

Evaluating Army Geospatial Data Collection Tools

Cadet Breawna Davis
Cadet Alexandria Sutherland
Cadet Megan Wilton
Dr. Michael J. Kwinn, Jr. Advisor

Department of Systems Engineering
US Military Academy
West Point, New York 10996
breawna.davis@usma.edu

Abstract—During the conflicts in Iraq and Afghanistan, there were thousands of different types of equipment delivered to Army units to support their efforts. These “rapidly fielded” systems did not follow the standard Department of Defense procurement process to become what is termed a “Program of Record”, or PoRs, meaning a program which has a funding stream to continue fielding and support. Now that the war effort is winding down, these systems will either be terminated or become PoR. One such system is the Buckeye system. This system provides very high-definition 3D photo capabilities which can provide Army units with near real-time pictures of the terrain which they are about to walk through or, in the case of helicopters, land on. To become a Program of Record, the Army must determine if the system provides the most cost-beneficial solution. In this paper, we evaluate the value of systems which can be used to evaluate terrain data for Army units using a process known as the Systems Decision Process.

Keywords—Decision Analysis, Military Acquisition, Value Focused Thinking, Cost-Benefit Analysis

I. INTRODUCTION

Terrain analysis is a fundamental step in the mission planning process. Soldiers need to understand the geography of the area of operation in order to move effectively and ultimately complete their mission successfully. The Army uses a wide array of tools to provide geospatial information to troops, ranging from a basic paper map to the orthorectified images of advanced geospatial data collection tools such as the BuckEye. The development of geospatial data over time began with combining technology such as aerial photography and remote sensing techniques [1].

The past fifty years yielded inventions such as the GPS (publically released in 1990) and Google Earth (released in 2005), making geospatial information more accessible and convenient to the public than ever been before [13,3]. The accessibility and quality of the available terrain data suits the average person with average needs, but does it meet the needs of America’s Army? As the Army transitions to a garrison force, decision makers are seeking ways to maintain mission effectiveness despite a shrinking budget.

This report will consider the tradeoffs associated with a number of geospatial data collection tools in order to recommend the most valuable and cost effective solution to the Army. To evaluate the different potential solutions to this terrain analysis requirement, we turn to an approach which is widely used in both the government and in industry to address such cost-benefit type problems: The Systems Decision Process [4].

This report is about the application of an analytical process to a significant Army problem. The data used is not official and therefore neither are the results.

II. APPROACH: SYSTEMS DECISION PROCESS

The Systems Decision Process (SDP) is widely known within the field of systems engineering. It is a collaborative process that focuses on the needs and values of a stakeholder when dissecting and creating alternatives for a given initial problem. It is broad in scope and narrowly tailored to fit the needs of the stakeholder based on given values and backed by thorough research [5].

In addition to the aforementioned focus on stakeholder values, there are other advantages of this approach. By focusing on what the client needs holistically, not just the problem they present, solutions and recommendations are more productive and satisfying. Another advantage is that it is an iterative process, requiring frequent communication with the stakeholders. This ensures the stakeholder remains informed of the progress and process behind the project and the solutions are centered on the stakeholder values. In figure 1, below, is the depiction of the process. The structure of this paper follows this process.

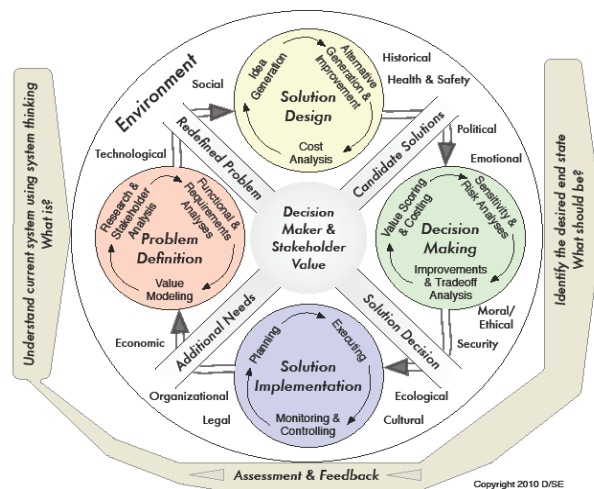


Figure 1: Systems Decision Process [6]

III. PROBLEM DEFINITION PHASE

The first stage of the process, depicted by the red circle in the diagram below, is the Problem Definition phase. This is the most important phase in the process because it is important to identify and solve the right problem for the client. Within this phase a systems team, given initial problem statement from the

stakeholder, conducts stakeholder analysis, functional analysis, and value modeling in order to determine the root cause of the issue at hand. Understanding what the stakeholder needs in the context of their values and environment, coupled with outside research, helps the systems team formulate a revised problem statement at the end of this phase [7].

