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Digital Engineering for a Soldier System of Systems

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Abstract: The Army and the Department of Defense (DoD) are transitioning from document-based systems engineering to model-based systems engineering (MBSE), sometimes called digital engineering. This transition is intended to help the Army cope with the complexity of modern military systems and system of systems (SoS). Part of the challenge of this transition is in integrating system architectures with models and simulations in a manner that facilitates improved acquisition decision-making. This project works to help correct these issues by examining the Soldier as an SoS and constructing a system architecture to help integrate multiple soldier models. Specifically, this work integrated a weight model, a weapons lethality model and an Executable Architecture System (EASE) model to help determine the best acquisition equipment decisions through the analysis of a Design of Experiments. This work provided insight in creating an architecture for an SoS and the process of integrating multiple models. Future work should continue working to integrate more models and improving the system architecture.

Keywords: System Engineering, System Architecture, Systems of Systems, Model-Based Systems Engineering

1. Introduction

The modern world, and consequently military operating environments, are becoming increasingly interconnected and complex. Historically, acquisition decisions have been made for singular military systems. This is no longer satisfactory given the complexity of the modern world. The Army must use Systems of Systems (SoS) to address contemporary problems. To effectively implement SoS engineering, engineers must employ model-based systems engineering (MBSE) or digital engineering.

To demonstrate how model-based SoS engineering may be done, this project architected the Soldier as an SoS using the Systems Modeling Language (SysML) and integrated this architecture with simulations to understand the impact of acquisition decisions. This construct is intended to allow decisions makers from Program Executive Officer (PEO) Soldier and Cross Functional Team Soldier Lethality (CFT-SL) to better understand how individual systems integrate and the effects of acquisition decisions have on important measures such as soldier load and lethality. In particular, the study examined design decisions for four developmental systems: The Next Generation Rifle, Fire Control System (FCS) and optic for the rifle, and the Improved Visual Augmentation System (IVAS).

1.1 Problem Statement and Methodology

The US Army Futures Command and Assistant Secretary of the Army for Acquisition Logistics and Technology ASA(ALT) need to quickly and comprehensively understand acquisition and design decisions on the attributes, performance, and interoperability of Army SoS. They desire to use MBSE and Modeling and Simulation (M&S) techniques to do this. The US Army is preparing to implement a next generation rifle, fire control system, heads up display, and an advanced optic. As the Army looks to choose what they will implement, they are focused on optimizing the weight and power of these systems, and MBSE for SoS is a method that can help make these decisions effectively.

We are using MagicDraw software to develop a SysML architecture of a soldier. This architecture translates into data tables to inform an attribute and lethality models about the Soldier SoS for different equipment configurations. With this, the team aims to create a system that allow leaders to quickly and efficiently see the effects of adding new equipment to a Soldier, aid them in making decisions for Soldier loadouts, and assist in the acquisition of new equipment. This system allows for seamless trade-off analysis between more power on the battlefield and weighing down Soldiers. Using the Executable Architecture Systems Engineering (EASE) modeling tool and SoS Architecture Principles, one can model and simulate a Soldier System of Systems, analyzing Soldier attributes and the design of the next-generation rifle, FCS, and IVAS to provide insight to CFT Soldier Lethality on the requirements & design of these pieces of equipment ("Welcome to EASE", n.d.).

2. Literature Review

2.1 Current Issues

The engineering world continues to increase in complexity; this may be attributed to the fact that SoS have begun to replace monolithic systems, or when singular systems are utilized, it's often within an SoS. An SoS is defined as a set or arrangement of systems that result when independent and useful systems are integrated into a larger system that delivers unique capabilities (DoD, 2008). This development towards SoS engineering only worsens the challenges of Traditional Systems Engineering due to the increasing complexity of SoS. SoS level decision makers have a difficult task due to the nature of SoS. SoS have multiple, individual systems operating and connected within one large system which exacerbates this problem even more. Failure in making sound decisions in this environment results in costly issues to a large group of people. An approach to addressing this challenge is using MBSE or digital engineering.

