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Towards the Development of an Early Lifecycle Cost Estimation Model

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Abstract: The Department of Defense's (DoD) Engineered Resilient Systems (ERS) is developing a suite of tools that could radically change how engineers conduct analysis of alternatives, impacting all major DoD acquisitions. To expand upon this ability, the Early Lifecycle Cost Estimation (ELCE) Parametric Model was created as a potential costing complement to ERS' TradeBuilder suite of high-powered computing tools. The model leverages Pre Milestone-A Engineering products that are readily available at the early stages of a system's development. Currently ELCE is conceptual with only two proofs of concept applied; however, the necessity of process mapping for use and coding of the ELCE tool into TradeBuilder inspired this research. This paper discusses the development of a use case for each cost parameter of the ELCE tool, a systematic approach for the prospective ERS user to create a cost estimate for a system, and the potential impacts of a coded ELCE model.

Keywords: Cost Estimation, Use Case, Logical Mapping, Engineered Resilient Systems (ERS), Systems Engineering

1. Introduction

A recent memo on acquisitions signed by General Milley of the Army and Secretary of the Army McCarthy stated "our processes are staff-centric and often stove-piped, which inhibits integration" (2017). This announcement about the inefficiencies apparent in the bureaucracy of the Army's acquisition processes have brought to light the necessity for efficient communication between users, subject matter experts, and developers (Tucker, 2017). Currently, it takes too long for a project to go from idea to delivery of capability to the end user (Freedberg, 2017). These delays have come at great cost to the Army's System Development and Demonstration [Research and Development] accounts with notable failures such as the Future Combat System (Tucker, 2017).

The intercommunication between users, subject matter experts, and developers is not only important for development but integration as well. Five reported issues with the government's website HealthCare.gov were related to the Patient Protection and Affordable Care Act (ACA) and included poor communication with contractors (HCBT, 2013; Payne, 2013). With most engineering efforts, coordination and synchronization are difficult endeavors (Boehm, n.d.). Specifically, the government and contractors faced issues integrating requirements into the website's user interface, which caused the site to collapse (HCBT, 2013).

The lessons learned from ACA's software implementation is information we hope to leverage in the project currently underway for the U.S. Army's Engineer Research and Development Center's (ERDC) project, Engineered Resilient Systems (ERS). ERS is a software based suite of tools – TradeBuilder – that helps engineers, project managers, customers and end users conduct analysis of alternatives (AoA)[1] in an effort to make more informed decisions along a system's lifecycle (AcqNotes, 2017). To run this program effectively, high-powered computing housed within ERDC offers the user a larger and more malleable trade space. Figure 1 displays how ERS is incorporated into the Department of Defense's (DoD) acquisition cycle.

[1] Analysis of Alternatives (AoA) is a methodical comparison of the operational effectiveness, suitability, and life cycle cost of alternatives that satisfy an established capability need. The AoA is conducted prior Milestone A (Analysis of Alternatives Handbook, 2016).

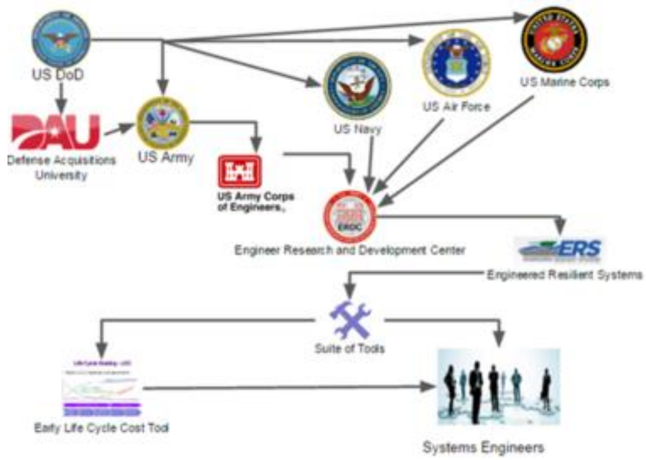

Figure 1: Hierarchical overview of Defense Acquisitions, ERDC, ERS and the ELCE suite tool.

