate with the SO for radar management and surveillance operations. C2 includes procedural control, managing mission changes, striking targets and directing battlespace logistical efforts (e.g. tanker flow). Develop an effective communications plan.

Surveillance Officer (SO).
Conduct effective radar timeline management; inform crew of sensor anomalies. Coordinate with SD for management of the Operations Section. The SO is responsible for signing out the SO Flyaway Kit from DOW and carrying on every mission flight. The kit will contain:

1. T.O. 1E-8C-43-1-1-1

2. AFTTP 3-1.JSTARS
3. Appendix H (Classified PHB)
4. Classified In-Flight Guide (IFG)
5. E-8C Security Classification Guide (SCG)

Senior Surveillance Manager (SSM).
Ensure tracking responsibilities/continuity in the AOR. Coordinate with the CST for JTIDS link operations. Oversee activities of Surveillance Section.

Air Weapons Officer (AWO).
Conduct BM-C2 mission execution with regard to F2T2EA using procedural control, target engagement, TAC (A), managing ATO/ACO changes and directing battle space logistical efforts.
Air Operations Technician (AOT).
Use sensor data for accurate tracking in assigned AOR.

Airborne Target Surveillance Supervisor(ATSS).
Maintain voice and SCDL contact with CGS to accomplish ground component commander objectives; process radar service requests as required.

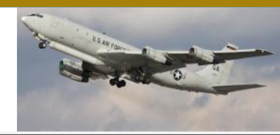
Airborne Radar Technician (ART).
Initiates, operates and maintains radar and O&C (computer) systems. Monitors system status and troubleshoots malfunctions to keep systems operational, and acts as primary fire fighter for emergencies involving these systems.

Communications Systems Technician (CST).
Initiates, operates and maintains all aircraft communications including voice and data link systems. Monitors system status and troubleshoots malfunctions to keep systems operational, and acts as primary fire fighter for emergencies involving these systems.

Appendix B: Storyboard

MEASURE OF EFFECTIVENESS FOR JSTARS GROUND MOVING TARGET INDICATOR: A VALUE FOCUSED THINKING APPROACH

Maj. G. Jerell Joyner
Advisor: Dr. Jeffery L. Weir
Reader: Lt.Col. Darryl K. Ahner
Department of Operational Sciences (ENS)
Air Force Institute of Technology



Research Question:

How can you measure the effectiveness of Ground Moving Target Indicator (GMTI) when there are no magic number of vehicles that makes this capability more or less effective.

Motivation:

Currently the effectiveness of most Intelligence, Reconnaissance, and Surveillance (ISR) assets are measured using measures of performance (MOPs). Unfortunately, MOPs only measure how well a system utilizes its resources and do not give decision makers the information they need to make procurement and deployment decisions. This research develops measures of effectiveness (MOEs) which are quantitative measures that give insight on how well the JSTARS and the GMTI capability are actually performing.

Research Goals:

Give Decision Makers a tool to help them make more informed decisions on where and when to use the JSTARS GMTI capability.

Give planners and flight crews more insight on the obstacles they will face once deployed to the Area of Responsibility.

Give flight crews insight on the variables they control and how they can improve their chances of obtaining higher values of information

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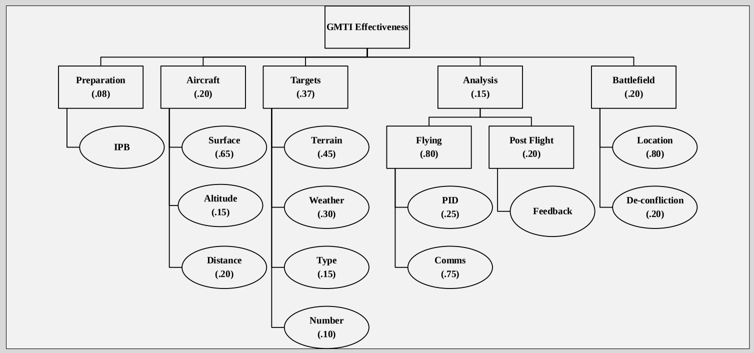
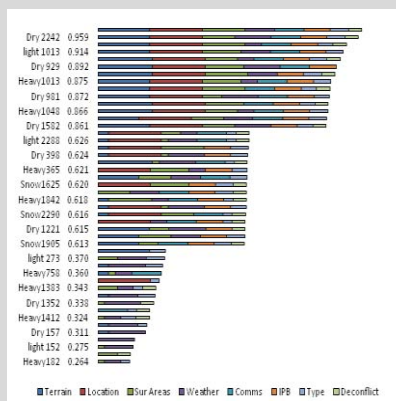
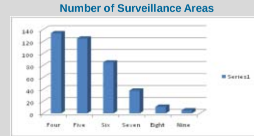
Value-Focused Thinking Hierarchy

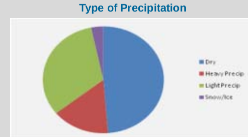




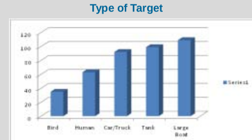
Number of Surveillance Areas



Type of Precipitation



Type of Target



GMTI Measures	
Controllable (.47)	**Uncontrollable (.53)**
Surface Areas (.13)	Terrain (.1665)
Communications (.09)	Location (.16)
IPB (.08)	Weather (.111)
Distance (.04)	Type (.0555)
De-Confliction (.04)	Number (.037)
Altitude (.03)	
Positive Identification (.03)	
Feedback (.03)	

Results:

Very hard to have a alternative that falls in the mountainous/urban or ice terrain categories to do well

Impossible to score well in the model if the aircraft is not in the correct location.

