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Value Modeling and Trade-Off Analysis of the Tactical Assault Light Operator Suit

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Author Note: Cadets Fairbrass, Genders, Perez-Ortega, and Swisher are all members of the Department of Systems Engineering at the United States Military Academy. This paper presents research performed for a Capstone Project in support of Joint Acquisition Task Force – Tactical Assault Light Operator Suit (TALOS), US Special Operations Command (SOCOM).

Abstract: The Tactical Assault Light Operator Suit (TALOS) is a powered, armored exoskeleton designed to enhance an operator's survivability, lethality, and mobility. The suit is a SOCOM initiative using rapid acquisition practices with a functional prototype expected in 2018. Value modeling allows the TALOS design teams to rapidly perform design trade analysis while ensuring that the proposed system is in-line with the operator's needs. A stochastic value model was built for the power subsystem through an analysis of the requirements to develop value hierarchies, swing-weight matrices, and value functions. An Excel based tool performed trade-off analysis to determine the best design solution. This tool accounts for uncertainty in raw data values to create distributions in the cost and value of each design alternative, which is critical for assessing risk. The model was expanded to other subsystems as well as the suit as a whole.

Keywords: Trade-Off Analysis, Value Modeling, Design Alternatives

1. Introduction

1.1 Overview of TALOS

"Several years ago during a hostage rescue operation in Afghanistan, a SOF (Special Operations Forces) warrior was killed going through the door. Afterwards, one of the young officers asked me a question I couldn't answer. He said, 'after all these years in combat, why don't we have a way to protect our operators going through the door?' With all the advances in modern technology, I know we can do better. Consequently, at SOCOM we have established a program called … TALOS" (McRaven, 2015).

The Tactical Assault Light Operator Suit (TALOS) system is a powered, armored exoskeleton inspired from Marvel comic book's *Ironman*. The suit provides technology that increases operator survivability, lethality, mobility, and spatial awareness in the current battlefield environment, especially in urban and room clearing operations. TALOS provides SOCOM operators a distinct battlefield advantage over enemy combatants through enhanced forced entry capabilities. As captured in Admiral McRaven's quote, SOCOM intends to rapidly develop and field the TALOS system. The project began in 2013 with plans to field a functional prototype combat suit by 2018 (Miller, 2016). This timeline is aggressive when compared to similar Department of Defense projects (McRaven, 2015). To meet the stringent timeline, SOCOM set up a Joint Acquisition Task Force (JATF), which places a government team as the lead integrator for the project. This team consists of Special Forces operators, acquisition officials, and engineers.

1.2 Probabilistic Value Modeling--Methodology

Value modeling is a powerful tool that allows engineers and acquisition officials to design a system that is in-line with the operator's needs. As shown in Figure 1, the value modeling process begins by performing a functional decomposition of a system. Next, the associated functional hierarchy progresses into a value hierarchy that depicts the functions, sub-functions, and objectives for the system. These objectives are then quantified into value measures, which assess how well an objective is attained (Parnell, 2011). Each value measure is linked to a value function that grades how well a design alternative performs in accordance with the system requirements, stakeholder feedback, and market surveys. The raw data for a design solution is entered into the value functions that map the raw data to a score between 0 and 100, where 0 is the minimal acceptable value and 100 is the ideal value. A swing weight matrix then assigns a weight to each value measure based on the stakeholders' priorities. The weights add up to one, with each value measure's weight being a percentage of the system value. These weights are then multiplied by their corresponding scores for each value measure. For each design solution, these values are summed to determine its overall value, which scales from 0 to 100. The candidate solution with the highest value score would give the highest overall value to the operator.

A value model is only as accurate as the raw data entered into the value functions; as such, it is commonly used for systems that utilize mature technologies where performance data is readily available. In systems that are using immature technologies, the raw data is typically ill defined. However, an initial analysis of the immature technology can readily yield a minimum, most likely, and maximum value for each value measure. These values form a triangular distribution, which are commonly used to capture expected performance for systems under development. When these triangular distributions are input into the value model, the value model outputs a distribution for the final value score for each design alternative. As the technology matures, the triangular distributions will become narrower and the variance of the final value score will decrease.

Simple value models can readily be built into Microsoft Excel. However, the complexity of distributions necessitates the addition of a Stochastic Information Packet Math (SIP-Math) add-on into Excel, which allows for the easy manipulation of distributions (Savage, 2016). The SIP-Math add-on was used with Excel to create a stochastic value-modeling tool that will aid the TALOS team in making design decisions.

