SYM-AM-22-047

Excerpt from the Proceedings

of the

Nineteenth Annual Acquisition Research Symposium

Acquisition Research:
Creating Synergy for Informed Change

May 11–12, 2022

Published: May 2, 2022

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

The research presented in this report was supported by the Acquisition Research Program at the Naval Postgraduate School.

Systems and Cost Effectiveness Modeling of Unmanned Systems Product Lines for Acquisition

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Abstract

This research investigated the systems and cost-effectiveness of unmanned system product lines to improve both the acquisition processes and warfighter's capabilities. Historically defined as the probability that a system can successfully meet an operational demand within a given time when operated under specified conditions, system effectiveness is the ability of a system to do its intended job. Traditionally applied to a single system acquiring DoD systems with overlapping capabilities are most economically acquired as integrated product lines. Therefore, more relevant measures are needed to evaluate product lines and similar systems of systems. Cost-effectiveness measures a system in terms of the cost of system effectiveness and its ability to fulfill the intended mission and total lifecycle cost (LCC). The LCC can be expressed in different ways depending upon specific mission or system parameters under evaluation. The "constructive product line investment model framework" (COPLIMO) applies to performing product line cost estimation and investment analysis. Initially oriented for software product line development, it is now a general framework for system product lines consisting of software, hardware, or combined elements. The Cost model is adaptable for different product types, processes, and estimation relationships necessary to cover unmanned systems. The cost model accomplishes this by employing product-specific parametric cost models to improve estimation fidelity versus using average assumptions. The overall model sums the software and hardware component estimates derived from their detailed cost models. The results of a student capstone report are the focal point of the paper.

Executive Summary

This research investigated the systems and cost-effectiveness of unmanned system product lines to improve both the acquisition processes and warfighter's capabilities. Historically defined as the probability that a system consistently meets an operational demand within a given time when operated under specified conditions, system effectiveness is the ability of a system to do its intended job. Traditionally applied to a single system acquiring DoD systems with overlapping capabilities are most economically acquired as integrated product lines. Therefore, more relevant measures are needed to evaluate product lines and similar systems of systems. Cost effectiveness measures a system in terms of the cost of system effectiveness and its ability to fulfill the intended mission, and total lifecycle cost (LCC). The LCC can be expressed differently depending upon specific mission or system parameters under evaluation. The constructive product line investment model framework (COPLIMO) applies to performing product line costs estimation and investment analysis. Initially oriented for software product line development, it is now a general framework for system product lines consisting of software, hardware, or combined elements. The cost model is adaptable for different product types, processes, and estimation relationships necessary to cover unmanned systems. The cost model employs product-specific parametric cost models to improve estimation fidelity versus using average assumptions. The overall model sums the software and hardware components estimates derived from their detailed cost models.

By way of background, unmanned underwater vehicles (UUVs) are advanced, versatile systems procured by the U.S. Department of the Navy (DoN) for use by forward-deployed forces. During and in conflict regions, UUVs are deployed singularly or within Smart Warfighting Array of Reconfigurable Modules (SWARM) configurations. Missions requiring UUVs can vary from surveillance of an area to an area-specific payload delivery. Missions may be conceptually different but still require similar capabilities. For example, in a surveillance mission, the UUV must be able to navigate to the point of interest. This requirement is also true when delivering a payload to the point of interest. Likewise, the requirement to autonomously navigate to a specific location is true across both missions. Designing system requirements for reusability across different missions yields increasing savings in systems engineering (SE) labor by including more missions in the reuse portfolio. If the baseline UUV mission SE requirements incorporate design for reuse, the initial labor investment will increase. However, the Constructive Systems Engineering Cost Model (COSYSMO) shows that if enough requirements and interfaces are reusable across different missions, this initial investment will have a high return (ROI) return.

Interest in UUV platforms is expanding as technologies advance while resources become increasingly constrained. Identifying and implementing SE artifact reuse across UUV missions is critical in determining potential cost savings. COSYSMO provides an industry-validated means to compare program SE LOEs while incorporating the reuse of SE artifacts. The student work investigated multiple essential system requirements and interfaces to identify and provide ROI estimates for support across district missions by UUVs developed via a product line approach to SE. The investigation of reusable system requirements and interfaces for UUVs identified efficiencies in applying a product line method to the SE process across different missions. The research determined, employing COSYSMO analysis, whether it is advantageous to develop reusable requirements and interfaces for an initial UUV mission and then reuse or delete those requirements for follow-on missions. Metrics for this analysis are in terms of SE labor. Ultimately, calculating an ROI for reuse versus independent development efforts determined if the investment was lucrative or not.

The DoN requires nine primary missions: Intelligence, Surveillance, and Reconnaissance (ISR); Mine Countermeasures (MCM); Anti-Submarine Warfare (ASW); Inspection and Identification (INID); Oceanography (OO); Communication or Navigation Network Node (CN3); Payload Delivery (PD); Information Operations (IO); and Time Critical Strike (TCS).