A. Background Research

The BuckEye system has been traditionally attached to fixed and rotary wing aircraft; however some experimentation was performed regarding an Unmanned Aerial Vehicle (UAV) platform. In a study conducted by Robert L. Fischer, et al., researchers documented the physical and systems integration of the BuckEye EO system (BuckEye 1B+, which is the current version of the electro optical system) and the Arrow UAV platform. The Arrow is a larger UAV designed by Titan Aircraft Company, and is subject to harder landings which required reinforced trusses to absorb the stress put on the landing gear. While the BuckEye was successfully integrated with the Arrow, there were some issues regarding overheating, poor calibration due to movement, and lack of bandwidth to support the ground station communications and the pictures taken by the system [17]. Although cameras have been successfully mounted on UAV platforms, due to the BuckEyes' larger weight (with the addition of the LIDAR component), it is more difficult to integrate it onto a smaller platform. Thus, there seems to be a relationship between weight and size of the aerial platform.

In another study conducted by Leonard Adelman et al., the value of the BuckEye system was assessed according to a set of criteria determined by selected subject matter experts. Those values were to reduce the time spent evaluating a piece of terrain, improve operator's ability to extract meaningful information, improve the operator's ability to evaluate an area, and increase the uniformity of participants' responses [11]. Although more time was spent analyzing the maps produced by the BuckEye, more time was saved because there were fewer requests for information (RFIs). Thus, the study concludes that BuckEye products saved soldiers' time because they provided a more accurate depiction of the terrain.

The Army Geospatial Center (AGC) and the TRADOC Capability Manager (TCM) Geospatial provided a number of resources explaining the development and advancement of BuckEye since it was first created in 2004. The most useful documents include the "BuckEye White Paper" written to examine the needs of ground fighters and compare the different sources of geospatial (topographic) technologies available for use by the Army. This initial research done by the AGC in conjunction with the TCM identifies and defines specific parameters that can be used to describe the value and viability of geospatial data collection technologies. The main conclusion of the paper is that BuckEye offers mapping data that is superior in coverage, currency, and resolution which meets Soldier needs in complex and urban terrain, especially in austere regions [10].

The findings determined by the White Paper contributed to the Geospatial Remote Sensing for Mission Command (GRSMC) Capability Production Document (CPD) which aims to clearly define the geospatial needs of the Army and how

BuckEye meets those needs. It also describes the costs and benefits associated with three possible Courses of Action (COA) for sustaining the BuckEye capability as it is adopted as an Acquisition Program [2].

In addition to the White Paper, the AGC and TCM also internally publish bi-weekly reports provided to the geospatial engineering community and customers. Useful information uncovered in the November 2013 issue was the many different types of interfaces that BuckEye uses to display geospatial mapping information. These interfaces include Command Post of the Future (CPOF), FalconView, SkyLine and GeoGlobe. Basically, each of these interfaces is a software program with the ability to display geospatial mapping and information. For example, GeoGlobe is a 3D based visualization and dissemination tool designed to make the discovery and exploitation of geospatial information easier [9].

In sum, background research provided key insights into the BuckEye system in particular. First, smaller systems are more maneuverable because they are easier to integrate onto aerial platforms [17]. Second, the long delays for processing and distributing data could potentially improve by increasing the bandwidth capacity [17]. Third, a key objective of soldiers on the ground include minimizing RFI's because it saves time [11]. Fourth, internal reports from the AGC revealed key stakeholder values: coverage, currency, and resolution, among others that will be covered in more detail in the next sections [10]. Finally, understanding the different system interfaces and capability expectations will help define the system boundaries.

While these internally published documents do offer important background information and insight to defining stakeholder needs and values from our client's perspective, they do have a degree of bias associated with them because they were written by the Army. Additionally, our research could be improved by securing hard data concerning the exact number of helicopter rollovers due to a lack of detailed geospatial information during the landing zone selection phase (versus pilot error, system malfunction, etc.). Going forward, we would like to continue our research by exploring other avenues of information in order to make this a well rounded study that considers not only high resolution data, but also other current mission analysis tools that may serve as a basis for comparison.

B. Stakeholder Analysis

Stakeholder analysis provides key insights as to what the client and other important stakeholders of the system value. In this part of the approach, the goal is to focus on the type of individuals who would be impacted by this system. Examples include the client (AGC), aviators, and soldiers on the ground.