2.2 Digital Engineering and MBSE Compared to Document Based Approach

The Army is currently in the process of improving and restructuring the role of systems engineering in the acquisition process by integrating Digital Engineering (DE). The DE Strategy was released in June 2018 and has only just started to integrate into the acquisitions process (DoD, 2008). According to experts, "digital engineering is a Department of Defense (DoD) initiative that will transform the way the DoD designs develops, delivers, operates, and sustains systems" (DoD, 2008). The idea is to modernize the acquisition process and use advanced technology in the acquisition process. DE ultimately affords a better understanding of the impacts of decisions to the different stakeholders involved.

One approach to implement DE is MBSE. MBSE is "the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases" (Walden, 2015). This approach to systems engineering requires a framework such as the Department of Defense Architecture Framework (DoDAF), a system modeling language such as SysML, and a modeling tool like MagicDraw. However, MBSE still proposes some challenges. Linking system architecture to performance models and simulations is difficult, but possible. A simulation model may show how design parameters affect operational performance. The challenge posed by this method, however, is that the number of requisite experiments becomes high for a large design space. These experiments can become unsound for even the fastest of computers (Beery, et al, 2017). There has been significant work done by using experimental design methods to (Kewley, 2018) statistically approximate the interconnections between design parameters and operational performances to address this issue (Beery, et al, 2017). "The other alternative is to develop very low-fidelity models that define an SoS's operational measures through analytic models that take a "best-in-class" or weighted average approach to define a set of systems' operational performance parameters through the performance of the constituent systems as done by" (Chattopadhyay, et al, 2008).

A document-based approach has difficulty assessing completeness, consistency, and relationships between requirements and design information due to the information being laid out across multiple, separate documents. This, combined with the complexity of requirement development with multiple stakeholders, can lead to prolonged system development and can jeopardized program success.

The DoD refers to this system as event based, where the program has a series of reviews from start to finish. These milestones require review from several levels within a hierarchy of offices and ranks. This process is lengthy and increases the time required for a product to continue development. The difficulties that arise with the standard document-based system engineering approach applied to all programs in the Army can result in inefficiencies within the system, which lead to increased cost, delayed schedule, and some potential quality issues (Friedenthal, et al, 2015). The Army has had a hard time keeping pace with technology developments due to the length of the process. A way the Army is moving towards combating a document-based approach is MBSE. A key activity in a model-based approach to systems engineering is to facilitate the integration of models and simulations across multiple disciplines. This can be used in the logical model of the system architecture to identify the elements of the system and to define their interconnections and relationships among the other system elements (Walden, 2015). By having models that parallel the living real-world systems, model-based approach to systems engineering fixes the obstacle of having multiple stakeholders with many requirements.

2.3 ASA(ALT) Architecting and Simulation Effort and PEO Soldier

The Office of the Chief System Engineer, in the (ASA(ALT)) is developing a framework to realize DE. It is using problems that face PEO Soldier and CFT SL as a demonstration of the utility. This framework is demonstrated in Figure 1. The center of this work is a tool called Executable Architecture Systems Engineering (EASE) that serves as a M&S integration engine as depicted in Figure 1 by the block "ASA(ALT) M&S Integration." This tool uses various simulations and means of visualization to compose and display complex models and simulations. These portions are being developed by other agencies associated with ASA(ALT). To more appropriately inform these simulations, however, this research team developed the two blocks on the left of Figure 1. The first is the SysML architecture of the system. The second is an experimental design engine that takes SysML data and build appropriate designs to serve as inputs to the simulation engine.