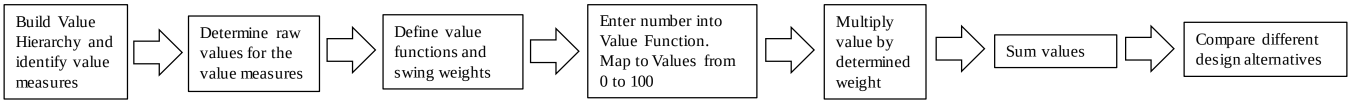

Figure 1. Value Model Process

1.3 Applying Probabilistic Value Modeling to TALOS

Currently, the JATF-TALOS uses an agile systems engineering approach with spiral development by producing and unveiling a prototype suit annually. With each iteration, requirements and design considerations are re-evaluated to ensure that the final deliverable has the highest value to the operators. As such, the stochastic value-modeling tool is ideal for performing design trade analyses for the TALOS system. Additionally, the distribution of value scores are directly linked to risk, such that the higher the variance on the final value score, the higher the risk on the overall project. Therefore, this technique allows JATF-TALOS to identify sources of risk and apply resources to better define the value, reducing the overall risk.

The TALOS system decomposes into the following five capability modules (CM): CM-Armor, CM-Power, CM-Exoskeleton, CM-Baselayer, and CM-C4I (Communications, Computers, Command, Control, Intelligence). Each CM comprises of a major subsystem of TALOS and provides a critical function, as described in Table 1. The capability modules are being developed in parallel, a probabilistic value based model is inherently useful in analyzing design trade-offs both internal to each CM and between the CM's on the TALOS system level.

Table 1. Description of TALOS Capability Modules

Capability Module	Purpose
CM-Armor	Protects the suit and the operator from ballistic threats
CM-Power	Provides power to the other Capability modules
CM-Exoskeleton	Augments the mobility and strength of operator
CM-Baselayer	Serves as a buffer between operator and the suit.
CM-C4I	Processes data and provides C4I capabilities

A preliminary risk analysis found that CM-Power had a high level of developmental risk. Additionally, if CM-Power does not meet its requirements (i.e. the power system cannot provide the required voltage at a constant rate), the other CMs will not operate. Therefore, JATF-TALOS prioritized the development of CM-Power and invested in a number of different power solutions. Probabilistic value modeling was applied in order to aid in analyzing these design solutions. Given the effectiveness of this analysis, this methodology was also applied to the TALOS System as a whole.

2. CM-Power Value Modeling

2.1 Qualitative Analysis: CM-Power

A functional decomposition of CM-Power identified the following top-level functions: generate power, manage power output, maintain system temperatures, and operate in silent mode (Nguyen, 2016). Additionally, the Module Performance Requirement (MPR) documents for TALOS detail the following two areas of system requirements: operability and reliability/safety. These functions and requirements were used to derive the value hierarchy shown in Figure 2. Altogether, 17 value measures were identified, and then derived from the objective functions highlighted in yellow.