When the trackers are monitoring more than six surveillance area, very difficult to have high mission scores.

No huge disparity in the scores when tracking different types of targets

Recommendations:

- Have tracker monitor six areas or less
- Fly higher by taking on less fuel during air refuelling
- Create better relations with outside agencies to facilitate better feedback, communication and the ability to get more positive id assets
- Track in low areas to the max extent possible

Appendix C: Single Dimensional Value Functions

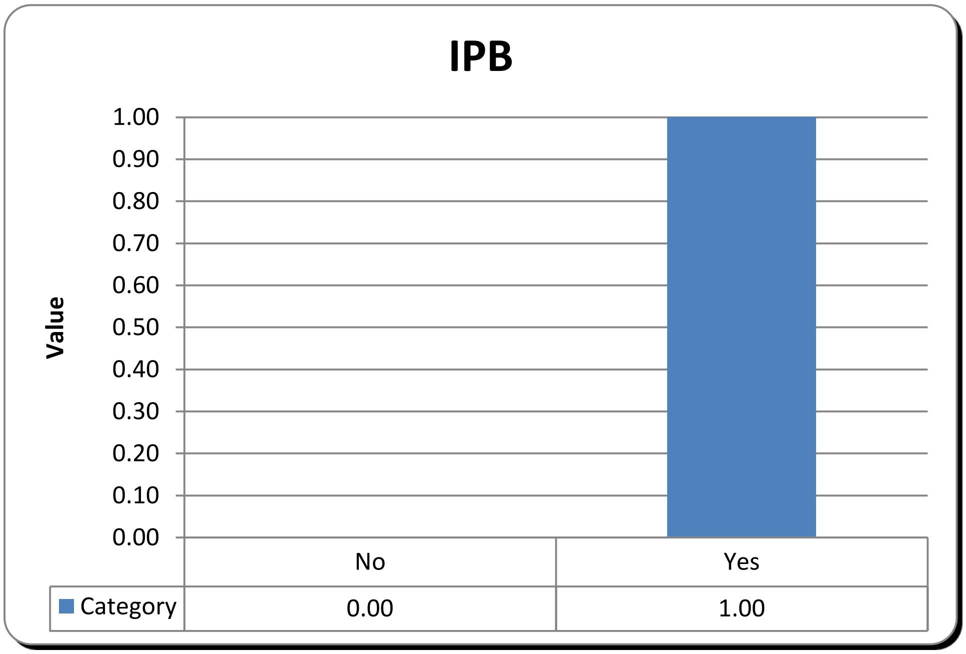


Figure 25: Intelligence Preparation of the Battle Field SDVF

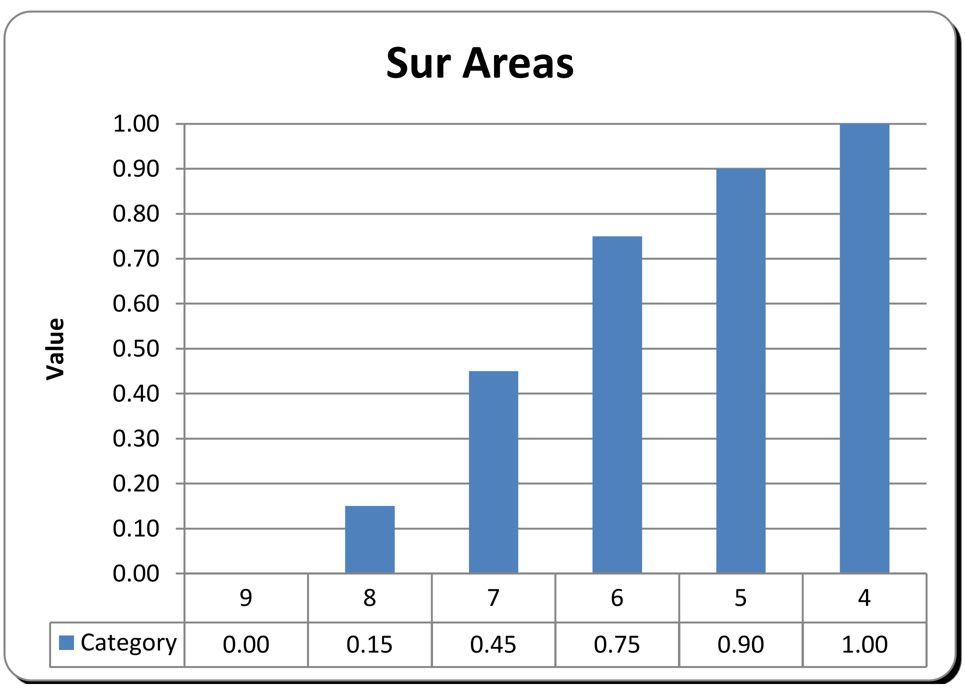


Figure 26: Number of Areas Tram is tracking SDVF

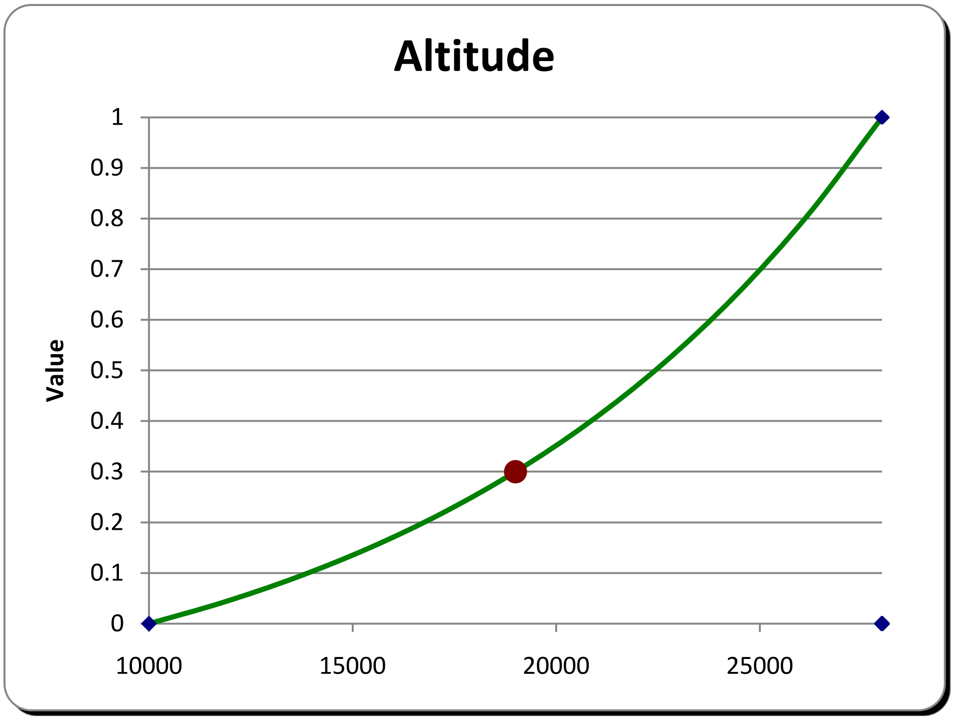


Figure 27: Altitude SDVF

Figure 28: Distance I SDVF

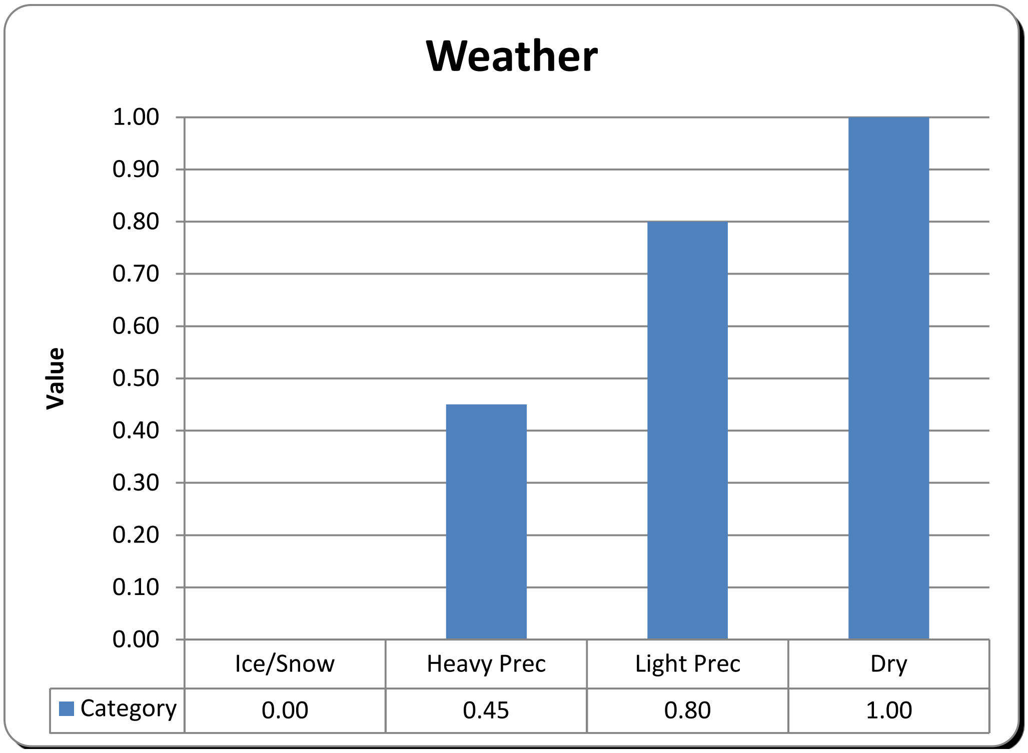


Figure 29: Weather aircraft is operating in SDVF

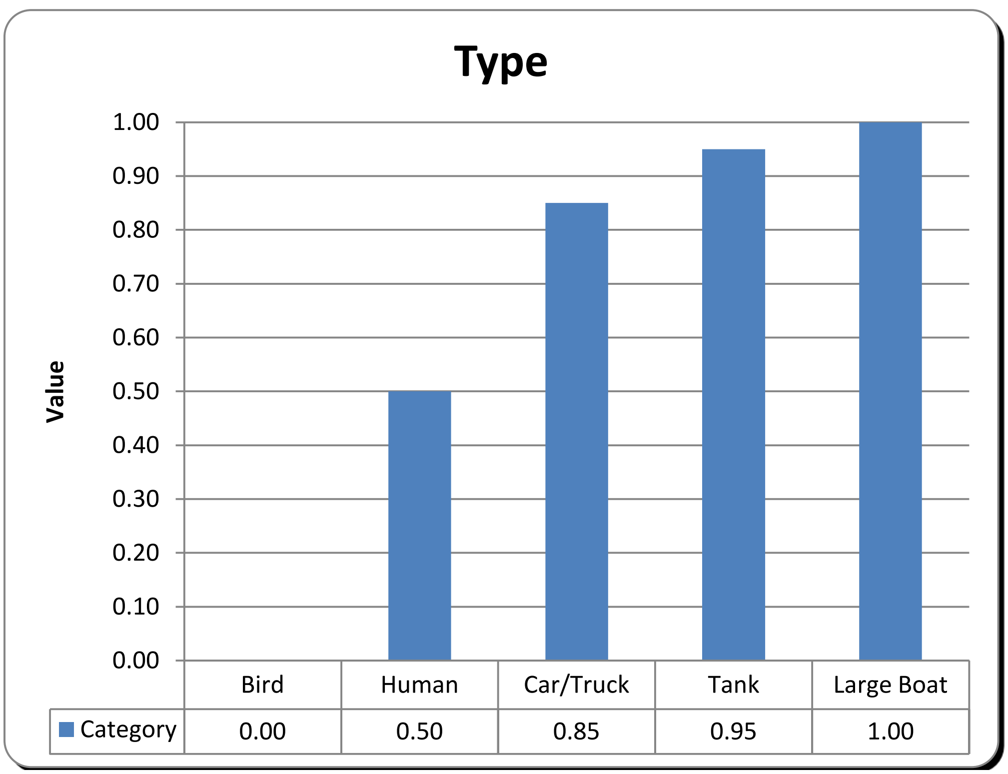


Figure 30: Type of target SDVF

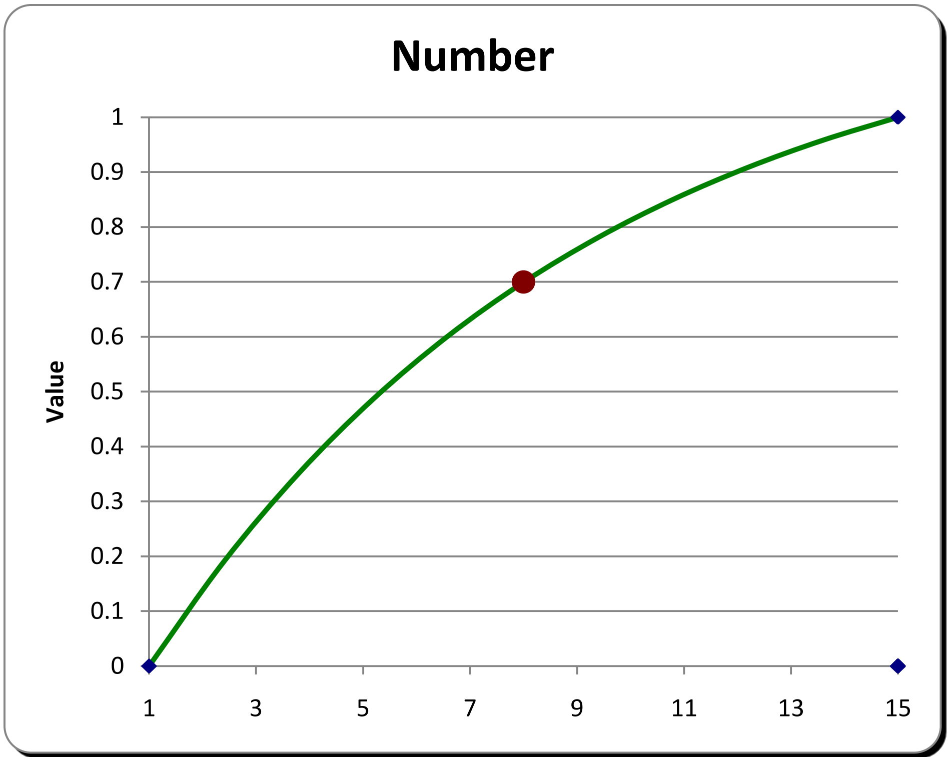


Figure 31: Number of Targets SDVF

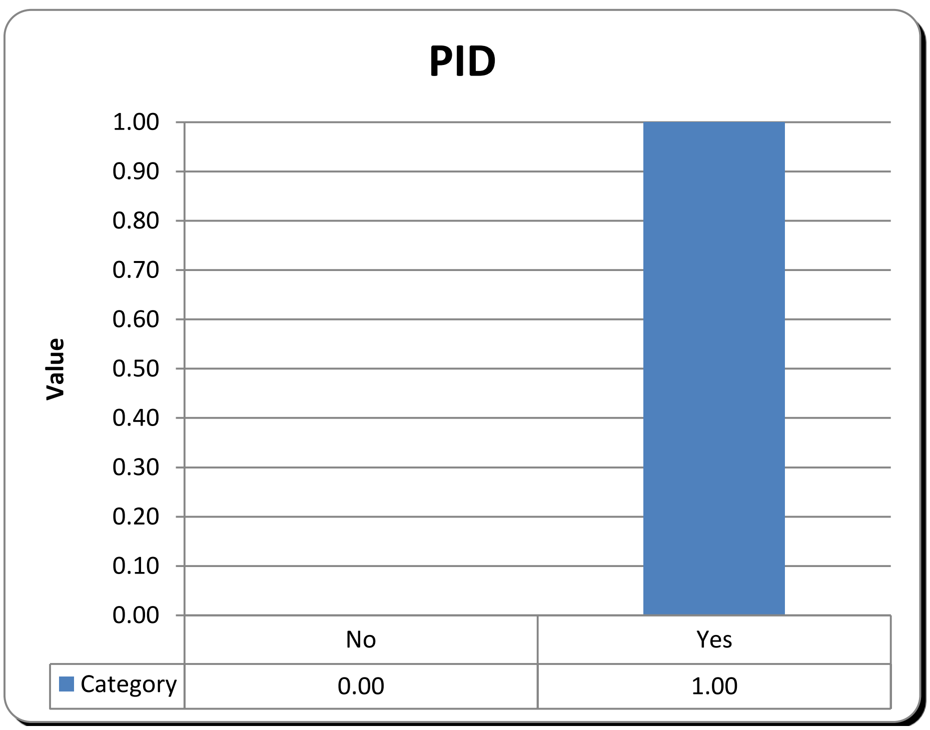