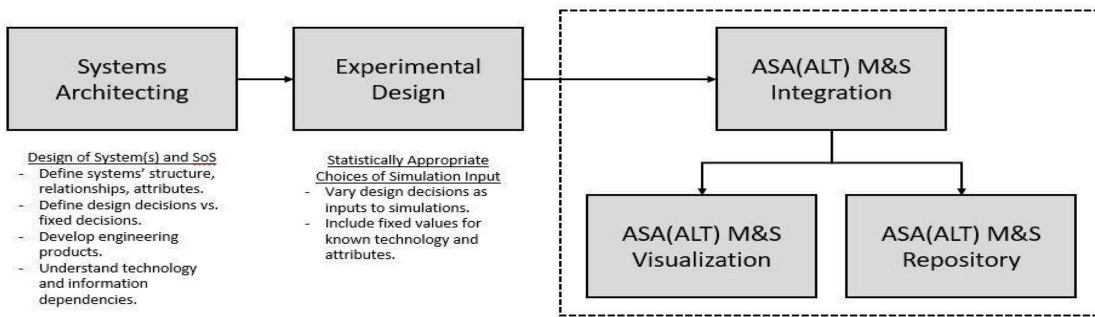

Figure 1. ASA(ALT) Architecting and Simulation Framework

3. Current Progress

3.1 Soldier Architecture

The first step this Capstone took was modeling the architecture of a soldier in SysML. The physical architecture for a Soldier is depicted in Figure 2. As an Internal Block Diagram, this SysML diagram shows the different Soldier equipment, interactions and characteristics. This model allows the different components of a soldier and their interactions to be shown in a neat way. The equipment includes both standard equipment commonly carried by Soldiers, and acquisitions equipment that are being developed and tested by PEO Soldier. The standard equipment includes the helmet, ruck and personal load Soldiers carry.

The fixed equipment include the personal load includes the standard six magazines included in a combat load. PEO Soldier provided baseline information that included the weights for each standard item of equipment a Soldier uses or carries. The system is divided into four sub-systems based on one of four categories: weight in the hands, weight on the head, personal load, and ruck. Each categories' total weight is the sum of the individual weights of each item.

The acquisitions equipment includes the Soldier's rifle, optic, Individual Visual Augmentation System (IVAS), fire control system, and external battery. The current IVAS we have designed for are night vision goggles. The helmet system includes both the IVAs and the helmet. The weight of this system makes up the weight on a Soldier's head. The rifle system includes the Fire control system, the rifle, and the optic. The fire control system is currently designed for a rifle mounted flashlight and laser sight. The weight of these items impacts the weight on the end of the rifle. The optic is designed to account for both the weight and zoom capability of the rifle.

