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

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MBSE in Shipbuilding Specification Development

I. Introduction and Background

- Modern naval ship design is more complex than ever
- Current specification development is steeped in document-based legacy and is redundant, archaic, inefficient and costly.
- MBSE offers a digital, modern alternative to legacy spec development
- Enables traceability, collaboration, and better decision-making.
- MBSE aligns with the DoN Digital Systems Engineering Transformation Strategy

II. Motivation for an MBSE-based Ship Spec

- Legacy Shipbuilding Specification Development:
    - Traditional development for a new ship build often entails reviewing like-specs (or parent specifications) 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. Reading sessions are not effective in removing all defective requirements. [Modeling the Specification, Doerry 2021]
    - 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. [Modeling the Specification, Doerry 2021]

- Helps define the problem statements and direct solutions by translating stakeholder needs into measurable, testable requirements for the ship's design and construction
- Eliminates reliance on disparate document-based artifacts
- Creates a hierarchy of main components aligned with the SWBS
- Derives system/subsystem requirements from stakeholder needs by performing functional analysis, which includes:
  - Allocates requirements to system components
  - Assesses risk in architecture development and in meeting requirements
- Builds the system architecture (requirements/functions, components, behaviors, constraints)
- Increases stakeholder communication and requirements management
  - Use cases to visualize success criteria, enable functional activity diagrams
  - Specifications, test plans, etc. can be generated from model
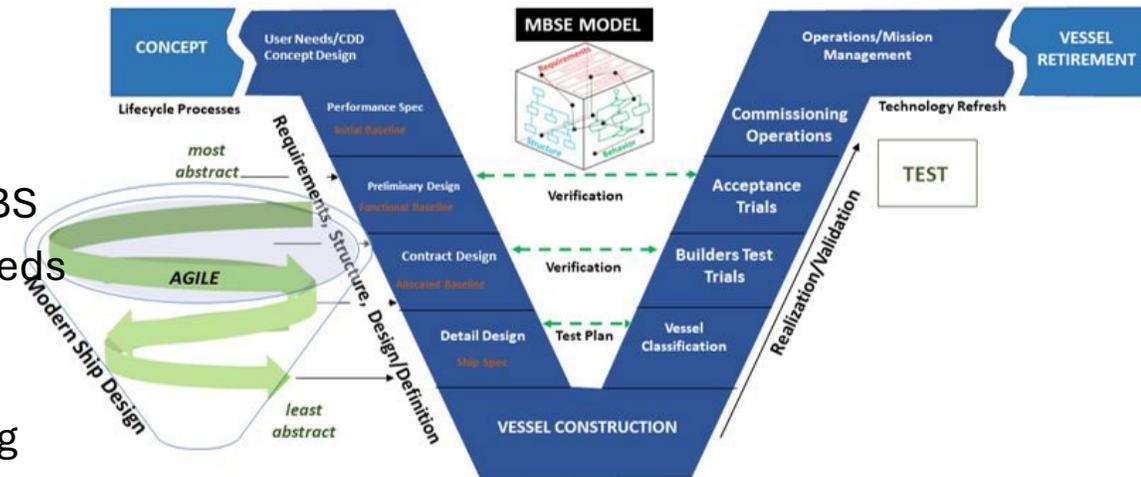
- The standard SE "V" shows activities from Concept to Vessel Retirement
- Design is focus of left side
- All data is captured in MBSE model as the Authoritative Source of Truth (ASoT)
- As design moves from user need definition through design phases, design becomes less abstract

III. Discussion

Demonstrate different methods of creating an output from a model – a digital ship specification – using varying levels of MBSE
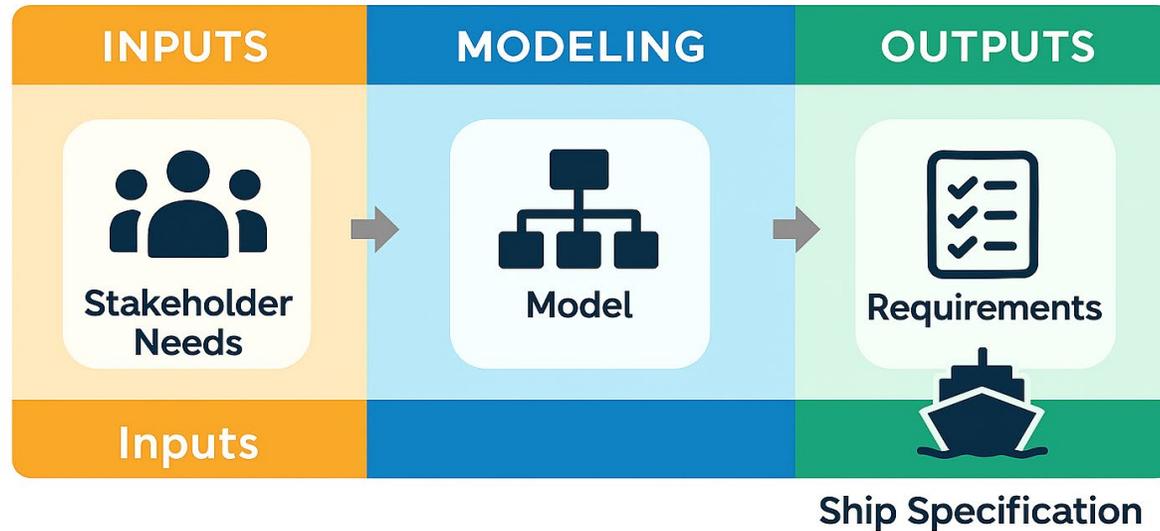
4 use case extensions have been developed that identify possible ships specification scenarios