Figure 32: Positive Identification SDVF

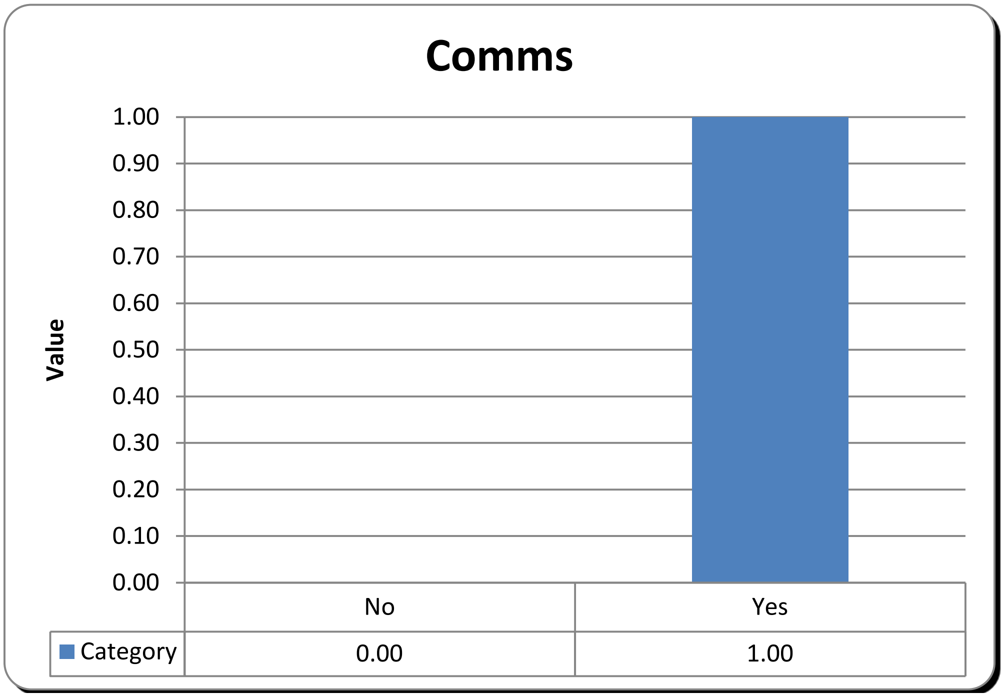


Figure 33: Communications SDVF

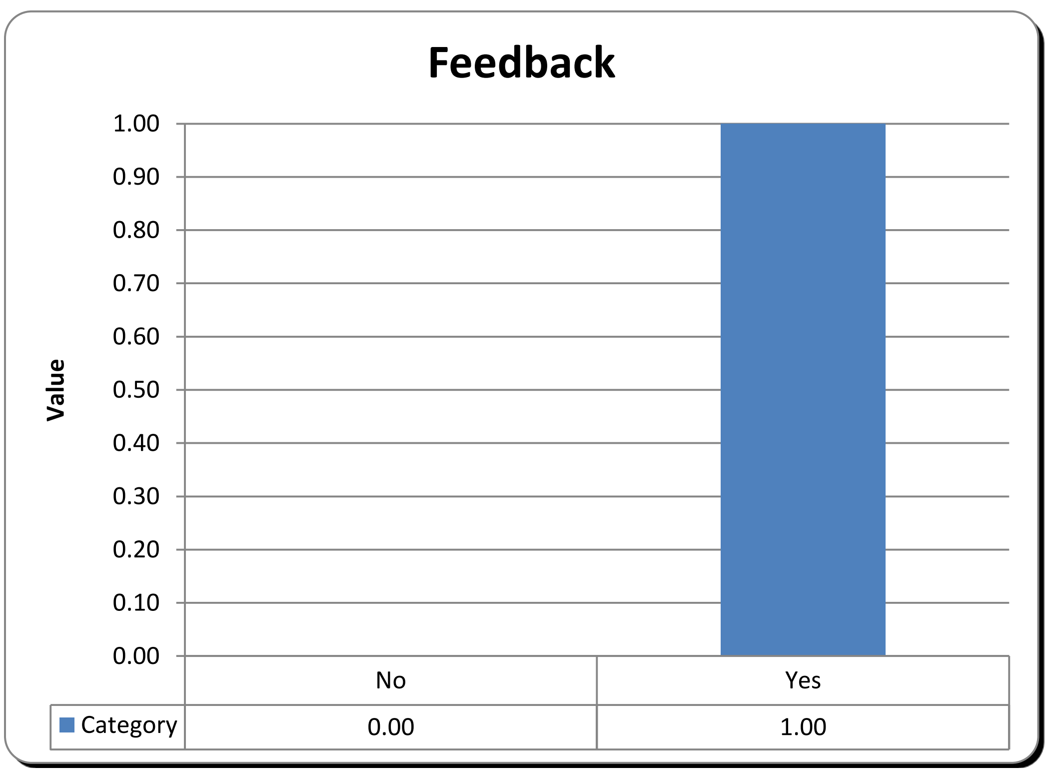


Figure 34: Feedback SDVF

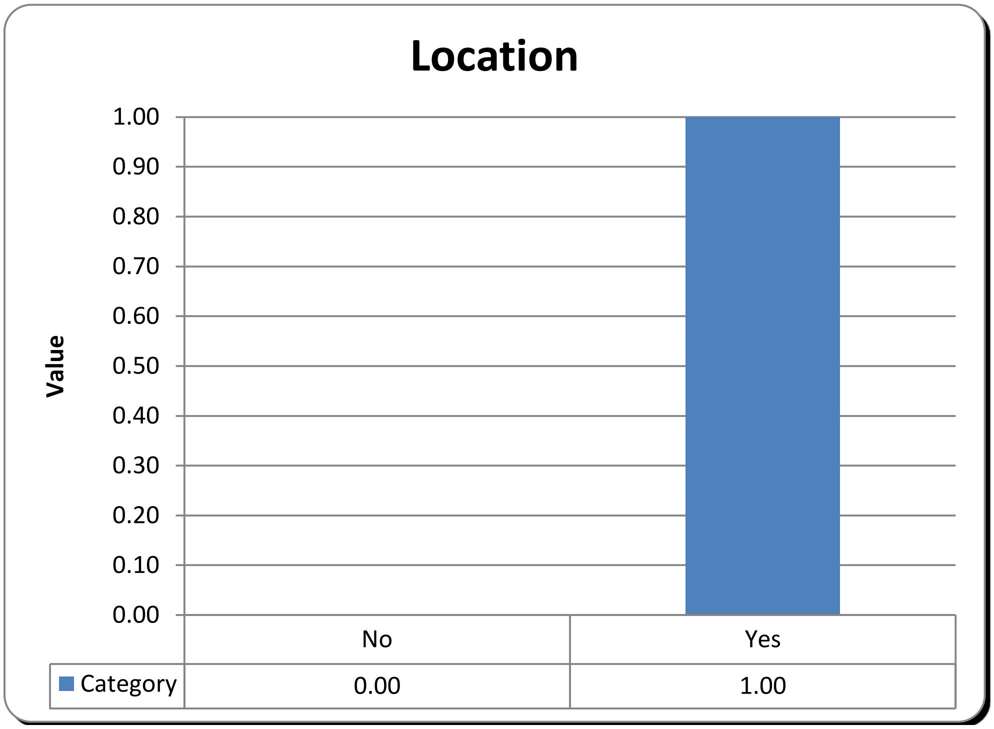


Figure 35: Location SDVF

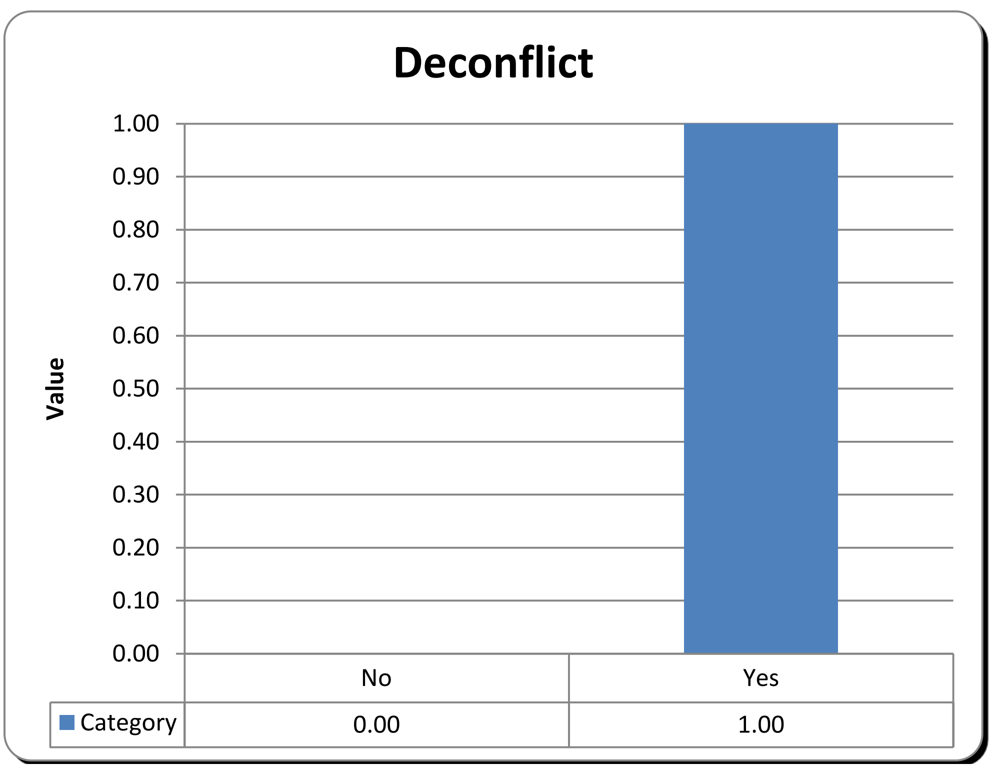


Figure 36: De-confliction SDVF

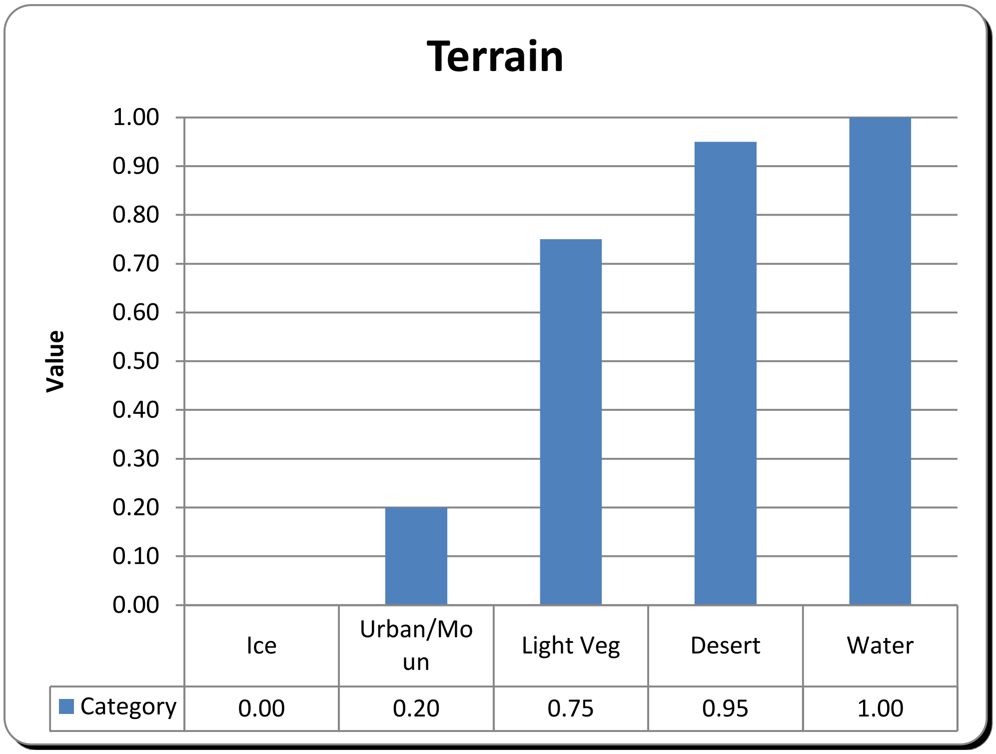


Figure 37: Target Terrain SDVF

Appendix D: Names and Positions of Subject Matter Experts

Rank	First	Last	Position
SSgt	Karis	Baker	AOT
Maj	David	Carrol	SD
Maj	Ari	Claborne	DMCC
TSgt	Dishone	Dozier	SSM
Capt	Carrie	Gardner	SO
LtCol	David	Omstead	MCC
Maj	Jonathon	Prindle	MCC
Maj	Barry	Spells	MCC

Appendix E: 8 Attributes of Intelligence

Anticipatory	Intelligence must anticipate the informational needs of the commander and joint force staff in order to provide a solid foundation for operational planning and decision making. Anticipating the joint force's intelligence needs requires the intelligence staff to identify and fully understand the command's current and potential missions, the commander's intent, all relevant aspects of the operational environment, and all possible friendly and adversary COAs.