Most aviators provided insight regarding what pilots experience as they land and what tools they used to conduct mission analysis. These interviews were done with the problem of helicopter rollovers in mind. Findings included the problem of brownouts on the LZ, leads on where to find crash data, and background concerning current interface tools used (CPOF, FalconView, etc.). Pilots mentioned that high resolution data would have been useful during the initial assault in Iraq as the terrain was unpredictable and subject to change due to the

urban environment and also when initially choosing LZs in an area of operation.

From our interviews with soldiers, they need geospatial data that is mission specific, reflects recent data, and can be disseminated quickly. We also found that a soldier is rarely aware that the map they are seeing is a product of BuckEye specifically and therefore where the terrain data comes from is irrelevant to them, though the quality of the geospatial data is important.

The interviews and the background research are now used to help identify the system boundaries which lead to a fuller understanding of the system under study. This is best depicted using a Systems Context Diagram.

A Systems Context Diagram is a method of illustrating the system under study. It shows the distinction between what this project will focus on when creating alternative solutions to solve the updated problem statement, and what factors are outside the scope of the system [8]. In figure 2, the items within the blue box are considered to be a part of the system under study. The items in the red box, although important influences, are not considered to be inside the system and therefore will not be items considered when developing alternative solutions.

Factors determined to be outside of the scope include soldiers, personnel, developers, interfaces, force structure, and data collectors. Soldiers and the users of the system and not deemed to be part of the system. In the same way, personnel, developers, and data collectors are needed to operate the system but they do not affect the quality or value of the data. Interfaces, to include CPOF, FalconView, GeoGlobe, etc, are methods of displaying the data and are also external to the system. Lastly, force structure refers to what level of the Army will own the geospatial data analysis tool that offers the best total value. These external factors are shown in the red boxes below.

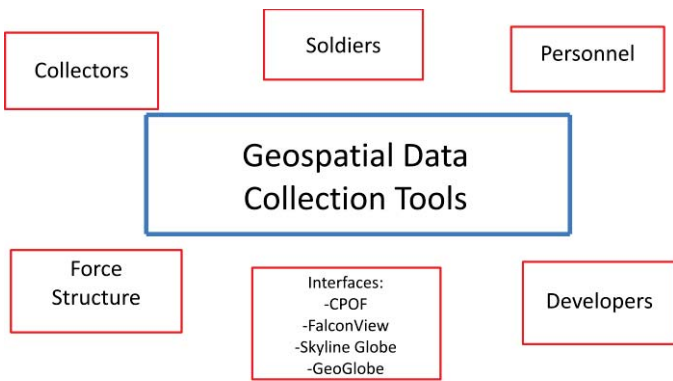


Figure 2: System Context Diagram

The product developed from the Background Research and the Stakeholder Analysis is a Revised Problem Statement (RPS). This RPS is a restatement of the issues identified after taking a holistic view of the situation presented by the client.

Or initial problem statement from the client was to assess the value of the BuckEye system to help in the decision to make it a PoR. From the previous research, this is the Revised Problem Statement for the client:

Determine the most valuable geospatial data collecting system to meet the needs of the Army.

This new problem statement encompasses all existing methods for conducting terrain analysis, not only high resolution data. The revised problem statement serves as the fundamental objective when considering the functions of the system which are presented in the next section.

C. Functional Analysis

The functional hierarchy for the system under study is a simple analysis technique and visual that captures, on a broad level, what the system is supposed to accomplish. It is not a traditional functional decomposition that an engineer would use to construct a geospatial analysis tool. This hierarchy was developed by identifying and categorizing specific system functions and sub functions. It will guide future alternative designs and ensure the system will achieve the specific performance objectives the stakeholders desire.

We started by evaluating the functions of the BuckEye System. Based on the background research described earlier and the interview results, we compiled an extensive list of tasks that the BuckEye does or should be able to do. Most importantly, the BuckEye system should produce geospatial imagery and elevation data that is spatially accurate, precise reliable, durable, intuitive, relevant to the mission, and unclassified [10, 2]. We then grouped these tasks into like categories, in order to identify the most important, broad level functions. For example, intuitive, relevant to the mission, and unclassified can all be represented by “accessible,” which contributes to the main goal of increasing mission effectiveness.

Based on our research and in compliance with the Army’s needs, what exists, what works, and what our soldiers and clients are still lacking, the four main functions a geospatial collection tool should be able to accomplish are as follows: reflect current information, cover relevant areas of operation, provide accurate products [10], and distribute data efficiently.