The initial step was to identify and compare requirements for each mission for similarity across missions. A systems modeling approach defines the necessary actions and interfaces required for each mission. MBSE System Modeling Language (SysML) diagrams created using Innoslate MBSE software (Innoslate) represent each independent UUV mission’s action, inputs, outputs, and requirements. From the models created, requirements and interfaces will be defined and input into COSYSMO. Outputs from COSYSMO will contain the total level of effort (LOE) needed, in person-months (PM), to perform the SE for each mission. COSYSMO will provide LOEs for independent and reuse mission SE artifact development. ROI assessment enables an informed decision on whether to invest more initially to receive savings later. COSYSMO results provided data for ROI. Program managers and sponsors can use ROI values to make informed investment decisions to develop cross-program and ultimately DoNwide cost savings. Implementation of SE artifact reuse does not have to stop with the DoN but can expand to include all DoD UUV mission development efforts.

The students referenced the COSYSMO output against current programs of record for accuracy, and the person-month labor estimates were found to be in the correct range. Based on the COSYSMO analysis, the students recommended investing extra labor during the first mission’s SE process to design all requirements and interfaces for reuse. Further, they recommend using the ISR mission as the base design reference mission. UUV missions contain similar system requirements and interfaces across the portfolio of missions. For example, UUVs must inherently be deployable, autonomous navigators, situationally aware, capable of communications, recoverable, and replenishable. Finally, the students recommend further investigation into alternate baseline missions. The students believe that analyzing each mission as a baseline could lead to more significant ROIs. For example, utilizing the mission with the most significant number of system requirements as a baseline may lead to greater reuse of requirements. Conversely, the students note that the result could increase deleted requirements. Developing a COSYSMO 2.0 analysis with each mission as the baseline would yield potential alternate results or further solidify the philosophy of using ISR as the reuse baseline.

Research Focus

The research investigates the potential benefits of using a product line approach for the SE of the nine main UUV missions in [3]. The specific questions this research intends to address are: 1. What are the activities, interfaces, and requirements of each of the nine UUV missions? 2. What are the complexities of the identified requirements and interfaces? 3. What is the optimal baseline mission for SE artifact reuse? 4. What is the reusability of the baseline mission's SE artifacts for the remaining missions? 5. What are the LOEs for each mission’s development using traditional and reuse methods? 6. What is the ROI for applying a product line approach to the UUV mission SE efforts? 7. Does operational modularity duplicated across UUV missions save on SE labor costs when the original system is designed for reuse, while still satisfying UUV demands?

Thesis Methodology

Nine UUV missions will be evaluated from the Concept of Operations (CONOPS) statements in [3]. The process will begin with modeling each mission in Innoslate to generate MBSE diagrams. The architecture model will follow SysML, which is a common language used in support of illustrating hierarchies and ontologies [8]. The MBSE diagrams will consist of activity, interface, and requirement diagrams of key mission-driven systems for all nine UUV missions. Comprehensive requirements will be derived from the activity and interface diagrams. The requirements and interfaces will be classified as one of three defined complexities, *Easy, Nominal, Difficult*, and input to COSYSMO to determine the LOE required to develop the SE artifacts for each mission using the traditional siloed development approach. The architecture breakdown of mission profiles will support classifying each and every requirement and interface within a mission [5]. Then the ISR mission will be selected as the reuse baseline. SE artifacts will be categorized into defined reuse levels: *New, Designed for Reuse, Modified, Deleted, Adopted, Managed* [6]. All ISR mission SE artifacts will be designated as *Designed for Reuse*. SE artifacts will be compared across missions and duplicates identified. For example, for a reconnaissance or a bottom survey mission, the sensor package, propulsors, and material types will be cross-utilized to provide a common cost and product line solution for both missions. The resulting database of classified requirements and interfaces will be input into version 2.0 of COSYSMO producing values that can be compared with those for traditional development. The resulting LOEs will be used in ROI calculations determining the benefit of utilizing the identified reuse relationships across the nine UUV missions. The primary deliverable for this research is the analysis that identifies a cumulative ROI showing the additional benefit gained from each mission added to the portfolio.

Thesis Assumptions

The following assumptions were held throughout this thesis and supporting research and analysis. They served to both bound the analysis and provide a stable base of reference in a diverse and dynamic space. Their presentation order implies neither importance nor significance.

- The CONOPS provided in [3] describe the UUV missions with uniform accuracy, depth, and detail.
- The SysML diagrams capture all required activities, systems, and interfaces from the CONOPS.
- Requirement extraction from the SysML diagrams was consistent across missions.
- Interface definition was consistent across missions.
- Requirement and interface classification for both complexity and reuse was consistent across missions.
- SE artifact complexity does not change from mission to mission.
- All missions are performed by a medium class UUV.
- The ISR mission is the best reuse baseline for the nine-mission portfolio.
- COSYSMO will reasonably predict UUV program development efforts.
- The CONOPS in [3] were generalized such that decomposition of the extracted requirements to the “sea level” [9] would introduce an unreasonable level of subjectivity in the requirement definition and classification.

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