This paper builds upon three previous research efforts that attempt to complement ERDC-ERS's TradeBuilder with an early lifecycle cost estimation (ELCE) tool. ELCE is a parametric cost model in the early stages of development that leverages readily available Pre-Milestone A (PM-A) products to generate its cost estimates. Ideally, ELCE will increase the ability of engineers to conduct AoA by utilizing existing automated methods such as TradeBuilder to pair a cost estimate with each alternative produced. The ELCE model described in this paper generates PM-A cost estimate for systems under consideration for acquisition by the DoD (Moody et al., 2017b). This paper focuses on turning the mathematical model ELCE, its associated processes, and required inputs into map-able logic that any software code engineer could implement into ERS' TradeBuilder. Our process mapping of the ELCE model will be an open source document, available for anyone to integrate into their systems engineering process.

2. Background

The Department of Defense (DoD) has a substantial interest in engineering resilient systems that can withstand extended durations of operations (Goerger, 2014). ERS attempts to satisfy this effort with unique approaches because traditional methods were no longer sufficient, from a cost and coverage perspective, for growingly complex systems (Goerger, 2014). Modeling techniques such as ERS' TradeBuilder delivers AoA in an environment of dynamic requirements to meet new challenges of the DoD (Goerger, 2014). Technology enablers for AoA, cost modeling, and unique approaches are necessary investments for ERS to continue its mission to provide detailed analysis of resilient systems (Goerger, 2014).

A portion of ERS' research on improving its suite of tools encompasses the ELCE model. The team developing the ELCE model researched a variety of established cost estimation approaches such as top-down, bottom-up, and parametric before development (Valerdi, 2008; Blanchard, 2011; Parnell, 2011; Moody et al., 2017a). Top-down cost estimation utilizes experts for a relatively quick approximation of total system cost based on their experience. This method usually requires analogous project and outcome understanding. Bottom-up estimates rely on knowledge of the smallest portions of a system in an effort to provide an estimate derived from the lowest level. Parametric models are mathematically based on input parameters that shape relationships between inputs and overall cost estimates (Valerdi, 2008).

Due to the scope of the project, as a PM-A lifecycle cost estimation effort, a comprehensive parametric model was identified as the best course of action (Moody et al., 2017a). The ELCE model takes inputs from multiple cost paradigms to generate a lifecycle estimate. This research leveraged available inputs early in a system's lifecycle to provide ERS with a PM-A cost estimation tool. The long-term end state is to fully integrate this tool into ERS's high-powered computing Tradespace analysis platform to support the DoD's Acquisition process. Upon the creation of this tool, the research team calibrated the model.

ELCE was created utilizing parametric modeling techniques and leverages engineered products from resources that already exist in order to create size drivers and coefficients, which provide an overall system cost estimate (Moody et al., 2017b). Complete costing data found within both the Government Accountability Office (GAO) and Cost Assessment Data Enterprise (CADE) calibrate lifecycle cost structure and size drivers in order to better estimate the lifecycle cost and work towards generating a more accurate estimate for future systems (U.S. Government, 2017). The DoD provides raw data inputs such as Cost Data Summary Reports (i.e., DD Form 1921s) within CADE for program and system level costs. Each DD1921 maps cost components of the project down to the lowest level of the Work Breakdown Structure (WBS) that helps organize the elements into cost categories.

Figure 2 illustrates the five cost categories that comprise ELCE: Systems Engineering, Software Engineering, Hardware, Project Management, and Integration. The model leverages two pre-existing cost models, COSYSMO and COCOMO II, for Systems Engineering and Software Engineering efforts, respectively (Valerdi, 2008; Boehm, 2000; Young, 2010). We leverage size drivers and cost estimation relationships, as experts and research demonstrate that almost all conceivable systems will have associated costs in these domains (Farr, 2016). For Hardware and Project Management costs, the model proposes size drivers derived from the inputs used in the SEER-H Model and Young's Model 2 (Galarath Inc., 2014; Young, 2010). The ELCE model attempts to account for the combination of these components by utilizing an integration element that adjusts the costs based on the amount of interactions between the categories. Accounting for all five cost categories in a single model enables ELCE to generate a PM-A estimate for the lifecycle of a system.