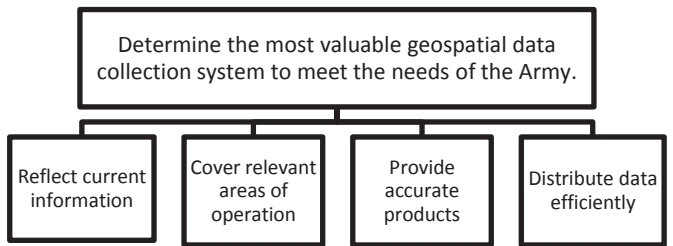


Figure 3: Functional Hierarchy

As depicted, each main function is as a product of the fundamental objective (i.e. the revised problem statement). “Reflect current information” captures the AGC’s desire to provide soldiers with the most up to date imagery to use during

mission planning. “Cover relevant areas of operation” encompasses the need for products that cover relevant terrain to a given mission. “Provide accurate products” represents the desire to have products that accurately depict the terrain surrounding any given unit in a given theater of operation. Lastly, “distribute data effectively” aims to ensure soldiers are receiving the geospatial data they need in a timely manner, ensuring wide and timely access to the necessary imagery. High resolution maps and elevation data may show details unlike any other but if it is outdated then it does not help troops on the ground. In the same way, a soldier’s request for geospatial data may be useless if the order takes too long to process. In the next section, we will discuss the specific value measures that we will use to quantitatively measure these functions.

D. Value Modeling

1) Value Hierarchy

Value modeling is an initial methodology used to evaluate the candidate solutions created in the solution design phase of the SDP. Using information developed from the background research conducted in combination with stakeholder analysis, value modeling pairs the functional requirements of a system with a method of measurement to transform a qualitative value into a quantitative score [7]. Depending on how each alternative performs according to these measures, we will be able to quantitatively score each alternative according to the values and compare them in order to make a recommendation that solves the problem. The value hierarchy below graphically represents the values and means of quantitative measurement for each function.

For example, we can measure the value of the “increase reflect current information” function based on the amount of time it takes to update the terrain data of a given region. The value is therefore “minimize time to update products.” Mission effectiveness can also be measured by the amount of data that is available upon request. A geospatial data analysis tool that has the ability to provide accurate data of a region is valuable to mission planning because it gives the soldier more information regarding where they will be operating. The value measure “maximize resolution” measures the accuracy of a given geospatial terrain analysis product. An old satellite image is less accurate than an image collected in the last 24 hours and is therefore, less valuable to the soldier.

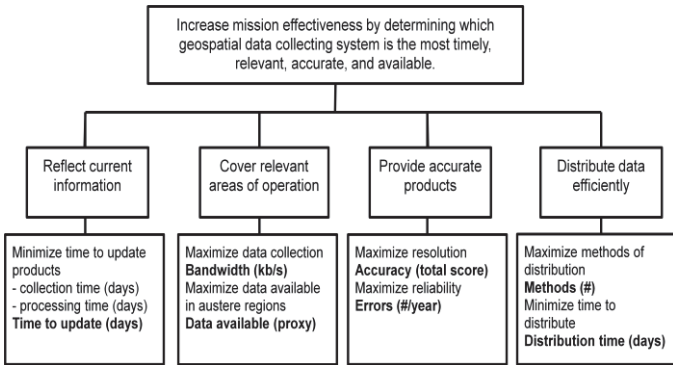


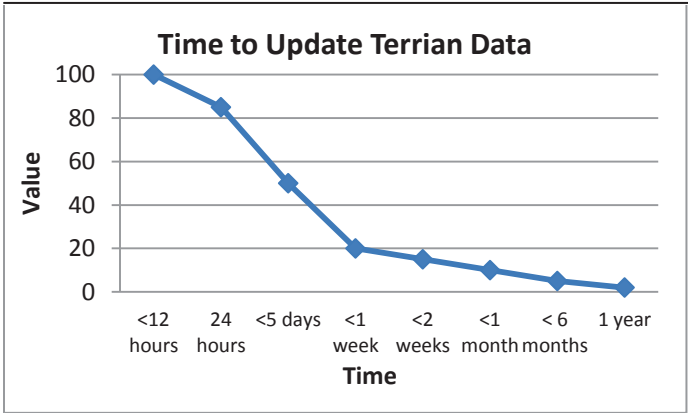
Figure 4: Value Hierarchy

2) Quantitative Value Model

To effectively evaluate the values associated with each function we must determine quantitative units of measure, called value measures. Through quantitative value modeling we can compare each candidate solution’s total score. Each value and the associated value measures are as follows:

1. Time to Update (days)
2. Bandwidth (MB/s)
3. Data available (expert estimate)
4. Accuracy (score)
5. Errors (expert estimate)
6. Methods (number)
7. Distribution time (days)

Each value measure is associated with a value curve, or a range of possible values. Value curves are either discrete or continuous depending on the value measure. For example, time to update new terrain data is continuous.



