# UTILIZING A MODEL-BASED SYSTEMS ENGINEERING APPROACH TO DEVELOP A COMBAT SYSTEM PRODUCT LINE

In 2017, the Chief of Naval Operations (CNO), ADM John Richardson, released "The Future Navy, A CNO White Paper." Within this document, the CNO discussed the need for a 355-ship Navy using advanced technology, new types of ships, and new methods of employing these ships and technology. The CNO described the need for the future Navy to have the ability to operate in blue water, as well as the littorals, with adequate numbers of ships and capability to defeat enemy attacks. Additionally, ADM Richardson described unmanned systems as "an integral part of the future fleet" that are networked and "affordable to buy in large numbers" (Richardson 2017). The need for a large, technologically advanced future Navy, with unmanned systems, further emphasizes the utility of a combat-systems product line due to the capabilities overlap that occurs when designing combat systems for blue water and littoral missions. These capability overlaps lend themselves well to the product-line engineering concept of designing a system with the planned intent of reusing and modifying various components to allow for mass customization of products. Additionally, planned reuse of system components results in a greater return on investment for the combat system customer.

Current U.S. Navy combat system suites are ship-class dependent. There are a variety of configurations that include sensors, weapons, and hardware/software integrations to accomplish similar goals. Aegis combat system is the integrated combat system of Ticonderoga-class guided missile cruisers and Arleigh Burke-class guided missile destroyers. Aegis's development in the 1970s was not conducted with the concepts of product line engineering (PLE) or open architecture (OA) in mind. Ship Self-Defense System (SSDS) combat system development for aircraft carriers and amphibious warfare ships incorporated OA and systems thinking; however, the application and integration of the combat system was unique to the ship-class (DOT&E 2011, 171). The Zumwalt-class guided missile destroyer utilizes the Total Ship Computing Environment (TSCE), which integrates engineering and damage control automation systems along with the combat system (Henry, Iacovelli, and Thatcher 2009, 21–22). Zumwalt's TSCE was also developed utilizing OA and systems engineering processes, but it is also ship-class specific and is not designed for integration on other platforms. The LCS-class and future frigate variant (FFX) use an Aegis derived system called COMBATSS-21 (Lockheed Martin 2017). Ship-class dependent combat system suites do not follow the Navy Surface Warfare Center's (NSWC) vision for the "development of reusable product line components into a single combat system architecture" (Murphy, Richardson, and Sheehan 2013, 11–12).

The disaggregated nature of current U.S. Navy combat systems is not optimal from a technical design nor from a cost perspective throughout the system's life cycle. Employing a product line engineering approach to future combat system design is beneficial for both the combat system developer and the customer. Product line engineering concepts such as building once and the planned reuse of system components, helps the Navy achieve the overarching strategic guidance of the CNO as well as technical guidance from NSWC.

This research explores the possibility of applying product line engineering and open architecture to develop a common system design for future Navy combat systems. Product line engineering and open architecture, including their application to combat system design are discussed in detail. A functional decomposition of current Navy combat system suites provides the framework for a product line incorporating the commonalities needed for effective combat capabilities regardless of platform or ship-class. The system architecture is used to integrate the commonalities into a functional system. Currently, no combat systems product line in the U.S. Navy exists. The benefits of PLE including cost savings and program continuity have not been realized by the Navy due to the current stovepipe arrangement of combat systems across multiple platforms.

A robust engineering product line, focusing on the functional components of Navy combat system commonalities across multiple platforms is developed. Additionally, a product line strategy economic analysis is conducted utilizing the System Constructive Product Line Investment Model (COPLIMO). This includes parametric cost analysis of hardware and software architectural options for the combat systems. The representative results utilizing analogous, current Aegis combat system cost data suggest a strong return on investment (ROI) of a product line approach.

The combat system AFD provides the model necessary for variation point identification and analysis. Variation point identification in the AFD is the first step in the orthogonal variability modeling process. Each variation point is decomposed into different variants that comprise the OVMs, these variation points and associated variants are described as requirements in the textual requirements step of orthogonal variability modeling. The textual requirements are then used to revise the Hatley-Pirbhai AFD model in more detail by allocating components (variants) to each variation point. Next, the individual variation point OVMs are developed from the allocated AFD and related textual requirements. Packaged variants used to represent three tiers of combat system and constraint dependencies on the individual variation point OVMs create the product line OVM. This model displays the feasible combinations of packaged variants, variation points, and variants for the product line.

The product line OVM is necessary for developing the inputs for System COPLIMO that completes the work presented in Chapter III. The System COMPLIMO requires identification of system components (variants) that are mission-unique, adapted, reused across products. These unique, modified, and common components are quantified in the System COPLIMO and are used to create an investment model that describes return on investment by using a product line engineering approach to combat system design.

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