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Remote & Autonomous System of Systems

A SYSTEMS ENGINEERING PERSPECTIVE

09/06/2022

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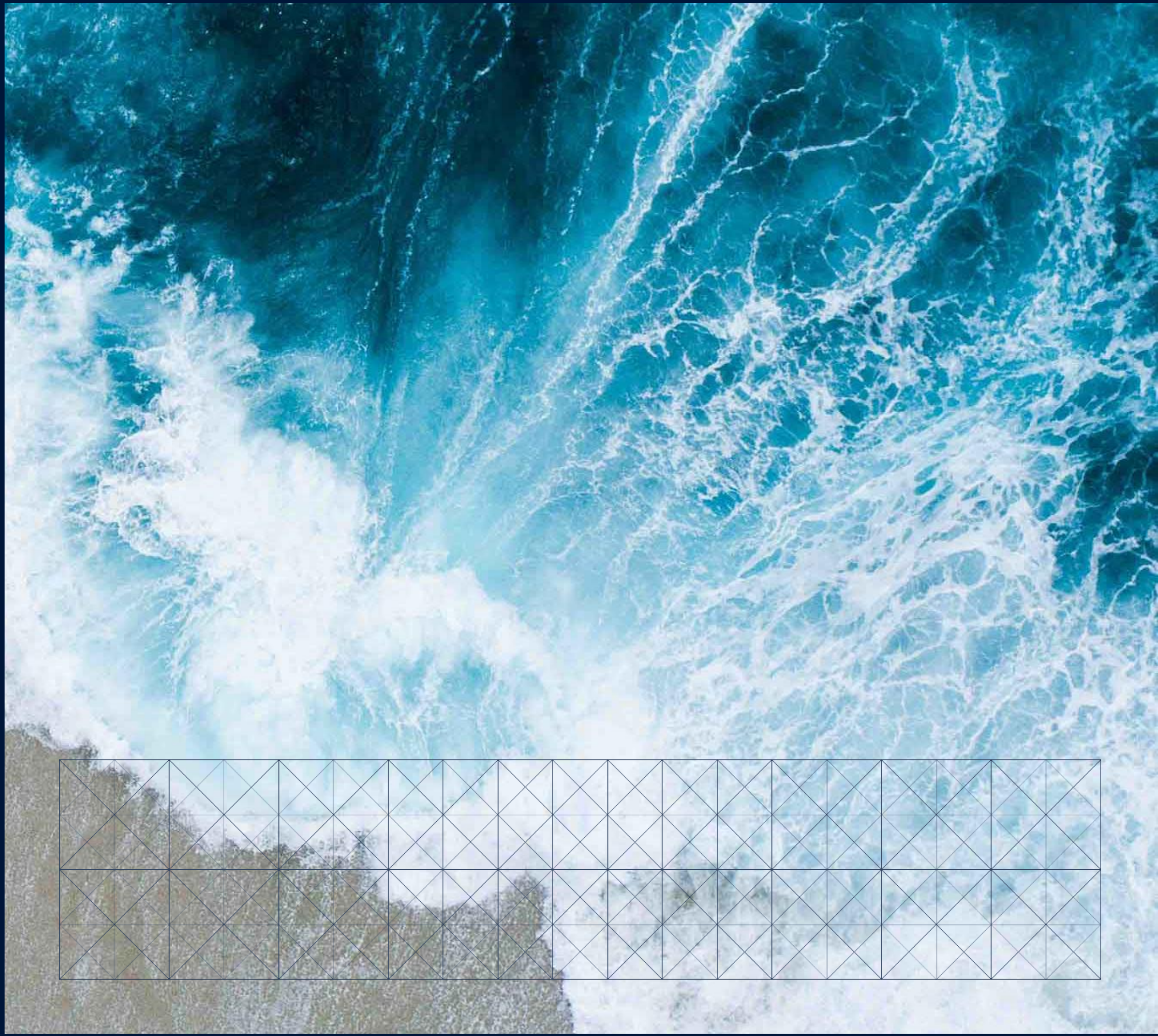
Next Generation Shipping
Integrated Solutions



<u>Definition:</u>

*“Systems Engineering is a **transdisciplinary** and **integrative** approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.”*

(The International Council of Systems Engineering (INCOSE)