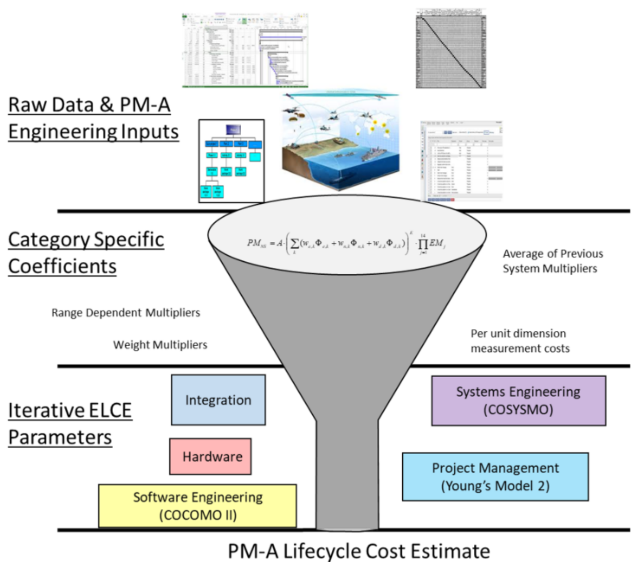

Figure 2: A visual representation of the Use Case, as a user gathers and enters engineering inputs such as work breakdown structures (WBS) and timelines, the user iterates the model and calculates an overall cost estimate consisting of those five categories shown.

Upon creation of the ELCE model, proofs of concept were necessary to explore and calibrate the model to a real system. The first proof of concept was the MQ-8 Fire Scout, a naval unmanned intelligence, surveillance, and reconnaissance helicopter (Moody et al., 2017a). This provided the first iteration of the model coefficients and size drivers. The second proof of concept, the Joint Light Tactical Vehicle (JLTV) represents the aspect of military ground combat, which expanded the application of the ELCE model to an additional domain (Werner et al., 2018). This proof of concept improved upon the assumptions and limitations of the model as it applies to ground systems, separate from the aerial domain. Expanding the model to a system with different capabilities (wheeled, ground, and manually operated) introduced the model to a wider range of cost variables that affected the detail specific inputs intrinsic to the model.

The development of the ELCE model implied that it could possibly be functional in estimating cost with a multitude of alternatives across the battlespace. With only two proofs of concept complete, the ELCE model has not yet been exposed to the extensive cache of capabilities that the DoD provides; however the success of the first two proofs of concept demonstrate that the ELCE model could greatly benefit from large-scale replication and integration into ERS.

3. Methodology

Building the use case required three main insights: definition of the system boundary, clear vision of how the use case informs the primary actor (typically the user of the system), and assertion that the use case meets the need of the client organization (Rotem-Gal-Oz, n.d., Probasco, 2000). Next, we identified the population of actors that could benefit from the use case (i.e. users seeking AoA, and software code engineers) with respect to the model and parent organization (Rotem-Gal-Oz, n.d.). Because of the wide range of potential actors in this use case, this research found it necessary to find a balance between the specificity required for software engineers to utilize the use case for coding, yet general enough for the user to replicate the

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model's process to another system with the model interface (Rotem-Gal-Oz, n.d). We determined that it was necessary to build an individual use case for each cost paradigm associated with the model, given the category-specific processes. The organization of the model in this manner facilitates navigation through the use cases and interfaces.

Upon completion of the identified tasks, we began to build the use cases. First, we determined the pertinent information that the user needs to make the use case effective. A system's boundary diagram helped identify information such as inputs, subsystems, and the output. This information is contained within the categories of description, preconditions, postconditions, and main success scenario. The description gives a general outlook about how the use case fits into the scope of the project. The preconditions and postconditions outline engineering products necessary for the model to function and indicate what the model provides to the user, respectively. Finally, the main success scenario provides the user with a systematic process for model operation. Figure 3 displays the use case's position within the overall model development process.

4. Results & Analysis

Five use cases were created to inform the user through each cost category of the ELCE model. Each use case was produced from a template containing the same categories displayed in Figure 4. The only differences between the use cases is the category specific inputs and derivations that the model provides the user to generate the category cost within the main success scenario. These in-depth descriptions allow cost estimation to occur with little burden on the user.