These measures are then weighted according to the stakeholders’ preferences. Assigning a relative measure of importance gives each measure an overall value that ultimately enables our team to quantify the tradeoffs between the value measures. The matrix below is called a Swing Weight Matrix because it organizes the value measures by impact and importance. The swing weight matrix accounts for both the stakeholder’s values and the variability of the data. Accounting for both factors is important because a value measure that is very important to a stakeholder may have very low variability, causing it to be less of a decision factor than the decision makers may realize at first. A value measure with low variability indicates that the candidate solutions have similar data points in that area and therefore, that value measure has a lower impact on the total value of the candidate solutions.

The top scale defines the importance of the value measure to the decision makers and stakeholders (high, medium, or low). The left side represents the variability of data provided—the more variability that a set of data has, the more valuable the data since there is more differentiation to distinguish between the other value score from the other value measures (high, medium, or low).

		Importance of the value measure to the decision makers and stakeholders		
		High	Medium	Low
Variability of data	High	Time to Update F1=100	Distribution Time F7=85	Methods F6=60
	Medium	Data Available F3= 70	Accuracy Score F4=45	Bandwidth F2=30
	Low		Errors F5=15	

Figure 6: Swing Weight Matrix

3) Weighted Value Measures

Once the swing weight values are selected, the weights are normalized to 1 using the following equation.

$$\frac{\text{Swing Weight Value}}{\sum \text{Swing Weight Values}} \quad \text{Eq. 1}$$

The result is a measure weight, summarized in the table below. Measure weights will be used to translate raw data into value scores for each alternative in the Decision Making Phase. The final value scores offer a quantitative means of comparison for the alternatives.

Value Measure	Swing weight	Measure weight
F1- Time to Update	100	0.247
F2- Bandwidth	30	0.074
F3- Data available	70	0.173
F4-Accuracy	45	0.111
F5-Errors	15	0.037
F6- Methods	60	0.148
F7- Distribution Time	85	0.210
Total	405	1

Table 1. Measure Weights

IV. SOLUTION DESIGN PHASE

A. Idea Generation

Different creative processes are used to flesh out all potential ideas that eventually form the alternatives. The focus of the idea generation process is not to eliminate or restrict ideas based on feasibility, but to explore every idea in attempt to cover the entire solution space. Screening ideas for feasibility comes later in the process; the purpose of idea generation is to be as creative as possible.

B. Alternative Generation

There are several different methods for generating alternatives, including brainstorming, brain writing, the use of existing methods, and generating unique alternatives tailored to the problem. The use of existing alternatives is used extensively in this analysis for two reasons. First, we were charged to evaluate existing collection and analysis methods so we have to analyze the existing alternatives. Second, we used information gathered through background research and stakeholder analysis to provide context to these alternatives. The list of alternatives below was given to us by AGC. The alternatives for this project were given to us by AGC for evaluation and they are explained more in depth in the next section.

Google Earth, MapQuest, Bing Maps: Commercial providers of geospatial data compete with one another by providing the most up to date data for customers. Terrain maps are created based on economic payoff and activity in a given region. There is little incentive to providing data for deserts, remote towns, etc. which makes this a difficult tool to use in austere environments, like those in Afghanistan [10].

BuckEye Lidar, Mapping System: The BuckEye system is a high resolution camera and Lidar combination that provides soldiers with up to date imagery on a request basis. It can be mounted on a helicopter, plane, or UAV to collect imagery. There are currently six BuckEye systems currently in operation in Afghanistan.

1:50,000 map: This is the most cost effective and primitive method of terrain analysis. It cannot be updated and does not provide recent imagery. For the purposes of this study, it will simulate a “control” as a basis for comparison.

Commercial Satellites: Remote sensing satellites provide wide swaths of imagery to soldiers, however the resolution fluctuates and coverage of an austere region is often subpar. There are few incentives to collecting data for austere regions so companies don’t generally dedicate money to do so.

National Geospatial-Intelligence Agency (NGA): The NGA provides a wide vast array of maps, charts, and safety of navigation products to the Army, Air Force, and Navy. The use of NGA has declined since 1972 when the production of maps was transferred to the Defense Mapping Agency. The bottom line is that NGA cannot collect all geospatial products required by the modern warfighter.