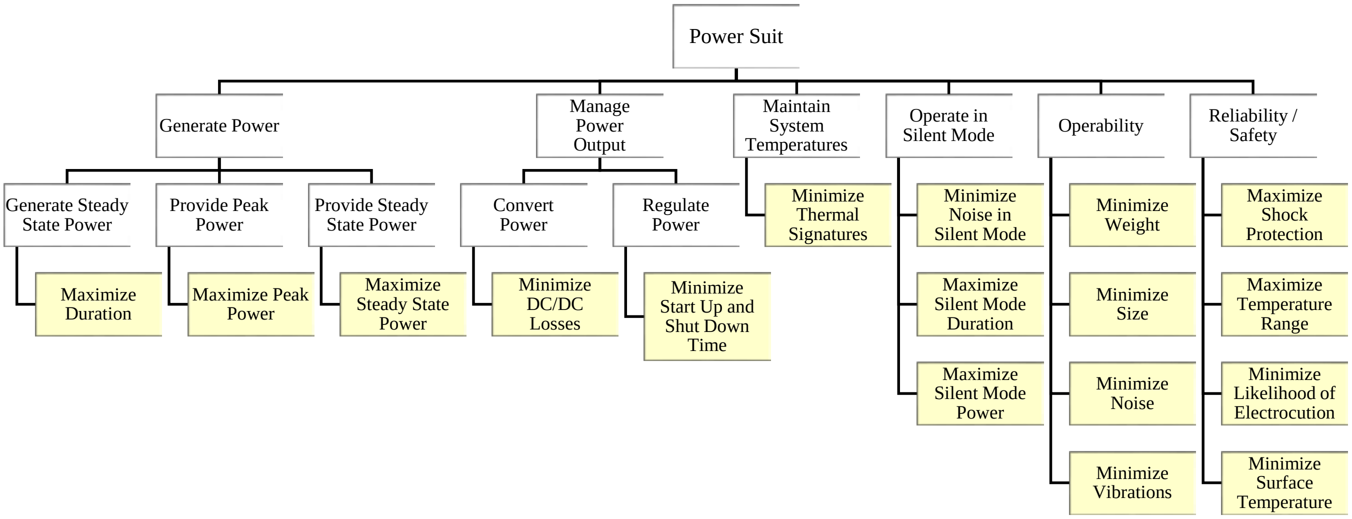

Figure 2. Value Hierarchy for CM-Power

2.2 Quantitative Analysis: CM-Power

In order to provide replicability and ease of use, this study in collaboration with the TALOS team, developed a modeling tool that incorporates all aspects of quantitative value modeling to provide quick evaluations of design options and decisions. This section details the results of the model from analyzing the value of the Power system and alternative solutions.

2.2.1 Design Alternatives

The power-system consists of two main sub-systems: the power-generation subsystem and the power distribution manager. The TALOS team considered six power sources for the power-generation and three bus-voltages for the power distribution manager.

The six power source alternatives included four battery options, a solid oxide fuel cell (SOFC), and a hybrid engine options. The first battery option, *Heavy Battery*, uses 10 standard military BB2590 batteries. The weight of this power solution is set to the maximum allowable weight. The second battery option, *Light Battery*, only uses 6 BB2590 batteries, reducing the energy capacity while also reducing the weight. The third battery option, *Heavy Advanced Battery*, uses 28 aviation-grade lithium-polymer battery cells. These cells have a higher energy density than the standard military batteries. The fourth battery option, *Light Advanced Battery*, uses 16 of these cells, allowing for a lighter system weight, but with a shorter mission duration. The *Solid Oxide Fuel Cell (SOFC)* reformulates propane into CO and H_2, which is processed through a high-temperature fuel cell to generate electricity. The *Hybrid Engine* uses a small 2-stroke aerial engine coupled with a small battery bank, which allows for a certain amount of silent-run time. The *SOFC* and *Hybrid Engine* are significantly more complex than the battery options; however, they provide a longer mission run-time.

The second design parameter that was analyzed was the bus voltage. Three bus voltages were identified at 48, 60, or 100 V. As the voltage increased, the exoskeleton actuators were more responsive; however, the weight and complexity of the system increase. Additionally, higher voltages are associated with a higher risk of electrocution to the operator.

The six power source alternatives and three bus voltages were combined into a morphological box as shown in Figure 3, yielding 18 different design alternatives. An analysis of the technologies allowed for the generation of a triangular distribution of raw data for each value measure for each of the 18 design alternatives.

Power Source Alternative	Bus Voltage
Heavy Battery	48 Volts
Light Battery	60 Volts
Heavy Advanced Battery	100 Volts
Light Advanced Battery	
Solid Oxide Fuel Cell	
Hybrid Engine	

Figure 3. Morphology Box for Generating Different Power Design Alternatives

2.2.2 Value Functions and Swing Weight Analysis

For each value measure, a minimum acceptable, a threshold, an objective, and an ideal value were derived from the MPR document for Power and Energy (MPR-TALOS-PWR) and stakeholder feedback. Each of those values were mapped to a score between 0 and 100 to create a value function, as shown in Figure 4.

Stakeholder interviews identified that the most important value measures were *system weight* and *mission duration*. The weight of CM-Power impacts the total weight of the suit, affecting how much effort will be required of the operator to perform missions. The heavier CM-Power is, the less value it provides to TALOS overall. Similarly, *mission duration* is vital to the utility of CM-Power, as this value measure dictates the length of missions. In particular, the time that the power system provides for a mission will dictate the types of missions that are feasible. As discussed in Section 1.2, the importance of each value measure was then reflected in the swing weight matrix. The Excel-based tool used a graphical user-interface that allows the user to readily vary the swing weights, allowing them to determine the impact of changing the weights.

