# Transforming Ship Specification Development with MBSE Use Cases: A Model-Driven Approach for Naval Systems Engineering

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## Abstract

The complexity of modern naval vessels challenges the traditional ship specification formation. The legacy, document-based approach often leads to fragmented or missed requirements, unclear activity scopes, and risk in meeting stakeholder needs. This paper presents alternatives that employ Model-Based Systems Engineering (MBSE) use cases to define and organize the major activities comprising the definition of a ship specification. By capturing stakeholder needs, Ship Work Breakdown Structure (SWBS) architecture, and system functions in an MBSE model, systems engineers can systematically trace each specification activity from top-level requirements through functional decomposition to interface definitions. This paper demonstrates how this use-case-centric workflow facilitates early validation of specification completeness, enables automated generation of activity matrices, and supports analyses for the functionality of ship systems. Use cases for different levels of MBSE involvement in the ship specification process are mapped to specification tasks to yield a cohesive, traceable specification that adapts iteratively as operational concepts evolve, and functional analysis of the ship system matures. Utilizing MBSE use cases serves as a basis for transforming the ship specification from a document-based process, steeped in legacy, into a living, digital model-driven artifact, enhancing collaboration among naval architects, systems engineers, and subject matter experts. MBSE streamlines the transition from concept to detailed design and reduces ambiguity and risk in requirements.

**Keywords:** Model-Based Systems Engineering (MBSE), naval ship, ship specification, Ship Work Breakdown Structure (SWBS), systems engineering

## 1 Introduction

The design and specification (spec) development of modern ships demands a rigorous, integrated approach to manage complexity across ship systems. Traditional document-based methods are often negligent in capturing the full scope of system interactions in the ship specification, leading to misalignment, rework, and inefficiencies throughout the shipbuilding lifecycle.

Model-Based Systems Engineering (MBSE), enabled by the Systems Modeling Language (SysML), offers a transformative alternative. SysML is a graphical modeling language that supports the analysis, specification, design, verification and validation of complex systems to facilitate the MBSE application [3]. This manuscript explores how MBSE-based activities can be tailored to develop a digital ship specification, enabling stakeholders to collaboratively define, analyze, and validate ship systems from concept to commissioning.

This paper introduces the limitations of legacy specification practices and the rationale for adopting MBSE. SysML use cases are then explored for different options of MBSE involvement in creating a ship specification.

## 2 Motivation for MBSE

### 2.1 Legacy Ship Specification Development

Modern ships are among the most complex engineered systems, integrating thousands of components across mechanical, electrical, software, and human systems. The ship specification is a translation of the engineering results and decisions into an organized text-based document. Traditional specification development for a new ship build often entails reviewing like-specs (or parent specs) and crossing those requirements with current design stakeholder needs and constraints. Reading sessions are the principal means for ensuring the shipbuilding specification reflects a design that meets Capabilities Development Document (CDD) requirements, is free of major technical inconsistencies, and that system interfaces are properly defined. There are normally two sets of reading sessions, which can take many weeks to accomplish [5]. A large portion of the change order budget in a ship acquisition, particularly for lead ship designs, is typically allocated to correcting defective specifications after the award of the contract and during the detail design and construction of the ship. This can amount to tens of millions of dollars in the procurement of a ship [1]. While physics-based modeling and simulation is

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conducted by ship design engineers to analyze design, it is not typically used to verify requirements. Managing complex user needs to ensure verifiable requirements dictate more than traditional shipbuilding specification approaches.

### 2.2 MBSE-Focused Ship Specification Development

Systems Engineering is often referred to as a document-based approach, characterized by the generation of textual specifications and design documents, and is rigorous, but has some limitations. Because information is spread across many documents, it can be difficult to assess the relationships between requirements, design, engineering analysis, and test [3]. MBSE offers a structured, model-centric framework that allows engineers to visualize and analyze the entire system architecture, making it easier to understand interdependencies and ensure design integrity from the outset. MBSE aligns with the DoN Digital Systems Engineering Transformation Strategy [7].