Shuttle Radar Topographic Mission Interferometric Synthetic Aperture Radar (SRTM IFSAR): One time data collection effort to gather topographical information. The data gathered will remain viable for the next several decades unless major construction projects are undertaken. Not updateable, and of little use when considering small villages.

TanDEM-X: A European satellite-based IFSAR program that has a mission to collect elevation data at 12m post spacing or better world-wide. This system is useful because it can provide current imagery, however its products are lower in resolution compared to the BuckEye or HALOE.

Unmanned Aerial System Reconnaissance and Surveillance Imagery (UAS R&S): the primary purpose of R&S sensors is to collect intelligence data – that is, information that is focused on two things: where is the threat, and what will the threat do next? The downside is that if they were used to collect wide-area map data, they are not doing their primary mission of gathering intelligence.

Corporate Remote Sensing Aircraft: Private companies are designing and developing remote sensing technologies similar to the BuckEye. It would be much more cost effective to deploy these commercial sensors on Army aircraft with Soldiers performing the tasks associated with high-resolution geospatial data collection.

The High Altitude LIDAR Operational Experiment (HALOE) program: geospatial data collection at high altitudes in operated by the BuckEye program in support of theater commanders. Mapping cameras are not included because the elevation is too high to capture adequate resolution.

Summary of Alternatives
Google Earth
BuckEye
1:50 K Map
Commercial Satellites
NGA
SRTM IFSAR
TanDEM-X IFSAR
UAS R&S Imagery
Corporate Remote Sensing Aircraft
HALOE

Table 1. Alternatives

In the next phase, the alternatives will be evaluated using a method known as value scoring.

V. DECISION MAKING PHASE

A. Value Scoring and Costing

Value scoring allows the alternatives to be numerically compared. The first step of value scoring is to collect raw data for each of the alternatives in the previously identified value measures.

Alternative	Time to Update (days)	Bandwidth (MHz)	Data Available (proxy)	Accuracy (score)	Errors (#/year)	Methods (#)	Distribution Time (days)
Google Earth	Twice a month	6 MB/s	Varied	2.1	L	1	model
BuckEye	once a day	5.6 MB/s	Yes	5.5	VL	4	model
1:50K Map	every 6 months	Instant	Yes	0.5	M	2	model
Com. Satellites	daily	5.63 MB/s	Yes	3.2	M	3	model
NGA	weekly	500 MB/s	Varied	3.2	L	2	model
SRTM IFSAR	11 days	20 MB/s	Varied	0.6	M	1	model
TanDEM-X IFSAR	daily	600 MB/s	Yes	1.25	M	1	model
UAS R&S Imagery	weekly	500 MB/s	Yes	1	L	1	model
Corporate R&S Aircraft	daily	100 MB/s	Varied	4.5	L	3	model
HALOE	daily	6 MB/s	Yes	4	VL	1	model
Airborne IFSAR	daily	500 MB/s	Yes	2.6	L	2	model

Table 3. Raw Data Matrix

The raw data attributed to a given alternative is transformed into a numeric value score according to the equation

$$\sum v_i * w_i \quad \text{Eq. 2}$$

where v_i is the piece of raw data and w_i is the weighted value measure. The resulting summation is a single number that represents the total value of a given alternative.

The total value of each alternative is represented by the stacked bar chart below. This is a tool to illustrate where each alternative carries its value; thus, if a stakeholder has a fixed amount of resources and wants to maximize the increase in value of a given alternative, they can see where each alternative draws its value.

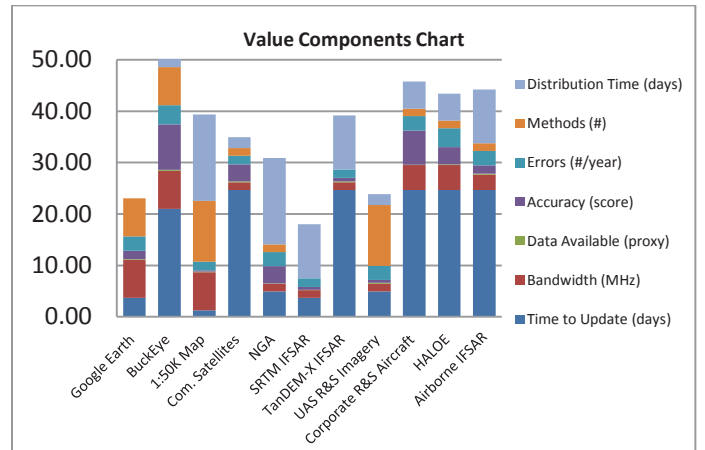


Figure 6. Value Stacked Bar Chart

B. Sensitivity and Risk Analysis

Sensitivity analysis determines if changing the weight of a value will have an effect on the overall score, or make one solution better than another. If two candidate solutions are closely ranked and one is better than another based on a given weighted value, then the stakeholder must decide which is most important. This also gives the stakeholder flexibility in the alternative ultimately decided upon. In some cases, more

research and modeling must be done in order to provide the stakeholder with more information to decide upon the best alternative.

