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MITRE Sensor Package Value Model

Bryce Milton, John Blodgett, Thomas Aldhizer, Noah Wallace, and Timothy Elkins

Department of Systems Engineering
United States Military Academy
West Point, NY

Corresponding author's Email: Bryce.Milton@westpoint.edu

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Abstract: Multi-Domain Operations requires the integration of resources between all military branches. This requires strategic planning by properly utilizing resources to ensure different equipment is used effectively and efficiently for each mission. Key tools that will be integrated are sensors and sensor packages. These sensors are an integral part of all military systems. Proper execution of deploying the right sensor for the right mission requires an in-depth analysis of each sensor's capability. Creating a value model will help select the best sensor per scenario by ensuring each utilized sensor meets the mission's parameters. Therefore, this research aims to produce a value model that will aid in sensor selection.

Keywords: Multi-Domain Operations, Sensitivity Analysis, Value Modeling

1. Introduction

The United States Military is currently changing operations as they pivot their focus from worldwide counter-extremism to near-peer adversaries. Recently, the United States began to utilize Multi-Domain Operations (MDO), the concept of managing joint forces concurrently to give the user a competitive advantage on the battlefield (TRADOC Pamphlet 525-3-1). Grasping the complexities of multi-layered defense is challenging; however, the MITRE Corporations has assisted in this area. The MITRE Corporation is a research and development center that works with public and private partners to develop solutions for the challenging issues the United States faces. This capstone team assisted the MITRE Corporation's development in long-range sensor capabilities by providing a value model, which will quantitatively score long-range sensor packages composed of assets across the entirety of the U.S. Military. This report gives an overview of the value-modeling process, qualitative and quantitative analysis, value scoring, and decision analysis throughout the project.

The Capstone team utilized the Systems Decision Process (SDP), developed by the Department of Systems Engineering at West Point, to guide the project's execution (Parnell, Driscoll, & Henderson, 2011). The SDP is an iterative cycle consisting of four phases: Problem Definition, Solution Design, Decision Making, and Solution Implementation. Within each of these phases are three key components. This process can be seen pictorially below in Figure 1. The MITRE Corporation's objective was to develop a value model. A more detailed explanation of our approach utilizing the SDP, specifically Problem Definition, follows.

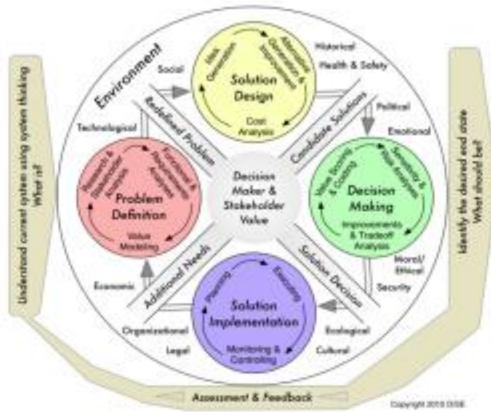

Figure 1. Systems Decision Process

2. Analysis and Results

The functional hierarchy is a breakdown of the functions necessary for the long-range sensor packages to accomplish the fundamental objective of Long-Range Sensors Enable Friendly Freedom of Maneuver. The fundamental objective is broken down into functions. The functions break down into objectives and then value measures. Our group identified three categories of functions related to the fundamental objective. The first function is a proactive warning system, functions two through six are reactive functions, and functions seven through nine are overall system functions. The first section seen in Figure 2 is colored green to signify the function's execution before the launch of an enemy threat. It is meant to be proactive to an enemy threat rather than just reactive. The scan battlespace function requires long-range sensors to look out across the area of operations for threats continuously. This function's objectives are to maximize the area scanned and maximize the time over the assigned Area of Operation (AO). The larger the percentage of this area covered, the more likely they are to detect a threat before it is launched.