- Focus is on 3 different use cases utilizing MBSE
- Legacy ship specification development (doesn't use MBSE) is not modeled but is a use case consideration for comparison

III. Create Ship Specification – MBSE Use Case
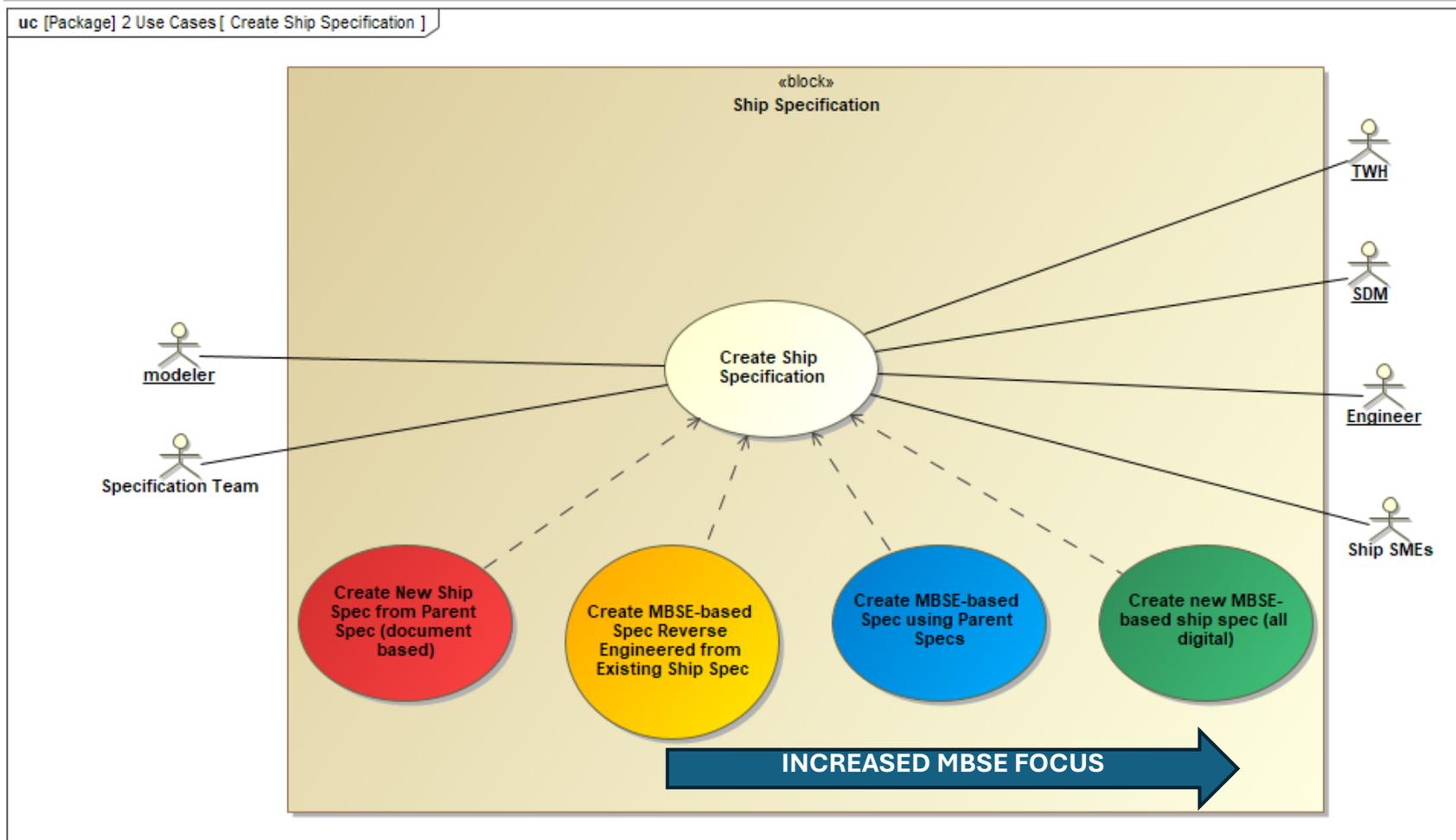
Use cases defined by increasing MBSE focus are derived into activities and requirements - aligned with systems engineering and specification development tasks.

