View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Industrial and Systems Engineering Review (ISER)

Engineered Resilient System Life Cycle Costing Model

Allen Blash, William Butler, Lindy Clark, Kyle Fleming, and LTC Jennifer Kasker

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

Corresponding author's Email: Kevin.blash@usma.edu

Author Note: The authors would like to thank Mr. James Richards at the Engineer Research and Development Center (ERDC), Mrs. Melissa Cyrulik at Tecolote Research, LTC (R) Steve Henderson at Software Engineering Institute, and Sean Vessey at the Deputy Assistant Secretary of the Army for Cost and Economics (DASA CE) for their support on the project. They supported the project by developing the skills we needed to develop an applicable tool to help the ERDC and the Department of Defense predict the life cycle cost of ground vehicles early in system development.

Abstract: In order to make the best use of the defense spending budget, it is critical that the Department of Defense (DoD) accurately predict the Research, Development, Test and Evaluation (RDT&E), Procurement, and Operation and Support (O&S) costs down to the third level of the Work Breakdown Structure for Major Defense Acquisition Project (MDAP) wheeled or tracked vehicles. This research utilizes historical data, extracted from government databases, to develop cost estimating relationships (CERs) that predict the life cycle cost of wheeled and tracked vehicles based on attributes. This research can also be leveraged for defense acquisition programs across the DoD portfolio. The model will be integrated into a tradespace analysis tool, ERS & CREATE-GV, which was developed by ERDC to predict the cost of each alternative created in the tradespace.

Keywords: Life Cycle Cost, Attributes, Wheeled and Tracked Vehicles, Tradespace

1. Introduction

Part of an Engineered Resilient System (ERS) is a flexible life cycle cost capability that enables cost-informed design space visualization and decision making (Richards, 2015). Tradespace analysis for ERS addresses the generation of large numbers of alternative designs early in the design process, and the evaluation of these multi-attribute designs across multiple dimensions so that better informed decisions can be made (Spero, 2014). One of the technical teams contributing to ERS is the Engineer Research and Development Center (ERDC). ERDC develops tools and procedures that enable the Department of Defense (DoD) to have Better Buying Power (BBP). BBP encompasses a set of fundamental acquisition principles that work towards "achieving affordable programs, controlling costs through the product lifecycle, incentivizing innovation in industry and government, and promoting effective competition" (Department of Defense, 2015).

This research is focused on developing a tool that will predict the life cycle cost (LCC) of wheeled and tracked vehicle alternatives within a tradespace. This research will allow analysts, developers, and engineers to assess the costs and use tradeoff analysis to determine the best option for the DoD. Leaders will be able to estimate and map out the effects of design decisions based on capabilities and total life cycle costs. This is important because the size of the Army and the budget are constantly decreasing, making it essential to be as efficient as possible with the funding.

In order to use this model, the decision maker must select desired attributes and then model the produces a predicted LCC from the given attributes and cost estimating relationships (CERs) as they relate to the historical cost data of eleven ground vehicles. The model also displays the costs allocated per year for each category, Research, Development, Test and Evaluation (RDT&E), Procurement, and Operation and Support (O&S), so that the user will know how much money is required in each phase of the LCC. This will enable decision makers to develop a system that is cost effective, robust, and resilient. We extracted cost data on current and past DoD vehicles from databases to develop CERs used in the model. This project is significant because this is a current challenge to which the DoD needs a solution. This model aims to meet the requirements provided by military agencies, for ultimate use by the DoD for design, contracting, and budgeting decisions.

2. Background

Defining the problem required extensive research in order to gain a complete understanding of the scope of the project. We began with a literature review, interviews with key stakeholders, and training on Automated Cost Estimating Integrated Tools (ACEIT) and Joint Integrated Analysis Tool (JIAT). Previous work on this project produced a prototype pre-Milestone A life cycle cost estimation framework that predicts the life cycle cost of a new system, however the tool did not take inflation into account and did not include all necessary costs such as detailed components of RDT&E, procurement, and O&S. In order to make a robust model for DoD, the current capstone team researched cost estimation techniques through the Department of the Army Cost Analysis Manual, interviews with subject matter experts, and trained with a life cycle cost estimating tool. The team utilized cost data from Army system databases such as Operating and Supporting Management Information System (OSMIS) and Capability Knowledge Base (CKB) to create a framework that allows the user to input characteristics of a desired system; from this information the framework presents a visual representation of the allocation of three main cost element groups—RDT&E, Procurement, and O&S. Our refined model follows the same approach as the previous model, however it accounts for inflation and has a more in-depth work breakdown structure (WBS) with an emphasis on O&S cost components.