A key strength of MBSE in specification development lies in its ability to ensure seamless traceability and consistency across all system elements — from high-level requirements to detailed design components. In legacy workflows, requirements are often scattered across disconnected documents, leading to gaps, redundancies, and costly errors. MBSE links every requirement to its corresponding system behavior and design element, ensuring that nothing is lost in translation and that changes are propagated accurately throughout the model.

Ship development is inherently multidisciplinary, involving naval architects, propulsion engineers, software developers, and more. MBSE fosters collaboration by providing a unified model that serves as a single source of truth. This shared framework reduces miscommunication, aligns expectations, and enables teams to work in parallel with greater confidence and clarity.

Early validation is another critical benefit of MBSE. Teams can simulate system behavior and performance before physical prototypes are built. This allows for early detection of design flaws, integration issues, or performance bottlenecks — significantly reducing risk and avoiding costly rework later in the development cycle.

MBSE supports rapid iteration by allowing changes to be made directly in the model, which propagates automatically to view impacts. This agility enables quick responses to evolving mission requirements, regulatory updates, or technological advancements without derailing the project timeline.

Ultimately, MBSE leads to significant cost and time savings. By streamlining specification development, reducing manual reconciliation, and minimizing errors, it enables more efficient use of resources across the ship's lifecycle. MBSE establishes an Authoritative Source of Truth (ASoT) — or a central element around which all activities and data revolve [6] — that connects design, testing, manufacturing, and operations — ensuring continuity and insight throughout specification development and ship build.

## 3 Discussion

### 3.1 Use Cases and Activity Diagrams

SysML is the modeling language often used in MBSE. In SysML, use case diagrams describe the functions of a system and the interactions between those functions and System actors or elements. An activity diagram is a behavior diagram often derived from a use case to describe a system's behavior. Activities can be captured in activity diagrams showing interactions between activities and allocations to structure elements [4]. Specification development has traditionally been document-based, and the DoN encourages more digital connectivity, but transitioning fully to MBSE development is a paradigm shift that many programs and program managers may be unwilling and/or unable to fully fund. This paper proposes several use cases that describe options of specification development with varying levels of MBSE focus in the activity diagrams for each.

### 3.2 Use Cases for Specification Development

An MBSE top-level use case diagram is shown in Figure 1. Here, the overarching use case "Create Ship Specification" is captured in the top circle. The figures branching out from this circle are called "actors", or entities that will perform the use case activity. Below the main use case circle are four use case extensions; these depict four different methods to create a ship specification, from the traditional document-based method, to a reverse-engineered spec, to an integrated/hybrid approach, to finally the MBSE-only digital approach. Note that the activities that will be described within each approach are not

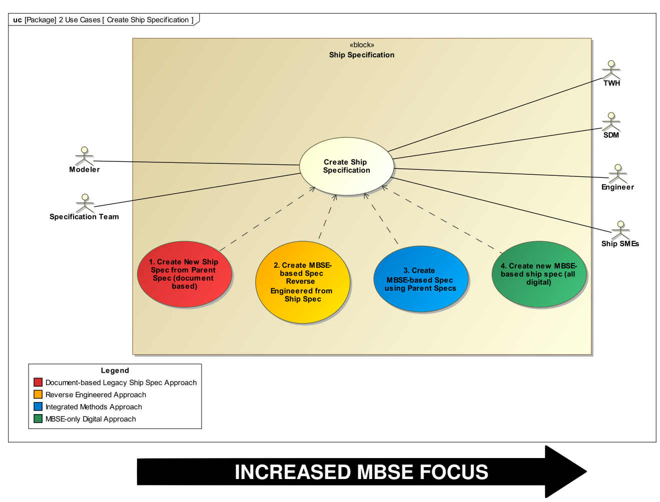


Figure 1: MBSE Specification Development Use Cases

all-inclusive but a summary of some of the main activities involved.