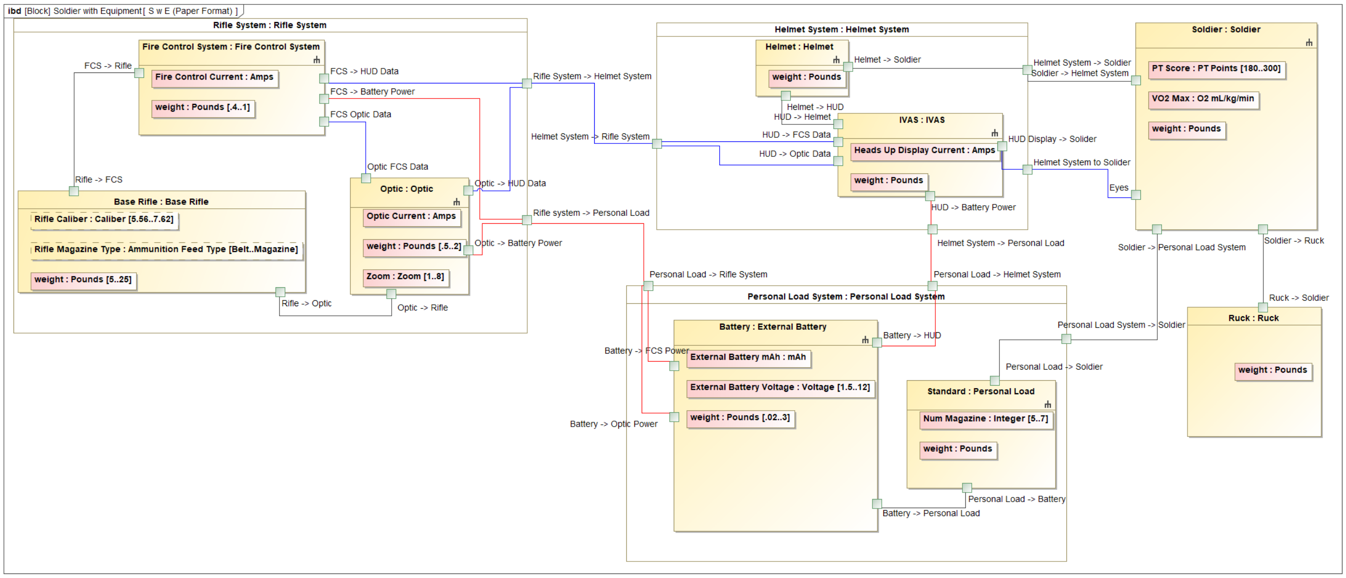

Figure 2. Soldier Architecture Internal Block Diagram

These affects the accuracy and the weight of the rifle. The rifle includes the weight, caliber and round feed type (magazine or belt fed). The caliber of the rifle affects the weight of the rounds and therefore the weight a Soldier carries, both in his hands and on his body. The weight of a round can greatly affect the weight of the standard six magazines that are included in a Soldier's personal load. The personal load system includes the external battery and a Soldiers basic combat load. The external battery is a potential addition to a Soldier that powers all electronic items the Soldier carries, to include the optic, IVAS, fire control system, and radio. The battery is designed to include the weight, voltage output, and capacity (mAh) of the battery.

The interactions between items of equipment are included and are color coded to represent different forms of interaction. Black connectors represent Physical interactions. These mounting systems like picatinny rails or brackets. Blue connectors represent information. This mainly includes visual information such as sight picture and night vision imagining. Red connectors represent electrical interactions. This includes current and voltage the external battery supplies to different electrical equipment a Soldier uses.

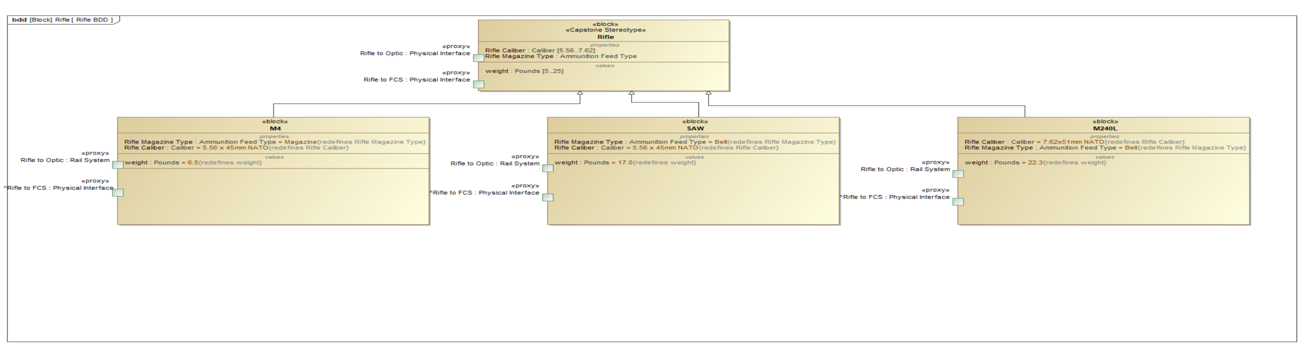

Figure 3. Rifle BDD

The acquisitions equipment in this model are also architected with Block Definition Diagrams (BDD). BDD define each block (in this case each aspect of a Soldier) in terms of structural and behavioral features and show its relationship to other blocks. Each acquisitions equipment in MagicDraw is also architected with a BDD that includes a base input and actual equipment used by the Army. Figure 3 above is the BDD for the rifle. The alternatives are the M4, SAW, and the M240L.

The base rifle includes ranges for the weight, caliber, and round feed type. These ranges of these characteristics are to be used for a DOE that we can run through a rifle lethality model and Soldier ruck-march model. The standard weapons are designed in order to provide realistic alternatives that can be input in order to compare lethality of current systems.