A cost estimate is the summation of individual cost elements, using established methods and valid data, to estimate the future costs of a program, based on what is known today (GAO, 2009). Managing cost estimates involves continually updating the estimate with the most recent data as they become available and revising the estimate to reflect the changes. Government agencies request and require an in-depth explanation as to how data was collected and analyzed so that the framework is validated. Cost estimates require documentation showing data sources, assumptions, methods, and decisions basic to the estimates (GAO, 2009). This is necessary because of poor estimating practices in the past, where historical cost data had been used for computing estimates that were sometimes invalid, unrealistic, or unrepresentative. Inflation must also be included in the cost estimate for the framework to be validated.

RDT&E costs are often difficult to predict, especially for a new system, due to the fact that very little is known about the specifics of the system in the early design phases of the system. All costs that occur prior to the actual production of the system and costs incurred during continued development post production start fall under this cost criteria. The costs of research and development include the time of a researcher determining the possible solutions for the system, testing the solutions, and evaluating the results of the tests (Farr, 2011). Procurement costs, as pertaining to this project, are a process of the DoD purchasing acquisition contracts for goods and services needed to deliver the system. O&S costs span from initial system deployment through the retirement of the system. O&S costs include costs of operating, maintaining, and supporting the system. These costs are incurred through personnel, equipment, supply, training, and supporting a system. Direct costs are costs that are immediately associated with supporting the system.

For the past three years, the United States Military Academy Department of Systems Engineering and ERDC have been developing a framework for assessing the life cycle costs of engineered resilient systems proposed by different services. This year, our project goal was to build upon the current model by accounting for inflation and gathering more data on the specific components of each cost category (WBS, 2015). This project will provide a high-level assessment framework capable of evaluating life cycle costs of highly resilient Army systems. The tool that we will create is a small portion of a larger tool created by ERDC, and our portion of the tool will fit into the wheeled vehicle demonstration.

3. Methodology

This research uses the System Decision Process to determine the most comprehensive approach to solving this complex problem and satisfy stakeholder needs (Parnell, 2010). The SDP is a four-phased problem solving process that takes a holistic, iterative approach to finding a solution for the decision maker or stakeholder (Parnell, 2010). The stakeholder is at the center of the SDP that places constant emphasis on value focused thinking and making decisions that add utility to the system. Utilizing the SDP to address improvements in the ERS LCC assessment framework included adjusting the level of detail in the work breakdown structure to produce a more accurate prediction for the total cost of a system.

After assessing the past work on LCC, our group determined that the problem definition and solution design phases were the primary considerations of the project. Decision-making and solution implementation are largely decided by the primary stakeholder. The first phase of the SDP, Problem Definition, is focused on understanding the full extent of the problem before prematurely moving to try to create a solution. The Problem Definition Phase is centered on research and stakeholder analysis, functional and requirements analysis, and value modeling to ensure that an in-depth understanding of how the system works within its existing operating environment is gained. This phase took the most time and was critical because it allowed the group to determine the approach we would take to make the existing model a better fit to the stakeholder's requirements. This included breaking down the subcomponents for the three major cost categories: RDT&E, Procurement, and O&S. The outcome of the Problem Definition phase was a Redefined Problem Statement that explicitly defined the existing problem which is to develop a model and framework that can predict the life cycle cost of systems for analysts and decision-makers to estimate the effects of design decisions on deliverable capabilities and total life cycle costs. To help our group understand what our LCC framework would look like, we created the functional hierarchy, shown in figure 1, to lay out the capabilities of our LCC framework. The next phase of the SDP, Solution Design, focuses on creating a solution(s) to the existing problem. Solution Design is driven by idea generation, alternative generation and improvement, and cost analysis. In the context of the problem, the operating environment was a large factor in the development the solution. The framework must account for all the critical components necessary for a wheeled or tracked vehicle that is used in training or in combat. A major component of this phase was cost analysis, the focus of this research.