## 3.3 Activity Diagrams for MBSE Spec Development

### 3.3.1 Reverse Engineered Approach

As the focus of this treatise is to explore MBSE in a shipbuilding specification, the first use case extension titled "Document-based Legacy Approach" per the legend in Figure 1 is not modeled. The next use case extension in the orange circle "Reverse Engineered Approach" is comprised of activities shown in Figure 2. This approach "reverse engineers" a ship specification into a digital model by deconstructing its core functions and components, comparing it to the original ship specification to arrive at a summary of findings, and then reconstructing the findings into a digital ship specification contained within an MBSE model.

The activity diagram for this use case shows functions that begin with acquiring the shipbuilding specification for an existing ship, the stakeholder needs and the SWBS. This information is ingested into the MBSE software. From this information, a bdd (Block Definition Diagram) is created to define blocks (or modular unit used to define a component, logic, etc.) in terms of their features and their structural relationship with other blocks [3]. This bdd compares the hierarchy of the system to the SWBS, and forms a basis to derive system components and sub-components that map to functions. Activity diagrams can be used to help establish these relationships and enable a complete functional analysis of what the system needs to do. A thorough requirements and functional review of the specification highlights any gaps in requirements or functionality that may pose risk to desired performance or effectiveness. An assessment of this risk determines if requirements should be rewritten or added, or otherwise mitigated. Any modified or added requirements are added back into the SysML spec for comparison to the original specification, and a summary of findings is created. The resulting shipbuilding specification, the original ship specification and all supporting artifacts are digitally linked in the ASoT model.

### 3.3.2 MBSE-Only Digital Approach

Figure 3 depicts the activities that encompass an MBSE-only digital approach to ship specification development (depicted in green in Figure 1). This method outlines the activities that rely solely on systems engineering principles and an MBSE methodology to create a completely digital specification that is not encumbered by a parent specification review. The SysML language and MBSE methodology can be more completely described in references found in [3] and [4], but here a summary is described. In the "MBSE-only Digital Approach" the SWBS, used as a basis in traditional ship design [5], is utilized as a structure reference, along with inputs from relevant