The main success scenario for each cost category separates the use cases. Each use case outlines the systematic methodology of generating cost estimations for its specific field. In order to outline the process for users unfamiliar with the model, we applied the procedure used for producing a cost estimation for the JLTV. This involved retracing our steps as we walked through the model from high level engineered products such as Cost Data Summary Reports and system timelines found in the DD1921 and GAO report, respectively. We then wrote each use case as we calculated a component cost for each paradigm of the model for the JLTV, producing five unique use cases. Figure 4 represents the use case for the Hardware cost component.

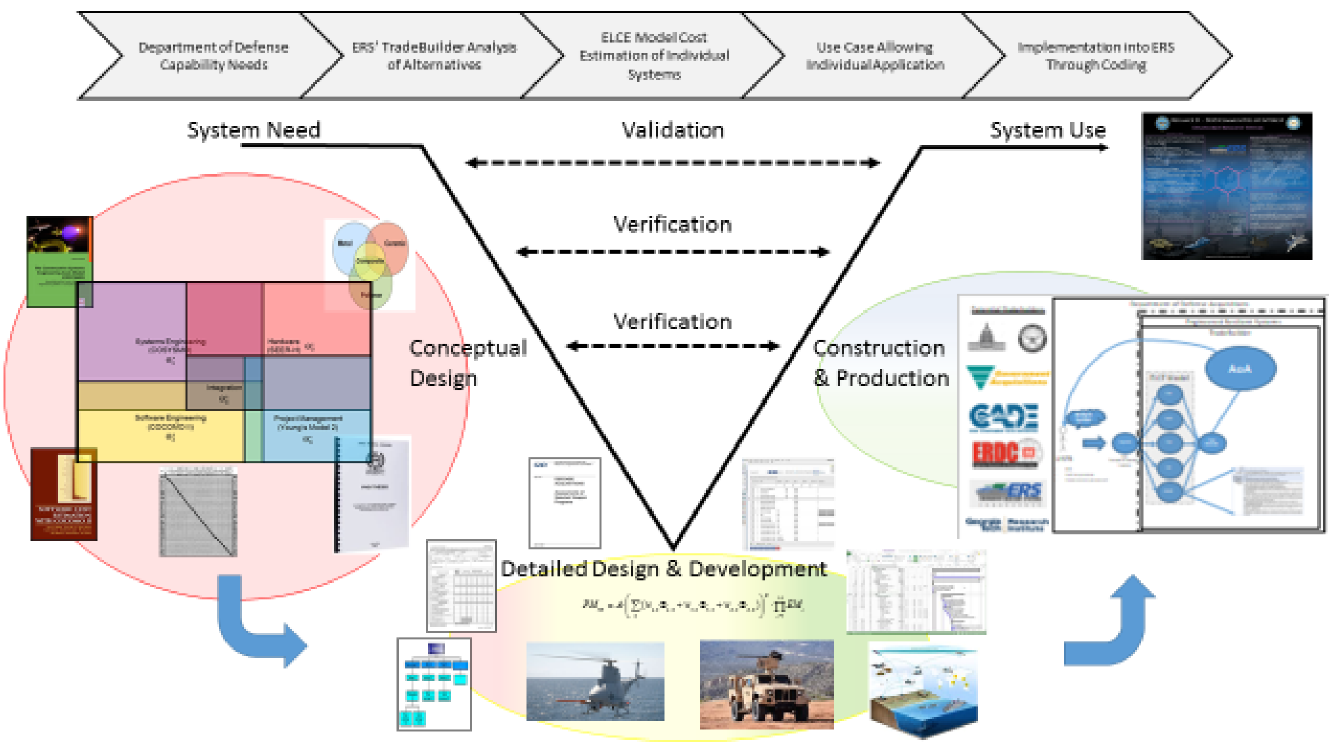

Figure 3: Vee diagram depiction of ELCE's use cases in the systems lifecycle. Early on in the lifecycle a systems boundary diagram identified the system need, proofs of concept verified the system, reaching the implementation phase with the use cases constructed.

Not only does the model provide a prospective cost estimator with a guide for using ELCE, the organized nature of the use case lends itself to modular programming by a software code engineer. The detailed nature of the step by step description could allow programmers to understand the information necessary to transform the process to coded logic. This logic could be applied to any coding language (i.e. python, java, C++) that the software code engineer chooses to employ. The combination with the use cases and spreadsheet interfaces provide engineer products necessary for the future.