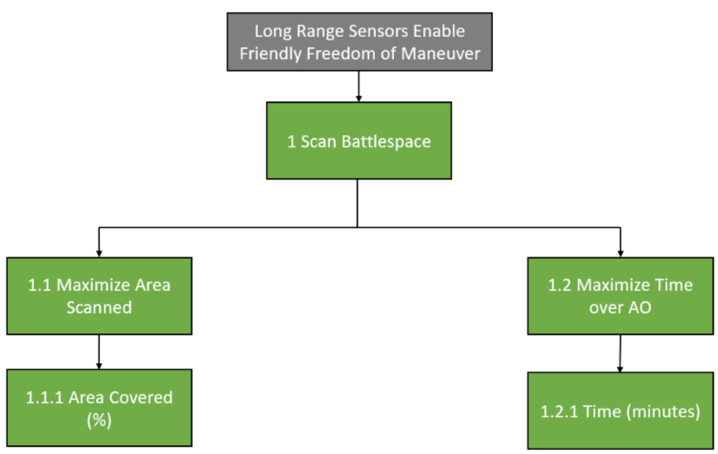

Figure 2. Functional Hierarchy Part 1

The second section of the functional hierarchy seen in Figure 3 consists of the functions executed after an enemy threat has been initiated. This is a key step that is vital for the follow-on functions to be executed properly. The three value measures of true positive identification percentage, false-positive identification percentage (less is better), and detection range are used to best measure the sensors' threat detection. Since detection is the key function the sensor packages will be executing, it is important that our model thoroughly measure it. After detecting a threat, the forces in danger of the threat need to be alerted (Function 3) as fast as possible to protect themselves if the threat cannot be stopped. Function four shows the requirement for the long-range sensors to integrate their communications. This means that once a threat has been detected, the detecting sensor needs to relay enough information about the threat so that other long-range sensors can also locate and track the threat. This builds redundancy in the system to lower the likelihood that one sensor going down will cause the system to fail. It also ensures the decision-makers have the most amount of accurate data at their disposal. After a threat is detected and the necessary friendly forces are alerted, the threat needs to be neutralized. Part of this is providing the necessary information to the defensive systems. By integrating the long-range sensors with defensive systems there will be a smoother and quicker neutralization of the enemy threat. Finally, the last function necessary for the system to execute during the second stage is to track the threat. A continuous following of the threat ensures that up-to-date information flows to the necessary units as close as possible. With all five functions in this section, the enemy threat will be detected and continuously tracked, friendly units notified, and other sensors and neutralizing assets integrated. After functions two through six have been executed and the threat neutralized, the sensor packages will cycle back to function one and continue in the iterative cycle.

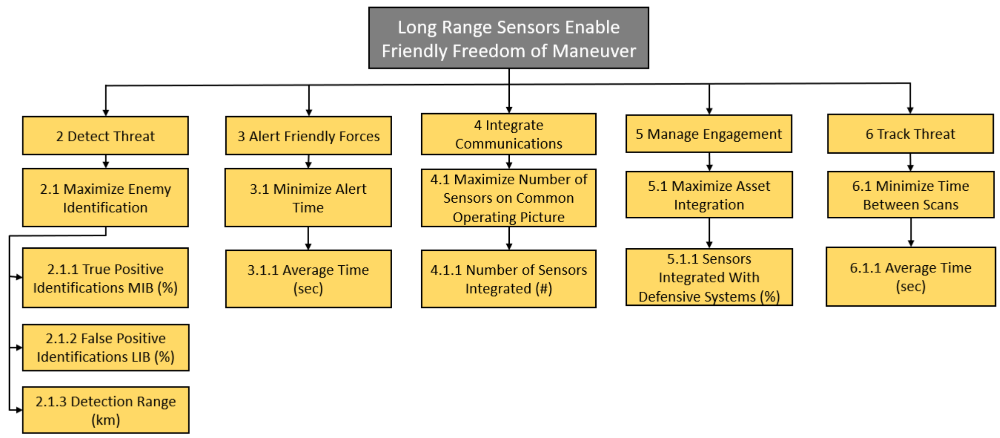

Figure 3. Functional Hierarchy Part 2

The final section of the functional hierarchy is in Figure 4, representing functions that occur throughout the entire process. This section of the hierarchy was created with the expertise of Mr. Andrew Valdez, who is a Chief Training and Capabilities Manager in sensor intelligence. The function of be autonomous is meant to limit the amount of manpower to run the long-range sensor systems. The survivability of the sensors is also important and is highlighted in function eight. The first part of survivability is electronic warfare (EW) resistance (DuQuesnay, D., & Valdez, A. 2019). After speaking to a subject matter expert, Mr. Justin Willman, an electrical engineer who works with the Army Night Vision Laboratory, it was concluded that the best way to measure EW would be to use a red, yellow, green scale. This scale takes the sensors' abilities and attributes and sorts them by low resistance to threats, circumstantial, or high resistance to threats. The other part of survivability is the resistance to weather, measured on a constructed scale. The last function the long-range sensor packages will need to execute is being reliable. This is measured by user ratings on the sensor package effectiveness and the ease of usability. Ideally, reliability data would be preferred but likely difficult to obtain from manufacturers.