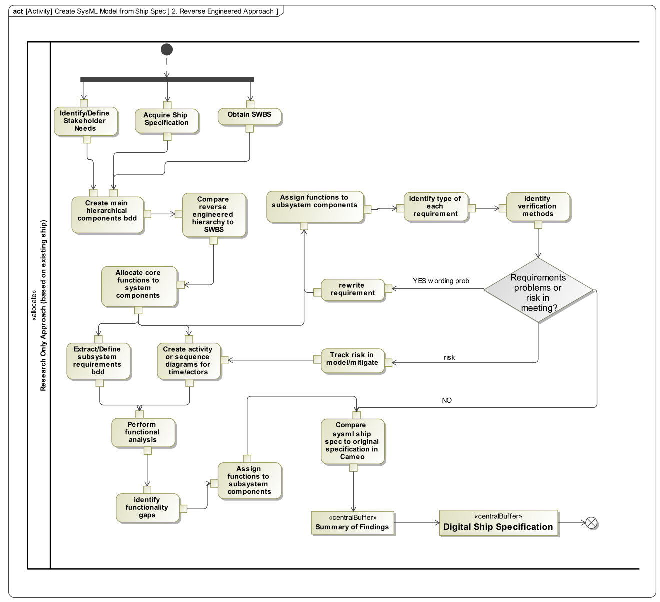


Figure 2: Reverse Engineered Approach Activity Diagram

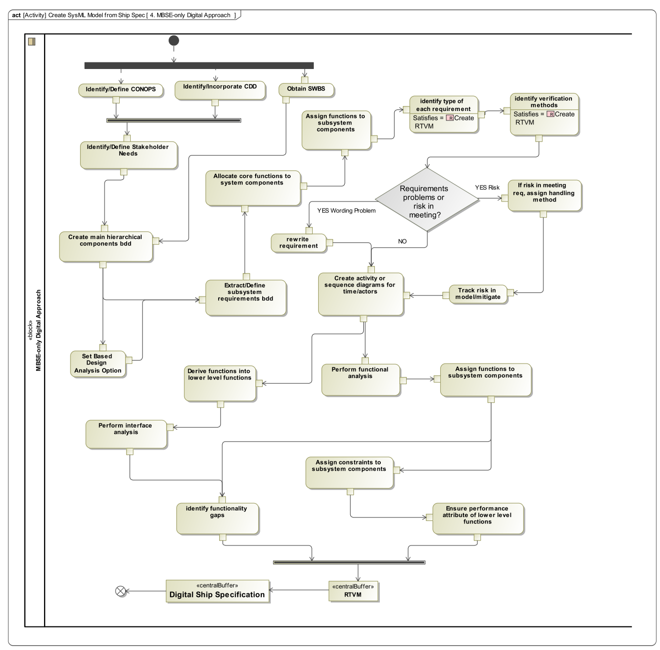


Figure 3: MBSE-Only Digital Approach Activity Diagram

program documentation like CONOPS or a CDD to define the stakeholder needs in the model. The main hierarchical bdd (described in 3.3.1) of the system is created in the model, and from this system and subsystem components are derived and then properly mapped to subsystem requirements. Requirements, functional analysis, risk analysis are conducted and behavior diagrams like activity or sequence diagrams are created to help uncover any gaps in functionality or missed requirements. These analyses ensures all stakeholder needs are translated into functions from the top down and allocated to the model structure from the bottom up. Performance attributes of functions (how well a function must perform) [4] are assigned as needed, and a Requirements Traceability and Verification Matrix (RTVM) is created to graphically show mapping of requirements and verification methods (shown at the top of Figure 3 as a "satisfies" relationship), and finally a digital specification can be created as an output of the model.

### 3.3.3 Integrated Methods Approach

Figure 4 shows the activity diagram for the "Integrated Methods Approach" use case (depicted in blue in Figure 1). The activities in this method are a hybrid of the "Reverse Engineered" and "MBSE-Only Digital" approaches, and begins with legacy ship design parent specification (which is a like-ship specification [5]). Program management might choose this approach to specification development as it integrates legacy ship design artifacts with the ASoT traceability and rigor of the MBSE environment. Here, risk is assessed in meeting requirements. Requirements can be rewritten, as in the "Reverse Engineered" approach, but more in-depth requirements and interface analysis, and MBSE system architecture development take place to ensure the model has connectivity from stakeholder needs through the summary of findings describing all the risks and differences between the parents spec and the model artifacts, to the digital specification. As in the other two methods, the shipbuilding specification is contained and linked in the model and can be exported digitally.