4 Use Case extensions:

🔴 Document-based Legacy Approach (non-MBSE)

🟠 Reverse Engineered Approach

🔵 Integrated Methods Approach

🟢 MBSE-only Digital Approach

Legend
- 🟥 Document-based Legacy Ship Spec Approach
- 🟧 Reverse Engineered Approach
- 🟦 Integrated Methods Approach
- 🟩 MBSE-only Digital Approach
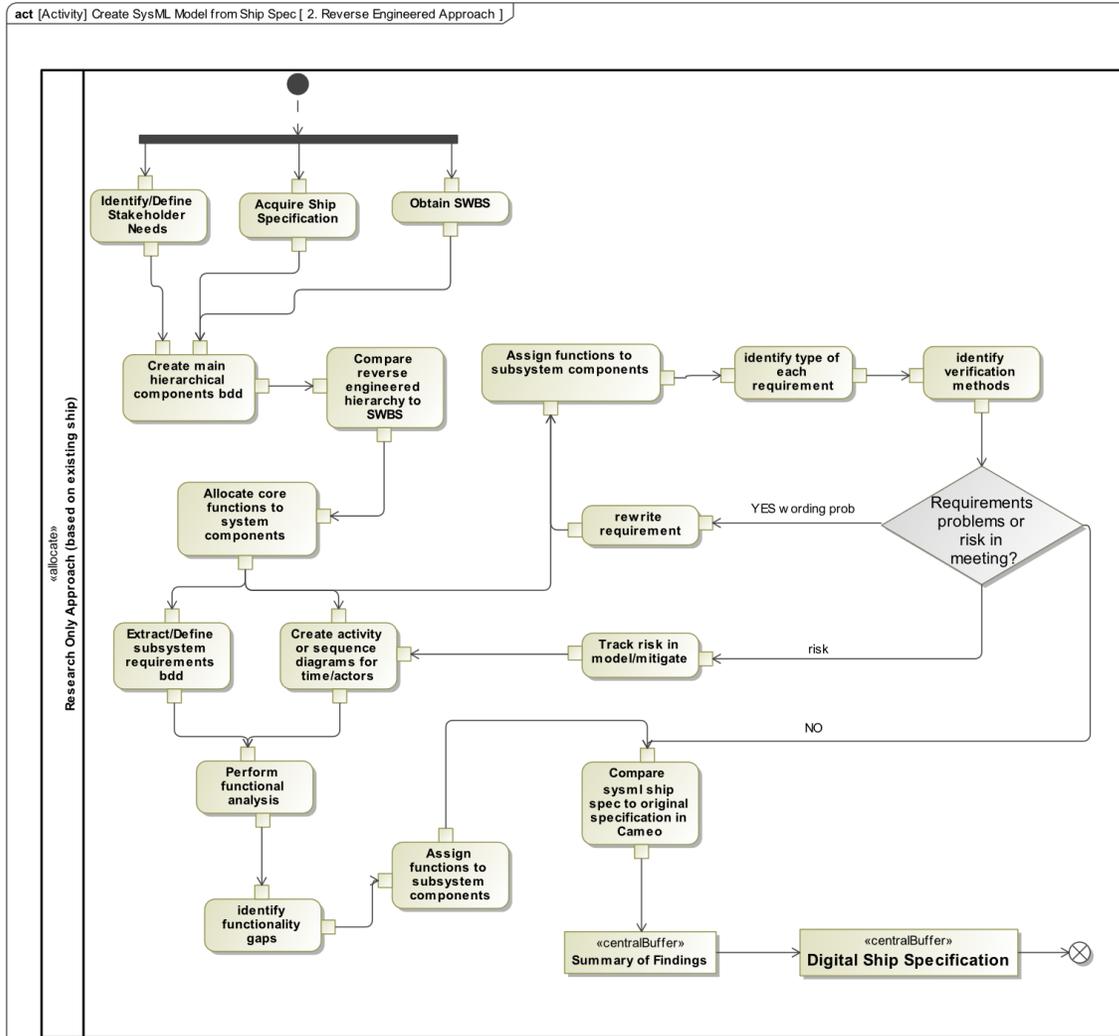
- Reverse-engineer existing ship specification document into digital MBSE model architecture
  - Comparison to original spec for requirements and functional analysis, risk
- Deltas examined, reported
- Digital specification traced to requirements is end product