3.2 Design of Experiments (DOE)

Using the MagicDraw Soldier Architecture, this Capstone worked to develop an algorithm to create a design of experiments (DOE). This DOE algorithm takes the different equipment outlined in the Soldier Architecture and produces different possible combinations of soldier equipment. This algorithm pulled the qualitative and quantitative variables of the Soldier system to create a full-factorial DOE. The algorithm used is shown in Figure 5. Implementing the exported CSV file from MagicDraw as a dataframe, this algorithm first scraped for all quantitative and qualitative variables then determined the levels of each factor and finally formed a full factorial DOE. This DOE was then exported as a CSV. Moving forward, this project should first improve this DOE algorithm, screening for all non-feasible models. Second, this DOE can be used for statistical analysis and to inform the other models used in this capstone.

3.3 Soldier Models

The next step in the project was integrating various Soldier Models with the newly created Soldier Architecture. In this project, two separate models were used: a new weight model and a pre-existing weapons lethality model.

To make the Weight Model, this capstone created code that pulled weights from a CSV file exported from the system architecture. Each piece of equipment provided a standard weight, and an upper and lower range weight. Using these weights, this algorithm created a triangular distribution on each element and exported this weight list. This weight distribution could then be used to inform other models. Figure 4 below shows this algorithm. Moving forward, this project will work to integrate this weight model with other Soldier models to create a methodology of integrating models, with the end goal of optimizing Soldier weight and analyzing the adversity of additional weight.

Finally, this capstone explored the preexisting Weapons Lethality Model, analyzing how to integrate it within the system architecture and with the other existing models. This model examines the lethality of a Soldier given a variety of parameters including rifle, time of day, exhaustion and mission type. Moving forward, this capstone will integrate the results of the other models to inform the Soldier Lethality Model and vice versa. Orchestrating the integration of these various models will provide great insight on developing a methodology.

Weight Model Algorithm

Input: CSV weight file

Output:

1. dataframe ← CSV weight file
2. **for** each *item* in Equipment **do:**
3. assign lower value, upper value and default value to variables
4. create a triangular distribution using the lower, default and upper values
5. add distribution with name to a weight list
6. Export weight list

Figure 4. Weight Model Algorithm

DOE Algorithm

Input: CSV file, desired factors

Output:

1. dataframe ← CSV file
2. **for** each *i* in length(dataframe) **do:**
3.   **if** desired factor **then:**
4.   **if** qualitative factor **then:** add to qualitative list
5.   **if** quantitative factor **then:** add to quantitative with values
6. **for** each *item* in qualitative list **and** quantitative list **do:**
7.   find number of *levels* and add to levels list
8. DOE ← full factorial Design of Experiment using levels list
9. **for** each *row* in DOE **do:**
10.   Convert from coded results back to names
11. Export DOE as CSV file

Figure 5. DOE Algorithm

4. Conclusion

In today's fight, the integrations of systems into an SoS becomes exceedingly important. Managing new technology to better soldier performance is no easy task. Organizations like PEO Soldier rely on models and experts to determine and develop the best equipment. As the complexity of the equipment on Soldiers increases, viewing the Soldier as a system of systems becomes necessary. Consequently, as the interactions between the different components of the Soldier affect the overall system performance, accurate and appropriate modeling is required to develop useful technology. This Capstone seeks to aid this process by devising a framework for integrating models to produce useful information to decision makers about what future equipment to invest in. Over the past year, this project has worked to integrate several models both with the soldier system and each other to provide informative and accurate results. Developing a framework to integrate models will become increasingly important as the role of technology continues to expand. Future work on this project would include the integration of power requirements. Soldier equipment is becoming increasingly dependent on electrical power. This requires soldiers to carry more batteries to power these systems, and even more to keep them powered for long periods. This added weight could greatly affect the effectiveness of a soldier. This work has the foundation to include the power requirements of different equipment but requires the computation to calculate the necessary battery capacity for the soldier.

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