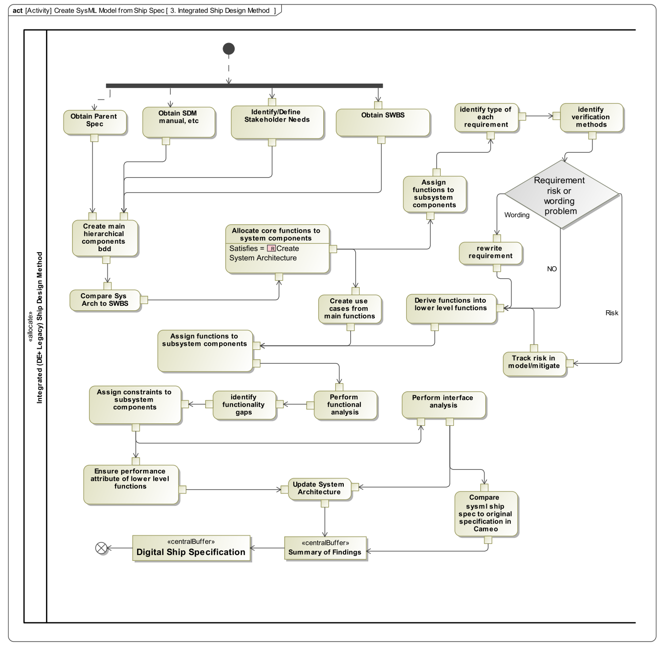


Figure 4: Integrated Methods Approach Activity Diagram


Figure 5: Specification Design Actions to Requirements Satisfy Matrix

# 4 Conclusion and Future Work

The DoN Digital Systems Engineering Transformation encourages a more connected, digital environment to maximize interoperability and reusability — this call can be answered in part by using MBSE to develop a shipbuilding specification. By modeling stakeholder needs, system functions, and architecture, MBSE enables traceable, adaptable, and cohesive specifications. It supports early validation, automated activity matrices, and dynamic analysis, replacing fragmented, document-based methods with a collaborative, digital workflow that reduces risk and enhances design clarity. This paper proposes modernizing traditional ship specification development by examining SysML model developed use cases of various levels of MBSE focus. The use cases presented are

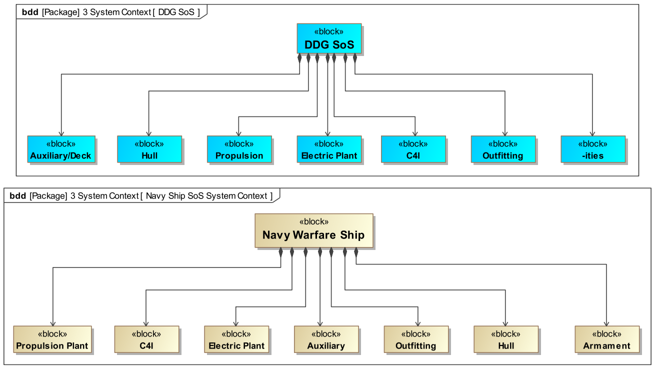


Figure 6: System of Systems (SoS) compared to SWBS

supported by activities that enable tailoring the level of MBSE integration to suit the specific needs of each application. Depending on needs, point in lifecycle, etc., program management (or other interested parties) can decide to fully utilize MBSE or choose a hybrid approach to perhaps satisfy legacy expectations, but in each case, a digital specification results.

All modeling diagrams presented herein were created in an MBSE environment. Requirements were developed for creating a ship specification, and then functions, or activities, to be performed for each approach were generated. Figure 5 shows a summary of activities depicted in these activity diagrams mapped to the requirements they satisfy. While this list is not exhaustive of activities, a matrix diagram showing the satisfaction relationships is a standard graphical illustration used in MBSE. Using the first method described in Section 2, one of the earliest activities involves comparing a system architecture to the SWBS architecture. An example of this comparison can be seen in Figure 6. This figure shows a System of Systems (SoS) of a notional destroyer compared to a SWBS. The SWBS described is the basic context within which the entire ship design effort is planned, managed, and documented [5].

Set-based design (SBD) is an approach used in engineering and product development that explores a wide range of design alternatives. Through a process of elimination, infeasible or highly dominated regions of the design space are discarded, and the design space becomes more restricted [2]. For future work, the authors may explore how MBSE can work with SBD by keeping track of all knowledge gaps, analyses, and resultant requirements, and enables naval architects and engineers to work with a common set of data throughout the life cycle. In addition, the MBSE environment offers an ASoT for all SBD data [6]. SBD can be seen as an optional analysis of the bdd activity in the MBSE-only Digital Approach diagram, but would warrant a more thorough analysis of activities if included.

# Declaration of Conflicting Interests and Views

The authors declare no potential conflicts of interest with the publication of this article. The views expressed herein are solely of the authors, not of a particular company or the Government.

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