III. Integrated Methods Approach

- Begins with legacy ship design Parent Specification (a similar spec)
- Reverse engineered Method + Hybrid of MBSE
- Integrates legacy ship design artifacts with MBSE-driven architecture
- Digital specification traced to requirements is end product

III. MBSE-only Digital Approach

- Not reliant on legacy ship design Parent Specification
- Focused on MBSE principles, digital traceability, and architecture-driven decision-making
- Digital specification traced to requirements is end product

III. Requirements Allocation to Approaches

From the 3 Use Case approaches, activities (functions) and requirements were developed

This table shows the overlap of the activities performed in each approach

#	Allocation	Name	△ satisfies
1	⊓ MBSE-only Digital Approach	Allocate core functions to system components	32 Allocate functions to components
2	⊓ Integrated (DE+ Legacy) Ship Design Method ⊓ MBSE-only Digital Approach	assign functions to subsystem components	32 Allocate functions to components
3	⊓ Research Only Approach (based on existing ship)	compare reverse engineered hierarchy to SWBS	34 Architecture analysis
4	⊓ Integrated (DE+ Legacy) Ship Design Method ⊓ MBSE-only Digital Approach	Assign constraints to subsystem components	33 Assign constraints to subsystems
5	⊓ MBSE-only Digital Approach	Create RTVM	29 Create RTVM
6	⊓ MBSE-only Digital Approach	identify type of each requirement	29 Create RTVM
7	⊓ MBSE-only Digital Approach	identify verification methods	29 Create RTVM 28 Identify requirement risk
8	⊓ Integrated (DE+ Legacy) Ship Design Method	Identify/Define Stakeholder Needs	9 Create Stakeholder Needs
9	⊓ MBSE-only Digital Approach	Extract/Define subsystem requirements bdd	11 Create Subsystem Functional Requirements
10	⊓ Integrated (DE+ Legacy) Ship Design Method ⊓ MBSE-only Digital Approach	Ensure performance attribute of lower level functions	36 Define parametric attributes
11	⊓ MBSE-only Digital Approach	Create activity or sequence diagrams for time/actors	35 Define physical architecture
12	⊓ MBSE-only Digital Approach	determine physical components	35 Define physical architecture
13	⊓ Integrated (DE+ Legacy) Ship Design Method	Obtain SDM manual, etc	22 Define system level requirements 21 Obtain Ship Design Manual
14	⊓ MBSE-only Digital Approach	Create main hierarchical components bdd	24 Extract main hierarchical components 12 Create System Architecture
15	⊓ MBSE-only Digital Approach	If risk in meeting req, assign handling method	28 Identify requirement risk
16	⊓ MBSE-only Digital Approach ⊓ Research Only Approach (based on existing ship)	identify risks or problems of requirements	28 Identify requirement risk
17	⊓ MBSE-only Digital Approach ⊓ Research Only Approach (based on existing ship)	Track in risk register	28 Identify requirement risk
18	⊓ MBSE-only Digital Approach	identify interface risks	17 Identify system interfaces
19	⊓ Integrated (DE+ Legacy) Ship Design Method ⊓ MBSE-only Digital Approach	obtain performance spec	21 Obtain Ship Design Manual
20	⊓ Integrated (DE+ Legacy) Ship Design Method ⊓ MBSE-only Digital Approach ⊓ Research Only	Obtain SWBS	8 Obtain Ship Work Breakdown Structure (SWBS)

IV. Future Work

- Integrating set-based design (SBD) with an MBSE model to evaluate design trade space in specification development
    - Set-Based Design (**SBD**) explores a wide range of design alternatives and selects the best solution based on a set of predefined criteria. SBD is increasingly being used to improve quality and responsiveness in U.S. naval ship design projects
    - Uses metachain queries, report wizards and traceability/compliance matrices to help map stakeholder needs to knowledge gaps and trade space analyses

V. Conclusion

- MBSE in shipbuilding specification development helps satisfy the DoN DE Initiative:
  - 3 use cases outline varying levels of MBSE involvement
  - MBSE specification development is customizable based on size of SE/MBSE team, funding, etc.
  - Can integrate MBSE with existing ship specification creation methods for a balanced approach