Timely	Intelligence must be available when the commander requires it. Timely intelligence enables the commander to anticipate events in the operational area. This, in turn, enables the commander to time operations for maximum effectiveness and to avoid being surprised.
Accurate	Intelligence must be factually correct, convey an appreciation for facts and the situation as it actually exists, and provide the best possible estimate of the enemy situation and COAs based on sound judgment of all information available. The accuracy of intelligence products may be enhanced by placing proportionally greater emphasis on information reported by the most reliable sources. Source reliability should be evaluated through a feedback process in which past information received from a source is compared with the actual "ground truth" (i.e., when subsequent events, reports, or knowledge confirm the source's accuracy).
Usable	Intelligence must be tailored to the specific needs of the commander, and must be provided in forms suitable for immediate comprehension. The commander must be able to quickly apply intelligence to the task at hand. Providing useful intelligence requires the producers to understand the circumstances under which their products are used. Commanders operate under mission, operational, and time constraints that will shape their intelligence requirements and determine how much time they will have to study the intelligence that they are provided. Commanders may not have sufficient time to analyze intelligence reports that are excessively complex and difficult to comprehend. The "bottom line" must be up front and easily understandable. Oral presentations should be simple and to the point. The use of approved joint terms and straightforward presentation methods will facilitate rapid and effective application of intelligence to support joint operations.
Complete	Complete intelligence answers the commander's questions about the adversary to the fullest degree possible. It also tells the commander what remains unknown. To be complete, intelligence must identify all adversary capabilities that may impact mission accomplishment or execution of the joint operation. Complete intelligence informs the commander of all major COAs that