The graph below depicts the influence changing a value measure would have on a given alternative's value score. For example, sensitivity analysis for the "time to update" value measure with a swing weight value of 50 shows that this particular value measure is not sensitive because changes in the swing weight value would not change the top two highest valued alternatives, BuckEye and HALOE. However, if the client was considering options with a lower total value in order to cut costs perhaps, the graph shows that the recommended system would change if the swing weight was different by plus or minus 20 points. This would require the stakeholder to reaffirm the swing weight before making a decision.

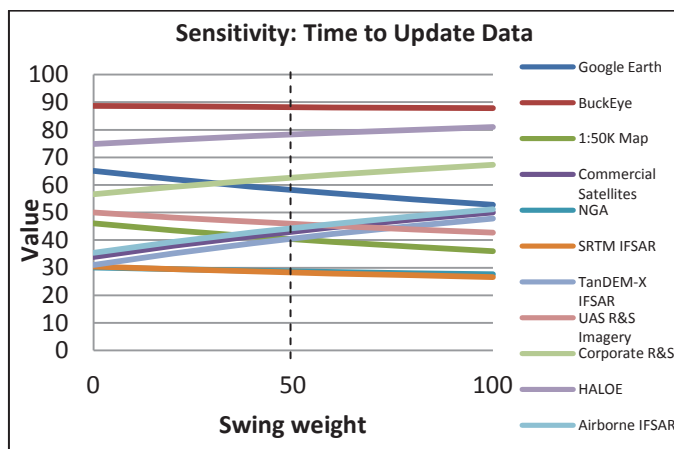


Figure 7. Sensitivity Analysis Chart

Risk analysis assesses the overall risks associated with a given alternative. If an alternative scores high in value but is accompanied by risk the stakeholder is unwilling to accept, the stakeholder is confronted with another decision point. Risk involving the implementation of the alternatives is also assessed in order to give the stakeholder the most information before making a decision.

C. Improvements and Tradeoff Analysis

Value-focused thinking will ensure the team conducts analysis in accordance with what the stakeholder deems important. One product of this process is a breakdown of each candidate solution based on the given values. This will show the stakeholder what changes they can make to bring more value to their solution. Generally presented in a stacked bar chart, the breakdown of value measures presents a visual representation of where a stakeholder can dedicate resources to get the "most bang for the buck."

When the total value score is graphed against an alternative's cost, the stakeholder can see how their money is being spent. An alternative with the largest value score may be out of a stakeholder's budget, which is good information to

have before making a decision. Tradeoff analysis is just another way to show a stakeholder.

VI. RECOMMENDATION

In our final research and evolution the recommended geospatial data collection system for use is the BuckEye System. The reasons why we recommend this system over the other alternatives is based on our value scoring and costing, sensitivity and risk analysis and improvement and tradeoff analysis. While background research on all systems served well in the early analysis of the alternate systems, it was when we compared each value measure to each other and based on those total value score were able to clearly see through mathematical models which system was the best.

BuckEye allows so many different approaches and alternatives in geospatial data collecting compared to the other systems mentioned. The BuckEye is able to collect data quickly, and based on the needs of the mission, can effectively and effectively delivers quality data.

VII. IMPLEMENTATION

The solution recommended will be implemented by the stakeholders. If there are any questions in the future, the systems team will be available for further consulting. As the solution is implemented, additional analysis can be performed to collect data on the actual performance of the chosen alternative. This will inform future decision makers and help assess the actual value of the chosen system.

VIII. SUMMARY AND FUTURE DIRECTIONS

The evaluation of terrain data using the SDP uncovered the value of each system based on stakeholder analysis and background research. Because of the iterative nature of the analysis conducted, the final recommendation of the BuckEye system encompasses everything the stakeholder is looking for in a geospatial data collection system, and is a solution that will bring the most value to the Army.

The purpose of this paper was to highlight the process and this specific application to geospatial analysis tools. The numbers used in this paper are for illustrative purposes only. They will be further refined as more detailed models are developed for the decision maker.

IX. ACKNOWLEDGEMENTS

The authors acknowledge the support of the Army Geospatial Center (AGC) who has graciously funded this research and supported the team. The results presented here have not been approved by the AGC and therefore the results should not be construed as official or final.