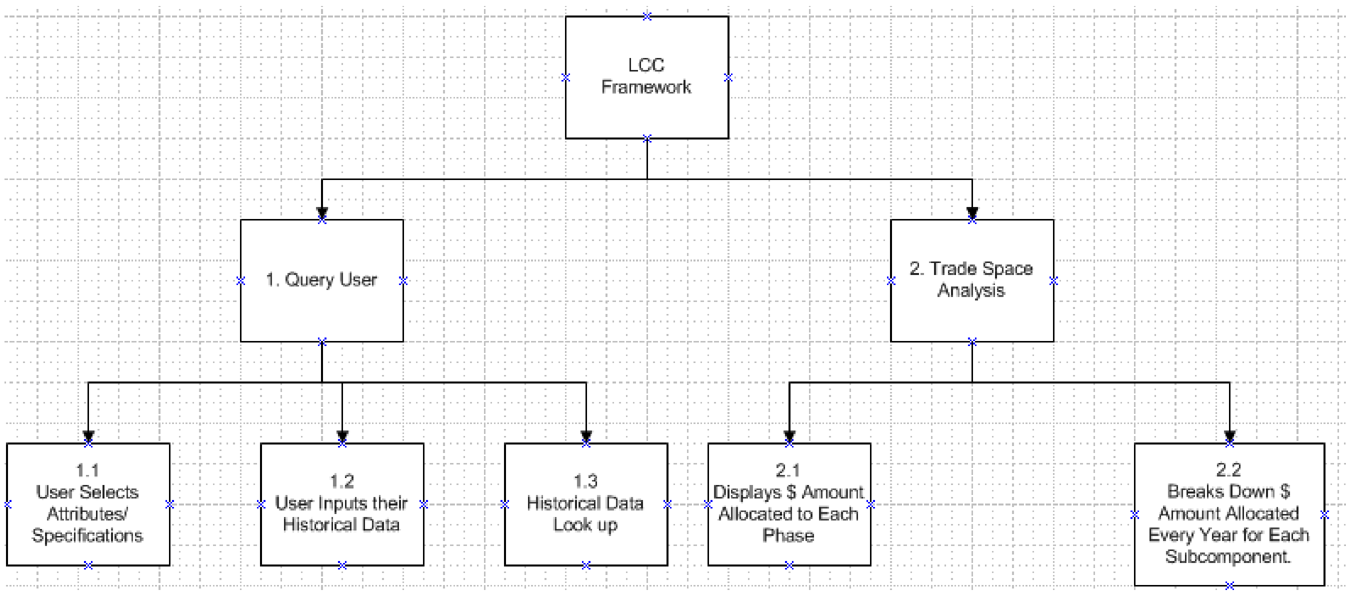

Figure 1. Functional Hierarchy of the LCC Framework

During our research, we compiled historical data on wheeled and tracked vehicles that are used in the DoD. Using the training that we received on JIAT and ACEIT we were able to go through each program and collect the data that we needed to develop an accurate model that produces as close to a point estimate as possible. Both of these programs are used and trusted by costs analysts in the DoD. ACEIT is a suite of tools dedicated to performing cost estimation. Consisting of four separate applications, ACEIT provides a structure for Cost estimators to automate the cost estimation process. We utilized the Automated Cost Estimation (ACE) and CO$TAT applications within ACEIT. CO$TAT is utilized for statistical analysis while ACE is the base model building application where the cost estimate is created. JIAT is an online program that is comprised of many databases such as Army Cost Database (ACDB), OSMIS, and CKB, and CERs. A description of these historical cost databases are shown in figure 2. We utilized these databases in order to obtain the data we required to develop and complete an accurate model. We selected eleven Army and Navy systems and browsed each of these databases to acquire the data needed to fill in the WBS for each system. These vehicles are the Bradley Fighting Vehicle, Expeditionary Fighting Vehicle, Family of Medium Tactical Vehicles, Joint Light Tactical Vehicle, Abrams, Stryker, Joint Mine Resistant Ambush Protected Buffalo, High Mobility Artillery Rocket System M142, Paladin, Palletized Load System in the Family of Heavy Tactical Vehicles, and the Light Armored Vehicle Mortar Carrier. Once we acquired all the data needed, we went through the different life cycle phases and contracts that were available for each system. For example, there are WBSs for the Bradley Fighting Vehicle (BFV) at the beginning of its production and development (P&D) in 1983 and also a WBS for 2003. We decided to use the most recent WBS because it had more up-to-date data for the BFV and it was further along in its life cycle. We went through each of the vehicles contracts and WBSs and selected which WBS we believed to be the most up-to-date and accurate. The accuracy of the WBS was a key component for the CERs that we created for our model. As shown in the functional hierarchy in Figure 1, the model produces a point estimate as well as a breakdown of the cost allocation for each component of the WBS per year.