Mission Duration Time (hr)		
	Raw Data	Score
Min Acceptable	0.5	0
Threshold	3	50
Objective	8	90
Ideal	12	100

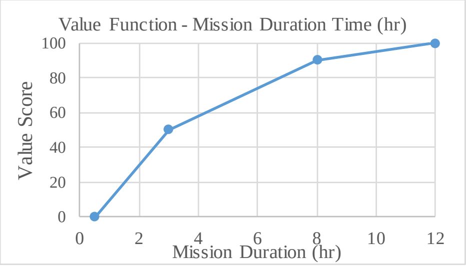

Figure 4. Value function for *mission duration*

2.2.3 Value Scores and Analysis

As shown in Figure 5, the value model takes the distribution of raw data, runs them through the value function and swing weight matrix, and assigns a distribution of value scores for each of the 18 design solutions. For the TALOS team to minimize risk, they would select the design that has the highest mean value score. The *Lightweight Advanced Battery (48V)* solution had the highest mean value score of approximately 68.6 out of 100. When uncertainty in raw data is taken into account, this value score can range from 66.3 to 71.6. The distributions for the other 11 battery solutions all had some degree of overlap with the *Lightweight Advanced Battery (48V)* solution. As the technologies mature, the uncertainty in raw data will decrease, decreasing the variance and perhaps shifting the mean for each value score.

Note that the total value score are based heavily on the swing weight matrix; though the swing weight matrix was developed through stakeholder interviews, the matrix is intended to be flexible to account for different stakeholder viewpoints. As such, certain solutions will earn a higher value scores with modifications to the swing weight matrix. For example, if mission duration increased in importance relative to the other value measures, the *SOFC (48V)* solution could achieve the highest value score.

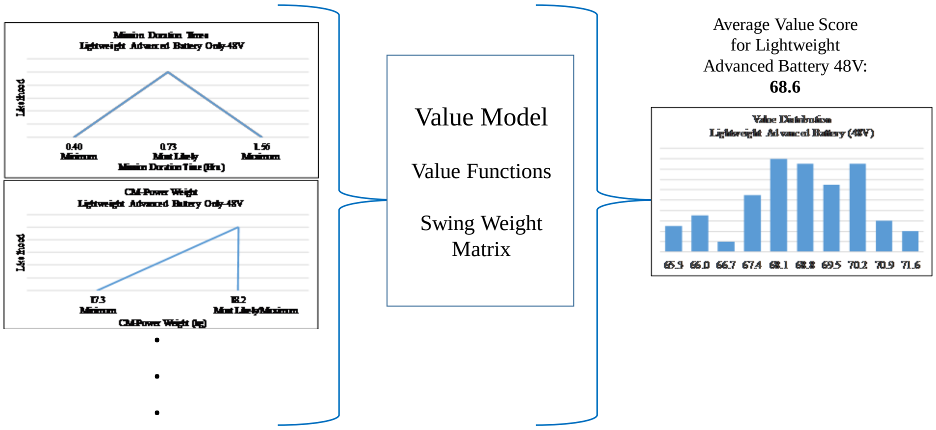

Figure 5. Probabilistic Value Modeling Process for Lightweight Advanced Battery Only Solution (48V)

2.3 Design Trade Analysis

A proper analysis of value must account for the cost of each design alternative. A bottom-up costing technique was used to estimate the probabilistic costs for each of the design alternatives. These costs include the non-recurring engineering costs for development, the testing of two suits, the fielding of twenty suits, and maintenance. These estimates were then fed into the value model to determine the best-valued solution in terms of cost. When combined with the value model, the cost versus value analysis is a useful decision making tool. This graph is shown in Figure 7. Figure 7 shows that the *SOFC* solutions are dominated due to lower value and higher costs. Similarly, the *Hybrid Engine* solutions are low in cost but dominated by the value of the *Battery* solutions. Among the *Battery* alternatives, the 48V solutions tend to dominate the other bus voltages.

The benefit of this model is in its adaptability and ease of use to provide the engineering teams a fast tool to perform design trade analysis and determine which solutions to pursue. Additionally, the distribution of values and cost allow for risk to be factored into a design decision. For example, though the *Lightweight Advanced Battery (48V)* solution appears to be the best solution from looking at the mean value score, when uncertainty is accounted for any of the other battery solutions could achieve a higher value score. As such, the 2018 will be using the *Lightweight Advanced Battery (48V)* solution. The risk associated with this design solution necessitates the development of the *Lightweight Battery (48V)* solution as a contingency.