ID:	**1**
Title:	Use Case of the Hardware Cost Parameter
Description:	Our overall cost estimation model is divided into five cost parameters to generate appropriate estimates for each significant type. This use case follows the hardware cost paradigm.
Primary Actor:	User
Preconditions:	Work Breakdown Structure, System Concept, Timeline
Postconditions:	A Hardware Cost Estimate for the entire lifecycle of the system
Main Success Scenario:	1) User determines the expected weight, length, width, and height for the system. 2) User assigns weights to the weight, length, width, and height parameters according to their perceived relative importance to the system function. These weights must sum to 1. 3) The parametric value weights are multiplied by the expected values. 4) The parametric values are multiplied by the calculated cost/ft and cost/lb scalar values derived from numerous iterations of the ELCE Model. This hardware cost estimate is used moving forward. 5) The user enters the system classification based on categories with associated cost multipliers. The categories and their assigned cost multipliers are the following: Very Low - 70%, Low - 80%, Nominal Minus - 90%, Nominal - 100%, Nominal Plus - 110%, High - 120%, and Very High - 130%. Depending on what category the user believes the system will be in while reviewing the SEER-H descriptions determines the selected category. 6) The user determines the system's material composition and allotted values to each material type. 7) An overall material multiplier for the system is determined by taking the sum product of the cost multipliers and their associated weights. 8) The user selects the manufacturer's capability category and determines which category the manufacturer falls under. The manufacturer's capability categories and their assigned cost multipliers are low - 1.15, nominal - 1, and high - 0.85. 9) The dimension hardware cost estimate is multiplied by the classification, materials, and capability cost multipliers to determine an overall hardware cost estimate for the system and outputs it to the user.

Figure 4: This figure is the use case template mapping the Hardware Parameter of the ELCE model for a given system. There are templates for each of the five cost parameters of the ELCE model that will allow a software engineer to choose the correct method of code for integration.

5. Discussion and Future Work

The methodology applied in this research predicated itself on assumptions that influence both the use of the ELCE model and how ERS TradeBuilder incorporates the model. The first assumption is that the user of TradeBuilder knows engineering products, such as WBS, operational scenarios, system level requirements, and initial planning constraints. The second assumption is that these products are compatible to ERS TradeBuilder. The final assumption is that ERS TradeBuilder will have up-to-date access to large cost databases, such as CADE, and that this access will allow for a cost complement to any AoA produced using TradeBuilder. These assumptions are currently limitations, because they are theoretically executable; however, much of the current research focuses on the logical application of such assumptions.

The implications of leveraging use case modeling prior to merging ELCE into TradeBuilder is twofold; first, it allows for ERDC-ERS to build a standardized process of how incorporate new AoA complements; and second, it provides the option to choose a coding language that best fits the integration of TradeBuilder, the ERS cloud, and other platforms within the DoD acquisition organizations. As ERS's TradeBuilder is refined, and more tools are added to drive earlier decisions along a systems lifecycle, standardizing the method to how more tools are included will ensure all stakeholders are working from a common set of expectations. Also, a use case is detailed enough to empower a software developer during implementation, but not force them to reuse a poorly selected language or have to debug poorly written code.

Future work for ELCE research as a cost complement to ERS's TradeBuilder should focus on addressing the aforementioned assumptions. Validating what engineering products are actually available PM-A and map-able into TradeBuilder will ensure that all AoA's created are not extra work for the user of ERS when seeking a complementary cost estimate. ERDC-ERS' ability to formalize consortiums or collaborate with other acquisition organizations like CADE, GAO, and CAPE will increase the applicability of ELCE to a given AoA, and allow for any of the AoA's to be more informed. As far as building a PM-A parametric cost model that informs TradeBuilder's AoA cost profile, more research needs to occur prior to claiming that ELCE is a proven or validated model.

6. Conclusion

This research provides the framework for the ELCE model to be imbedded into TradeBuilder. The goal is to minimize potential failure in communication between user and developer, similar to the ACA scenario previously described. The products for each cost parameter accomplish two objectives. Specifically, they provide an understandable, code-able process for a software engineer to integrate ELCE into ERS' TradeBuilder, serving a potentially integral role on the path to replication for users to create a cost estimate of a system using ELCE. Regardless of the success of implementation of the ELCE model, ERS' TradeBuilder will continue to provide the DoD with AoA of perspective systems.

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