Source:	Description:
ACEIT	Automated Cost Estimating Integrated Tools: This tool allowed for us to incorporate accurate inflation rates into our model. We were able to take the base year costs and convert them into current year dollars.
ACDB	Automated Cost Data Base: This database was the primary database that we used to pull the data for our model. It provided WBS for each of the vehicles in our model.
OSMIS	Operating and Support Management Information System: OSMIS provided a more in depth analysis of the O&S costs in the WBS
JIAT	Joint Integrated Analysis Tool: JIAT is the platform we utilized to access Army databases.
CKB	Capabilities Knowledge Base: CKB provided the Base Year and Appropriation numbers we needed to fill out WBS in ACEIT

Figure 2. Table of Data Sources

The CERs for our model consist of the following attributes: vehicle weight, wheelbase, engine power, weapon caliber, and crew capacity. They will be individually compared to the WBS chosen for our analysis for the eleven wheeled and tracked vehicles because we felt that they would provide us with a wide array of data and attributes to create an accurate model. Our model is an attribute based model in which the user can input their own historical data in order to receive the most accurate LCC estimation. After the user inputs their data into the model or selects attributes, the model will then look at the CERs we created from the WBSs and give the user an estimated cost for their proposed system. In order to develop an accurate model, it is critical that the CERs are based on accurate historical data.

In order to create a framework for life cycle costing, there are critical ground rules and assumptions that must be followed. Most systems require O&S costs such as mid-life upgrades or service life extension programs associated with the current planned system life and should also be included (Operating, 2015). O&S costs include: System life, O&S phasing, year dollar/inflation indices, discounting, war/peace conditions, and scope of the estimate. The O&S estimate should extend over the full life expectancy of the system. As stated in the operating and support cost-estimating guide, it is important that we validate the information we are gathering from various resources and databases. By utilizing JIAT, we ensured that we were obtaining data that is supported by the Assistant Secretary of the Army for Financial Management & Comptroller. The Army defines an authoritative data source through DoD Directive Number 8320.03 as “a recognized or official data production source with a designated mission statement of source/product to publish reliable and accurate data for subsequent use by customers. An authoritative data source may be the functional combination of multiple, separate data sources.” (Department of Defense, 2015). Based on this definition, JIAT qualifies as an authoritative data source that is supported by the Army and DoD.

4. Analysis

Our framework will be based in Python for easy incorporation into ERDC’s tradespace tool and will be exceptionally simple to utilize and gain LCC estimates. The model consists of six attribute inputs: Gross Vehicle Weight, Wheelbase, Engine Power, Weapon Caliber, Track or Tire, and Crew Capacity. While the model consists of these six attributes for the wheeled vehicle demonstration, the methodology is extensible to additional attributes for other systems. The noted attributes are cost drivers, achievers of desired capabilities, as well as easily obtainable pre-milestone A, alternative-design attributes. ERDC’s ERS & CREATE-GV tradespace tool currently uses these six attributes, along with others, to fill the tradespace. While our model is focused on developing the life cycle cost of a wheeled or tracked vehicle, the methodology can be applied to any proposed vehicle or aircraft across the Armed Services. The model for wheeled and tracked vehicles will provide the framework for future models.

After the user inputs their desired vehicle attributes, the model will utilize CERs based off historical contracting and cost data to fill both a basic LCC estimate consisting of RDT&E, Procurement, and O&S costs, as well as a more in-depth LCC estimate down to the third level of the Mil-Standard 881-C Surface Vehicle System WBS.

At this point the model will have a point estimate of a wheeled or tracked vehicle LCC. The model will then display the cost allocated per year for each element of the work breakdown structure and add inflation factors to ERDC's ERS & CREATE-GV tradespace tool over the assumed 25-year project lifecycle. Lastly, the model will provide visuals on the LCC to aid in visualization of WBS component costs.

The tradespace tool will utilize our model to determine a LCC estimate for each ground vehicle alternative design within the newly populated tradespace. Because our model will be fully integrated into the tradespace tool, no additional user inputs will be necessary to determine a LCC estimate.