REFERENCES

- [1] P.R. Baumann. (2001). *History of Remote Sensing, Aerial Photograph*. [Online] Available: <http://www.oneonta.edu/faculty/baumanpr/geosat2/RS%20History%201/RS-History-Part-1.htm>
- [2] F. Erst, "Capability Production Document (CPD) for Geospatial Remote

Sensing for Mission Command (GRSMC), Increment I,” U.S. Army Geospatial Center, Washington D.C., PoR Proposal, Jul. 13, 2013.

- [3] Google. (2013. Oct. 6). *Google Company History* [Online]. Available: <http://www.google.com/about/company/history/>
- [4] G.S. Parnell *et al.*, “Chapter 9: Systems Decision Process Overview,” in *Decision Making in Systems Engineering and Management*, A. Sage, Ed. 2nd ed. Hoboken: Wiley & Sons, Inc., 2011.
- [5] G.S. Parnell *et al.*, “Chapter 9: Systems Decision Process Overview,” in *Decision Making in Systems Engineering and Management*, A. Sage, Ed. 2nd ed. Hoboken: Wiley & Sons, Inc., 2011, pp.280.
- [6] G.S. Parnell *et al.*, “Figure 9.5 Systems decision process,” in *Decision Making in Systems Engineering and Management*, A. Sage, Ed. 2nd ed. Hoboken: Wiley & Sons, Inc., 2011, pp.281.
- [7] G.S. Parnell *et al.*, “Chapter 10: Problem Definition,” in *Decision Making in Systems Engineering and Management*, A. Sage, Ed. 2nd ed. Hoboken: Wiley & Sons, Inc., 2011, pp.297-351.
- [8] G.S. Parnell *et al.*, “Chapter 2: Systems Thinking,” in *Decision Making in Systems Engineering and Management*, A. Sage, Ed. 2nd ed. Hoboken: Wiley & Sons, Inc., 2011, pp.31-38.
- [9] K. Bergman, “Bi-Weekly Report, 29 Nov 2013,” U.S. Army Geospatial Center, Washington D.C., Bi-Weekly Rep., Nov. 29, 2013.
- [10] K. Bergman, “BuckEye White-Paper: Courses of Action for Geospatial Remote Sensing,” U.S. Army Geospatial Center, Washington D.C., Tech. Rep., Oct. 2013.
- [11] L. Adelman *et al.* "Evaluation of High Resolution Imagery and Elevation Data," *AFCEA George Mason University Symposium*, 2009.
- [12] L. Roskop, “U. S. Rotorcraft Accident Data and Statistics,” 2012 *FAA/Industry Safety Forum*, FAA January 2012.
- [13] LSU Center for GeoInformatics, “30 Years of GPS,” *Louisiana State University Website*, http://c4g.lsu.edu/c4g15/index.php?option=com_content&view=article&id=39:30-years-of-gps&catid=13:cntr-for-geoinfo&Itemid=33. Edited in 2011.
- [14] M. Colburn, “The 10-Year Helicopter Accident Reduction Initiative,” *Air Beat Magazine- Journal of the Airborne Law Enforcement Association*, Airborne Law Enforcement Association, January-February 2009.
- [15] M.D. Pritt, M. Gribbons, and K. LaTourette, "Automated cross-sensor registration, orthorectification and geopositioning using Lidar digital elevation models," *Applied Imagery Pattern Recognition Workshop (AIPR), 2010 IEEE 39th*, IEEE, 2010.
- [16] M. Hardaway *et al.*, “Statement of Work: BuckEye Project,” U.S. Army Geospatial Center, Washington D.C., Statement of Work, Oct. 15, 2013.
- [17] R. L. Fischer *et al.*, "Development, integration, testing, and evaluation of the US Army Buckeye System to the NAVAIR Arrow UAV," *SPIE Defense and Security Symposium*, International Society for Optics and Photonics, 2008.
- [18] “Problem Description,” *Statement of Work*, Department of Systems Engineering and Army Geospatial Center, Oct. 15, 2013.
- [19] V. M. Soldatkin, A. A. Arkhipov, A. A. Ugllov, and V. A. Olaev, "A Starting System of Warning the Critical Conditions for a Single-rotor Helicopter," *Russian Aeronautics*, vol. 55, no. 2, pp.184-91, 2012.
- [20] X. Sun *et al.*, "A Precision Geo-referenced Digital Airborne Camera System," *Geoscience and Remote Sensing Symposium, 2006, IGARSS 2006*, IEEE International Conference on IEEE, 2006.