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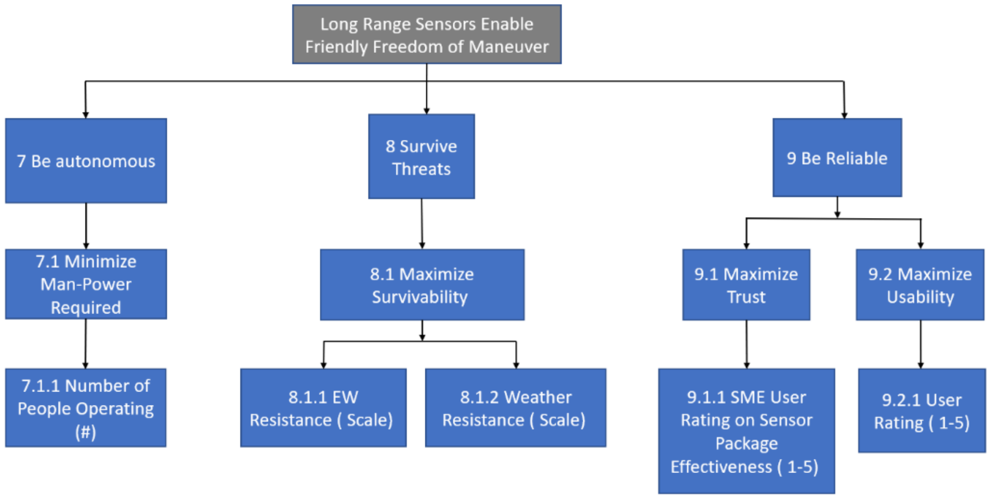

Figure 4. Functional Hierarchy Part 3

Once the qualitative analysis was completed, the following step was to take what has been qualitatively defined and convert it into a quantitative value model. Creating the qualitative value model required developing weights for the value measures and value functions.

Swing weights are used within the quantitative value model to rank the value functions based on their importance to the stakeholder. These swing weights are metrics that gauge the relative importance of each value function. To quantify each value function's relative importance, the stakeholders' needs, wants, and desires need to be considered. This was done by surveying the key stakeholders individually and averaging their values. If we were to create a stochastic model, the weights' uncertainty would then be used to create distributions. When deciding which value measure should be most heavily weighted, the stakeholders considered relative importance and relative variability in the value measure. For example, if a measure were both important and highly variable, then the corresponding swing weight would be much higher. Once the data on each of the stakeholders' views were gathered, the weights were normalized. This was done by dividing each value measure swing weight by the sum of all the weights as seen in Equation 1 (Parnell, Driscoll, & Henderson, 2011), leading to Table 1 below.

$$w_i = \frac{f_i}{\Sigma_{i=1}^{n} f_i} \tag{1}$$

Table 1. Swing Weights

Value Measure Swing Weights		**Normalized Swing Weights**	
User Rating	100	User Rating	0.14
SME User Rating on Effectiveness	95	SME User Rating on Effectiveness	0.13
True Positive Identifications (%)	80	True Positive Identifications (%)	0.11
False Positive Identifications (%)	75	False Positive Identifications (%)	0.13
Time (Min)	70	Time (Min)	0.13
Average Time (Min)	65	Average Time (Min)	0.09
Area Covered (%)	50	Area Covered (%)	0.07
Weather Resistance	45	Weather Resistance	0.06
Number of People Needed (#)	40	Number of People Needed (#)	0.05
Sensor Integrated with Defensive Systems (%)	35	Sensor Integrated with Defensive Systems (%)	0.05
EW Resistance (Scale)	30	EW Resistance (Scale)	0.04
Number of Sensors Integrated (#)	25	Number of Sensors Integrated (#)	0.03
Detection Range (km)	20	Detection Range (km)	0.03
Average Time (Sec)	5	Average Time (Sec)	0.01

Value functions are used to convert the raw data from a value measure to a unitless score to compare all value measures. The stakeholder determined the scores for each value measure. The x-axis for each value measure is the unit each respective value measure is naturally measured on, and the y-axis is measured on a scale from one to one hundred. A graphical example is seen below in Figure 5, which shows the value measure of 1.1.1 Area Covered as a value function. The functions for each value measure were developed with stakeholder and subject matter expert's input.

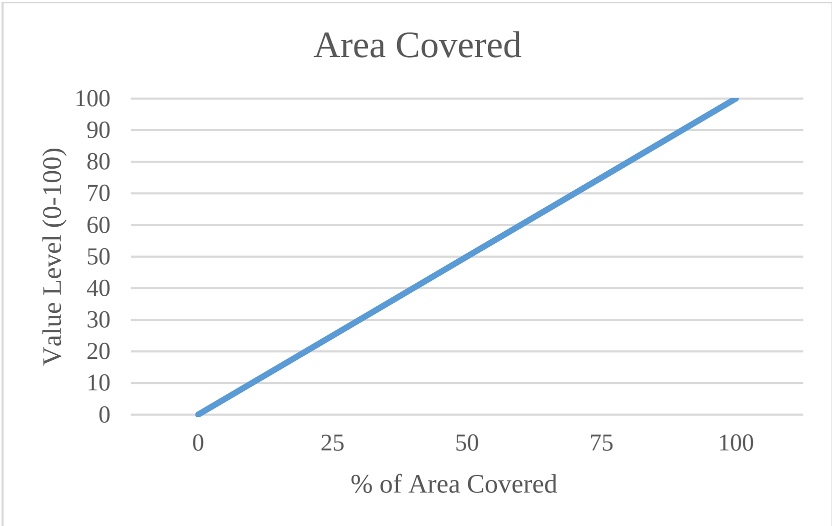

Figure 5. Example Value Function Graph

The value functions are used to convert raw data of an alternative into a total value score. To do this, Equation 2 below is used where the total value score for an alternative ($v(x)$) is the sum of each single-dimensional value ($v_i(x_i)$) multiplied by the corresponding measure weight (w_i) (Parnell, Driscoll, & Henderson).