5. Results

The resulting LCC framework is a functional, user friendly, cost estimation tool capable of predicting the total LCC cost of a system based on query user attributes. The purpose of this framework is to provide cost analysts a way to determine the cost effectiveness of using a specific system characteristic over other options created in the tradespace. Figure 3 below presents the framework for developing a LCC CER. Using this methodology, the user initially selects the type of system for analysis; a wheeled or tracked vehicle. Following this decision, the user inputs attributes of the system. The framework automatically links these inputs to historical acquisition systems that share similar characteristics and displays the life cycle cost tables that the project team acquired from historical Army databases, such as OSMIS and CKB.

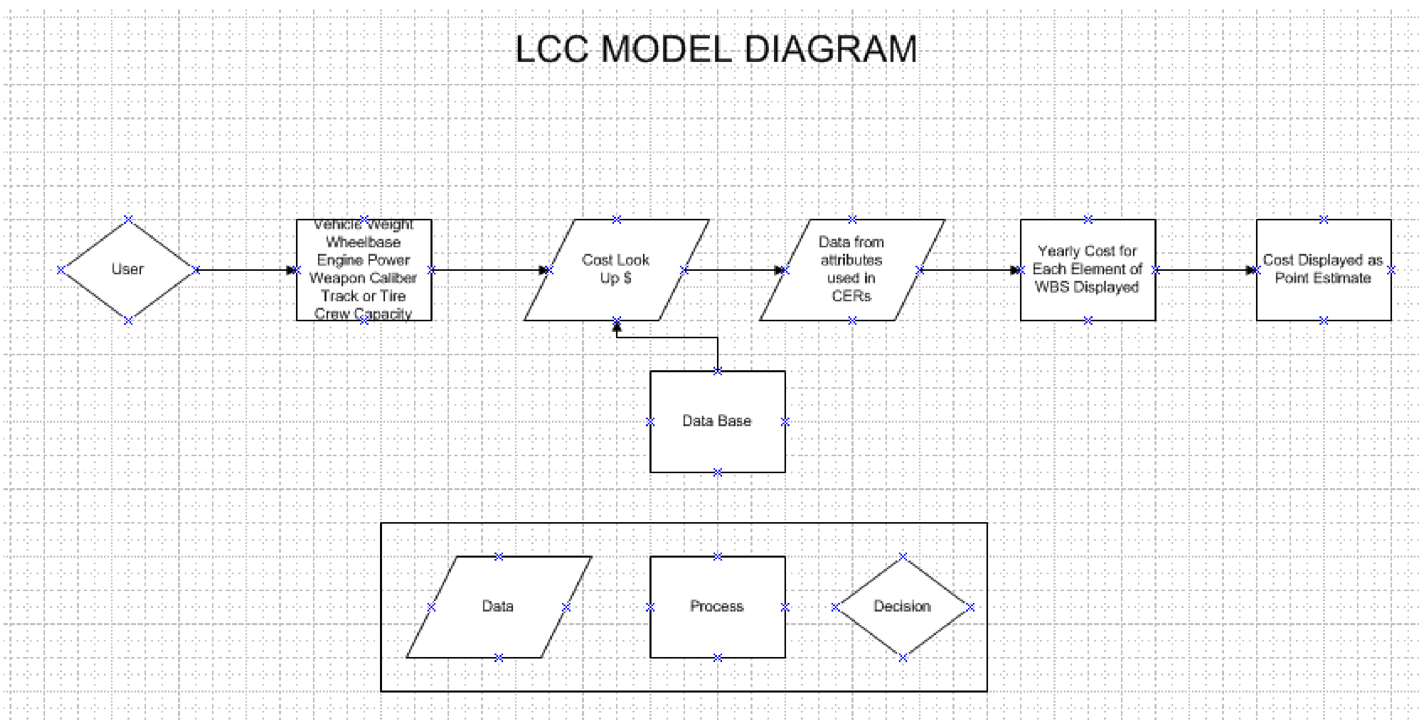

Figure 3. Model Flow Diagram

This refined LCC framework is an extension of the pervious effort, however we have focused solely on wheeled and tracked vehicles. We decided that in order to provide a more precise estimate, our model should encompass the MIL Standard 881-C WBS down to the third level. We used the first contract for each vehicle found in JIAT because this provides the most accurate data to develop a CER to determine LCC of proposed systems. Another critical difference is that our model not only produces a total overall cost for each system, but also the individual cost for each WBS element per year. In addition to those differences, the attributes we are using to determine cost differ slightly. We are no longer using Height, and

Speed in our model. Also, we redefine Width as Wheelbase, Horsepower as Engine Power, and Gun Size as Weapon Caliber. Finally, we are using two new attributes; Track or Tire, and Crew Capacity.