are available to the adversary commander, and identifies those assessed as most likely or most dangerous. The effort to produce complete intelligence never ceases. While providing available intelligence to those who need it when they need it, the intelligence staff must give priority to the commander's unsatisfied critical requirements. Intelligence organizations must anticipate and be ready to respond to the existing and contingent intelligence requirements of commanders and forces at all levels of command.
Relevant	Intelligence must be relevant to the planning and execution of the operation at hand. It must aid the commander in the accomplishment of the command's mission. Intelligence must contribute to the commander's understanding of the adversary, but not burden the commander with intelligence that is of minimal or no importance to the current mission. It must help the commander decide how to accomplish the assigned mission without being unduly hindered by the adversary. Commanders

	must communicate their intent and their operational concept to the intelligence staff if relevant intelligence is to be produced. Requirements must be updated and refined as the friendly mission or the adversary situation changes.
Objective	For intelligence to be objective, it should be unbiased, undistorted, and free of prejudicial judgments. The objective analyst must remain open-minded to all hypotheses and should never attempt to make the facts fit preconceptions of a situation or an adversary. In particular, intelligence should recognize each adversary as unique, and should avoid mirror imaging. Red teams should be used to check analytical judgments by ensuring assumptions about the adversary are valid and intelligence assessments are free from mirror imaging and cultural bias.
Available	Intelligence must be readily accessible to the commander. **Availability is a function of not only timeliness and usability, but also appropriate security classification, interoperability, and connectivity.** Intelligence producers must strive to provide data at the lowest level of classification and least restrictive releasability caveats, thereby maximizing the consumers' access, while ensuring that sources of information and methods of collection are fully protected.