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i) \quad (2)$$

After creating globalized swing weights and value functions, the value model was used to create total value scores for each of the long-range sensor packages. These scores were then compared to each other to determine which was the best alternatives. A visual representation of this is seen below in the stacked bar chart of Figure 6. Each color corresponds to a specific value measure. There are also two additional stacked bars representing an ideal solution and an all-star solution. The ideal solution has the best score possible of 100%. The all-star solution takes the highest value from the candidate solutions per value measure and combines them to show the best score possible using the parts from the other alternatives. Note, neither the ideal nor the all-star solutions are feasible; they only provide a reference for decision-makers. The capstone group created each alternative with varying sensors in each.

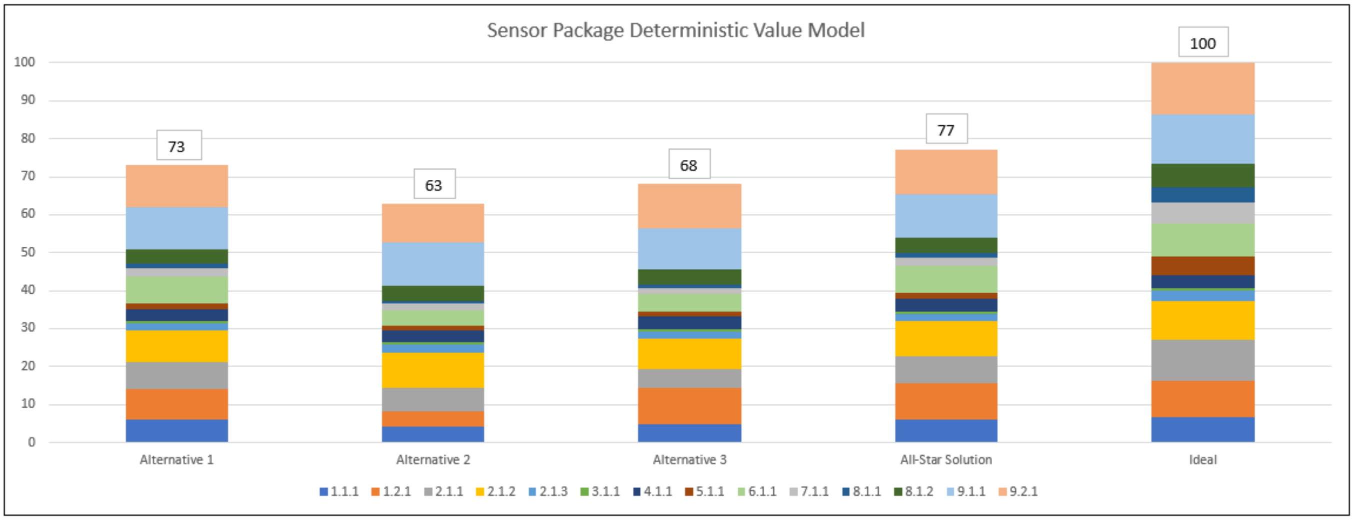

Figure 6. Alternative Stacked Bar Chart

A sensitivity analysis was also conducted on the model. Swing weights corresponding to the value measures are varied to see if the final solution chosen varies with the changes. If the chosen solution does vary within a ± 10% change in the swing weight value, that weight is considered significantly sensitive. If the chosen solution varies within any other change outside the ± 10% value change of the swing weight, it is only sensitive. Keep in mind that cost was not a consideration, as the decision-makers decide between options that are already in their inventory. Therefore, the cost is an irrelevant factor to consider.

3. Conclusion

This Capstone aims to address the challenges posed by Multi-Domain Operations, specifically in long-range targeting. The United States needs every competitive advantage to succeed in the technologically advanced nature of the future battle, and this model is intended to provide an advantage in sensor selection. Now that a full model has been developed, the stakeholder can enter the proper values associated with any given sensor package to produce an output. The scores provided by the value model can be compared directly to each other so that the stakeholder can select the best option. While this score does not consider all factors that may go into selecting technology, such as cost for the reasons stated above, it incorporates every meaningful value expressed by the MITRE Corporation. A stochastic value model can be made for follow on work using multiple subject matter experts' inputs by accounting for variability in swing weight and value functions values.

4. References

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