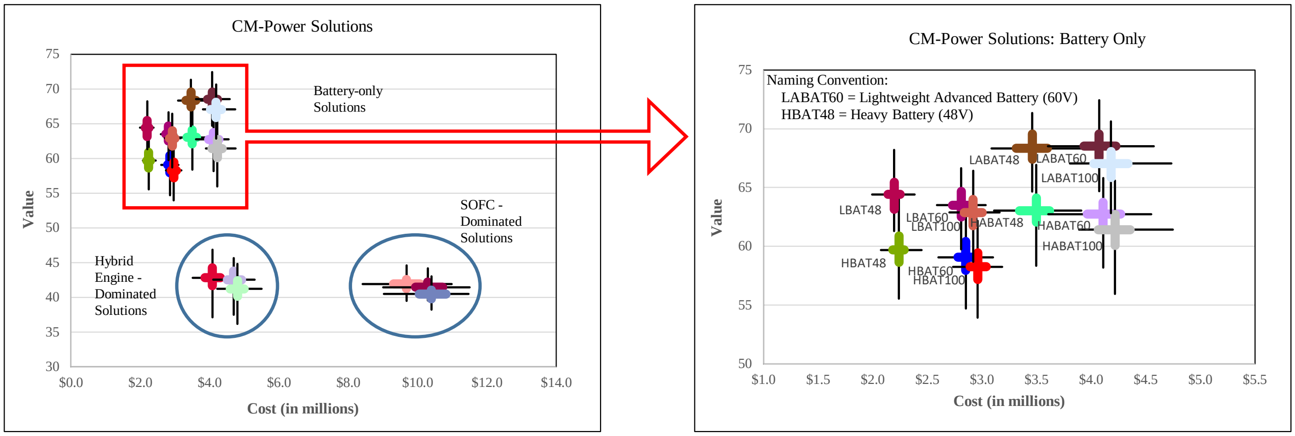

Figure 6. Cost and Value Distributions for Different CM-Power Design Alternatives.
(Left: All 12 design alternatives, Right: Battery-only design alternatives)

3. TALOS Value Modeling

Probabilistic Value Modeling has been shown to be effective for evaluating design alternatives for CM-Power. Therefore, a similar value modeling process can be applied to the individual CM's to determine design solutions and minimize risk in prototype development. Additionally, TALOS is a system-of-systems; as such, a value-based model can be applied to the TALOS system itself. This value model will allow the development team to evaluate how well each design iteration aligns with the operator's needs. For example, the 2018 deliverable might earn a total value score of 70. The subsequent suit will be developed with an objective total value score of 80 and so on. This modeling technique allows the engineering teams to assess both the performance of specific design solutions as well as perform trade-of analysis between the CM's on the TALOS level.

The stochastic analysis tool discussed in Section 2 was expanded to encompass the top-level design trade-offs for the entire TALOS system. The underlying value model was developed for the TALOS suit based on stakeholder interviews and requirements analysis. The TALOS value model incorporates 38 value measures derived from system objectives, with *mission duration*, *suit weight*, and *suit size* being the most heavily weighted. Value functions were built for each value measure based on requirements and stakeholder interviews.

As TALOS prototypes and design alternatives are developed, the tool can be used to determine the distribution in value scores for that design. Not only does the tool give the design team the ability to evaluate how close the suit is to meeting the user's needs, but it also allows them to account for risk in their design decision.

4. Conclusion

The expedited development of TALOS necessitates the use of value modeling to evaluate different design alternatives and to determine alignment between designs and stakeholder criteria. Two value models were built to aid JATF-TALOS in their systems engineering effort. Within these models, stochastic value based modeling techniques were used to analyze the system and perform design trade analysis. This effort included analysis of the requirements to develop value hierarchies, swing-weight matrices, and value functions. An Excel based tool was then used to perform trade-off analysis that allows the user to adjust features for determination of the best alternatives. This tool accounts for uncertainty in raw data values by creating distributions in the cost and value of each design alternative, which is critical for assessing risk. The first of these models is for CM-Power, which evaluates 18 different design alternatives to determine which power solution has the highest value. This model found that a lightweight advanced battery solution with a bus voltage of 48V had the highest stakeholder value. The second model expanded the analysis to include the entire TALOS system; this model will be used in future studies to assist TALOS engineers to evaluate the impact of design changes on the overall system value.

5. Acknowledgement

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