6. Conclusion

In order to develop a framework that could be utilized by ERS, we had to revise and modify the model developed by previous capstone groups. Previous research included an attribute based model that allowed for the user to input specific attributes for a proposed system. Their model did not take inflation into account and was missing much of the O&S costs for the systems that made up their framework. This year's research improved upon this framework by incorporating inflation and O&S costs into our model.

Once we determined the scope of our model, we utilized JIAT and ACEIT. These programs provided the inflation and O&S data that we needed for our model. Using the historical data provided by JIAT, we selected WBSs for each of the vehicles that would provide the CERs for our framework. After the data was pulled from JIAT we exported the data into an excel spreadsheet and created CERs for each component of the WBS. Excel served as the initial platform for our model but we exported this data into Python in order for it to be incorporated into the ERS framework. With the completed model, the user will be able to look up and select attributes, provide their own historical data, or look up historical data that we have provided. Once the user selects their desired attributes, the model will provide a point estimate of the LCC for the proposed system. The model will return a point estimate cost for the proposed system for up to twenty five years and will provide the individual cost for each WBS element per year.

7. Future Work

Future research on a LCC model that predicts cost of Major Defense Acquisition Project (MDAP) systems can take multiple different approaches. The model can be expanded to include Air Force and Naval vehicle attributes so that the model is not limited to wheeled and tracked vehicles. The model can also go more in depth to the fourth and fifth level of the Work Breakdown Structure to predict a more accurate and precise life cycle cost than this research team was able to predict. Based on this research, any follow up efforts to use CERs for LCC of wheeled and tracked vehicles should follow these steps when initiating the next phase of this project. The team must begin their research by performing a literature review to understand the terminology of LCC. The team then needs to receive training on ACEIT, then JIAT, then on the ERDC's ERS & CREATE-GV tradespace tool. The team should receive this training early on so that they can make the best use of their time and create a more in-depth and accurate model than the past LCC capstone teams.

8. Acknowledgement

Thank you to Mr. James Richards for providing direction and meeting with us to work out questions and problems we faced. The guidance and input from him was critical to the success, implementation, and analysis of stakeholder analysis for this project. Thank you to ERDC and DASA CE for supporting this endeavor. This paper was previously published and presented in the Donald R. Keith Memorial Capstone Conference at USMA in May of 2015.

9. References

Department of Defense. (2014, March). *Operating and Support Cost-Estimating Guide*. Retrieved 28 February, 2015, from <https://acc.dau.mil/adl/en-US/188404/file/77020/CAPE O_S Cost Estimating Guide (March 2014).pdf>
Department of Defense. (2015, January). *Better Buying Power Acquisition, Technology and Logistics*. Retrieved 23 February, 2016, from <http://bbp.dau.mil/index.html>
Department of Defense. (2015, November). *Unique Identification (UID) Standards for Supporting DoD Net-Centric Operations*. Retrieved 01 April, 2016, from <http://www.dtic.mil/whs/directives/corres/pdf/832003p.pdf >
Farr, J. (2011). *Systems life cycle costing: Economics analysis, estimation, & management*. Boca Raton: Taylor & Francis.
Parnell, G. S., Driscoll, P. J., & Henderson, D. L. (2011). *Decision Making in Systems Engineering & Management*. 2nd ed. Hoboken, N.J.: Wiley.

Richards, J. (2015, December). *Update for Cadet Capstone Team: ERS LCC Update.* Retrieved 18 August, 2015, from PowerPoint Presentation.

Spero, E., Bloebaum, C. L., German, B. J., Pyster, A., & Ross, A. M. (2014). A research agenda for tradespace exploration and analysis of engineered resilient systems. *Procedia Computer Science, 28*, 763-772.

U.S. Government Accountability Office. (2009). *Cost Estimating & Assessment Guide d093sp.* Retrieved 19 February, 2016, from <http://www.gao.gov/new.items/d093sp.pdf>.

Work Breakdown Structures for Defense Material Items. (2011). Retrieved 6 October. 2015, from <http://www.mcri.com/wp-content/uploads/2014/09/Military-Standard-881C-----Department-of-Defense-Standard-Practice-----Work-Breakdown-Structures-for-Defense-Materiel-Items-MIL-STD-881C-3-Oct-11.pdf>. (151-161)>