Appendix F: Blue Dart

The Department of Defense (DoD) dedicates a huge amount of its budget and manpower to the intelligence gathering process. In today's war environments where the fighting is mostly unconventional, the DoD depends on their intelligence gathering platforms more than ever to provide timely and accurate information. Unfortunately, it can sometimes be very difficult to almost impossible to ascertain how effective any particular intelligence gathering asset really is. A problem that has plagued intelligence gathering systems for years is that their overall effectiveness is determined using measures of performance rather than measures of effectiveness. Measures of Performance (MOPs) describe how well a system utilizes resources, but Measures of Effectiveness (MOEs) are quantitative measures that give some insight into how effectively a unit is performing. For example, if a ISR assets is scheduled to fly 8 hours and flies 8 hours an MOP would consider that asset 100% effective, but the true effectiveness could and usually is far less.

With tighten fiscal restraints the DoD is now under scrutiny to find ways to cut useless and redundant equipment and systems. They have to justify every piece of equipment required to maintain the safety and security of the nation. With such tight constraints, every asset has to prove its worthiness or face possible budget cuts. Additionally, decision makers require the most accurate information possible to make decisions on deployment and procurement considerations of intelligence assets.

One of the systems and capabilities that is under budget attacks and uses MOPs to measure its overall effectiveness is the Joint Surveillance Target Attack Radar System or JSTARS with its Ground Moving Target Indicator (GMTI) system. The difficulty with the system is that it can see one hundred or one million vehicles, but their overall effectiveness does not increase or decrease based on the number of vehicles seen. History shows that there have been situations where JSTARS has been extremely successful and others where the platform has struggled to have an impact on the conflict. Using this information allows MOEs to be created which give much better insight into how effective the JSTARS asset can and will be in the future.

Understanding the complexities and constraints of the system using the Decision Analysis discipline, the Air Force Institute of Technology has created a value-focused thinking model which models the JSTARS intelligence gathering process. The model is built in a hierarchal structure and identifies values and measures that are important to the GMTI process onboard JSTARS and assign weights to those values and measures. Single dimensional value functions are then assigned to each measure which allows a score to be assigned to every possible scenario or environment that the assets could possibly enter. Using the assigned scores and sensitivity analysis allows the user to identify scenarios where the asset/capability will be extremely effective and when it would be better not to use the system as the value of information provided by the system will be extremely low.

The model helps identify key controllable and uncontrollable factors that affect the system and the ones that should be addressed first to increase mission values. By using this model, decision makers will have the ability to make better decisions on what theaters will be most applicable to using the JSTARS GMTI capability. They will also have better insight on what upgrades or equipment would allow the aircraft perform its mission more successfully. The data will also help planners better understand where and how to employ the asset to maximize its effectiveness. Furthermore, crews will have insight on the factors that will affect their mission prior to ever being deployed into theater. They can then focus their efforts on the controllable variables such as feedback or having a positive identification asset in an effort to increases the overall mission scores. Finally, this research will help other modelers better model GMTI and thus make more accurate assumptions about how many GMTI assets are required and what can actually be seen using a GMTI asset.

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Vita

Major Gardner Jerell Joyner graduated from Fuquay Varina High School in Fuquay Varina, North Carolina. He entered undergraduate studies at the Fayetteville State University, Fayetteville North Carolina where he graduated with a Bachelor of Science degree in Mathematics Teaching in May 1997. He was commissioned through the Detachment 607 AFROTC at Fayetteville State University where he was chosen to be an aviator in the US Air Force.

His first assignment was at Pensacola Florida as a student in Undergraduate Navigator Training in September 1997. He completed his training In Dec 1998 and was assigned to the 911th Air Refueling Squadron, Grand Forks, North Dakota where he was a navigator and squadron scheduler. While stationed at Grand Forks he deployed often to Operations Northern and Southern Watch. He then PCS'ed to Warner Robins AFB, where he was a member of the 116 ACW. While there he deployed multiple times to Operations ENDURING FREEDOM and IRAQI FREEDOM. After completion of this assignment he moved on to be a part of the 552d ACW. There he was a flight commander and the chief of flight deck training for the wing before moving on o his next assignment in San Antonio, Texas. In San Antonio, he was assigned to the Air Force Personnel Center where he was responsible for the assignments of all C2ISR pilots and navigators. While there he also had the pleasure of standing up the Air Force's newest weapon system, the MC-12. In August 2009, he entered the Graduate School of Engineering and

Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the Robins AFB, GA.

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14. ABSTRACT
As the nature of warfare has shifted from a conventional approach to more guerilla type warfare, intelligence has become more important than at any other time in the history of the United States Military. With the stochastic nature of intelligence gathering, it is almost impossible to know with any degree of certainty where and when the next piece of information that could possibly change the course of the battle or war will be obtained. US intelligence gathering assets have long been plagued with using useless measures of performance rather than measures of effectiveness to determine their worth. This research uses a value focused thinking approach to determine the effectiveness of a specific capability or asset. Specifically, it looks at Ground Moving Target Indicator onboard the E-8C Joint Surveillance Target Attack Radar System. This research attempts to provide a model to a decision maker so he or she will know in advance the approximate value of information they will receive from a particular asset or capability before the asset is ever deployed into the area of responsibility.

15. SUBJECT TERMS
Joint Surveillance Target Attack Radar System, Ground Moving Target Indicator, Measures of Effectiveness, Value-Focused Thinking

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