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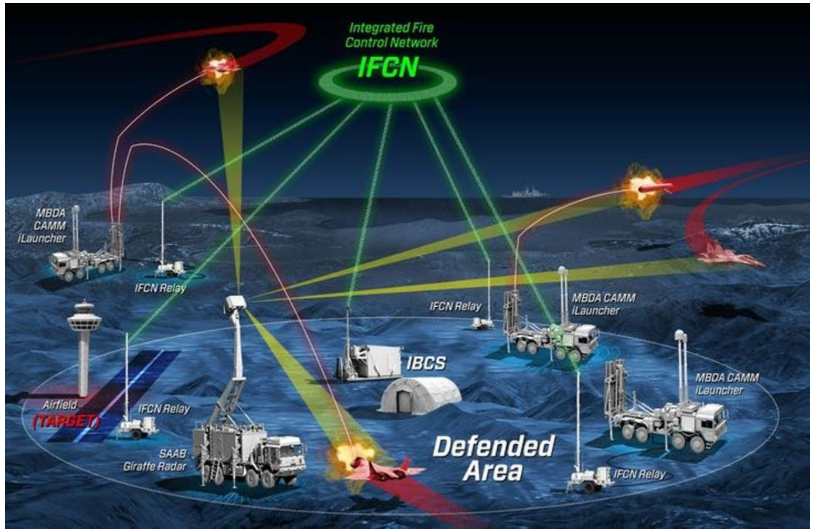
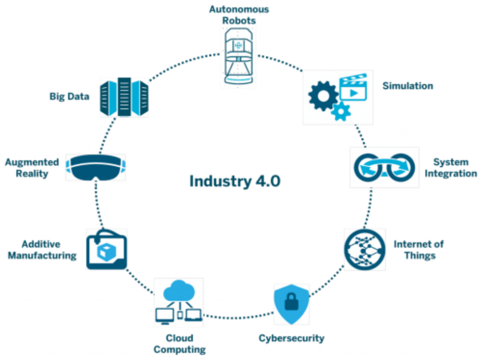
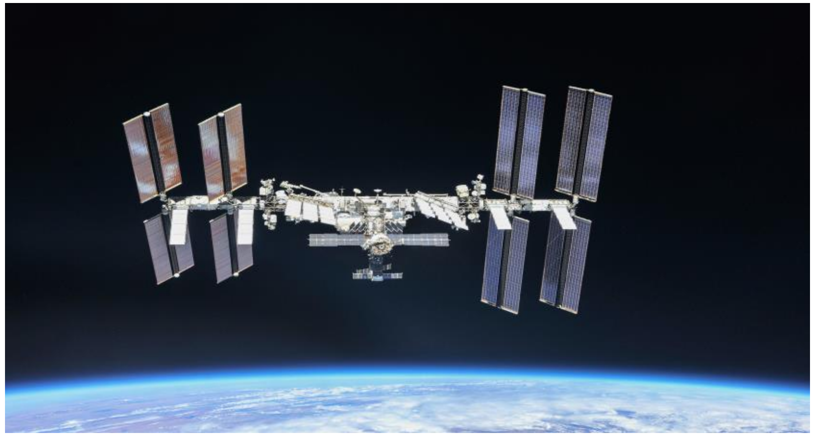
Systems Engineering Entering other Industries

Required to Manage Complexity







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Complexity in Systems

- Advances in technology have led to larger, more complex systems, which implies:
  - A need for a clear concise way to express the system design (clear, logically consistent semantics.)
  - A need for larger, distributed teams
  - A need to model emergent behavior
  - A need for systems engineering tools to enable collaboration across the entire lifecycle.
- Shift in customer needs in maritime industry
  - Products -> Integrated Solutions
- Shift in industry roles
  - Original Equipment Manufacturer -> System Integrator

1950s Era TV

2020 Smart TV

Complexity has been identified by many as a critical problem facing system engineers.

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Introduction

Educational Background Systems Engineering

- MSc from Marine Systems Design at NTNU
  - Master's thesis on Autonomous Systems Design
- Professional Certificate from MIT
  - Architecture and Systems Engineering: Models and Methods to Manage Complex Systems
- Ongoing ASEP Certification Process with International Council of Systems Engineering (INCOSE)
  - ISO/IEC/IEEE 15288:2015 - Systems and software engineering — System life cycle processes

Professional Experience Systems Engineering

- MBSE, systems architecture, design and requirements scoped for the Kongsberg Maritime Remote & Autonomous portfolio of projects/programs

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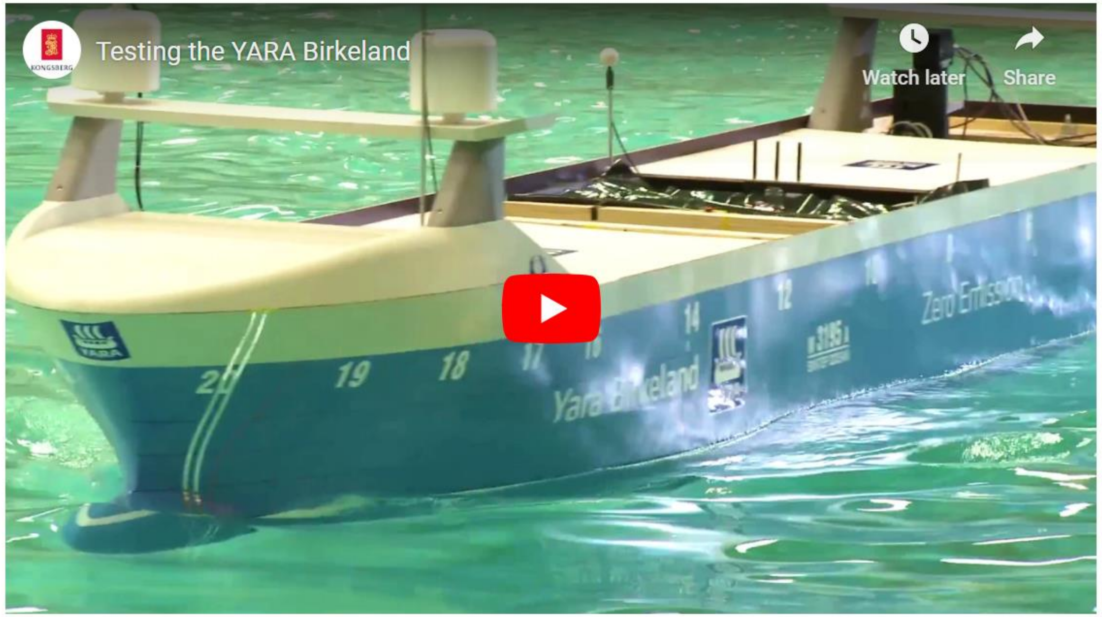
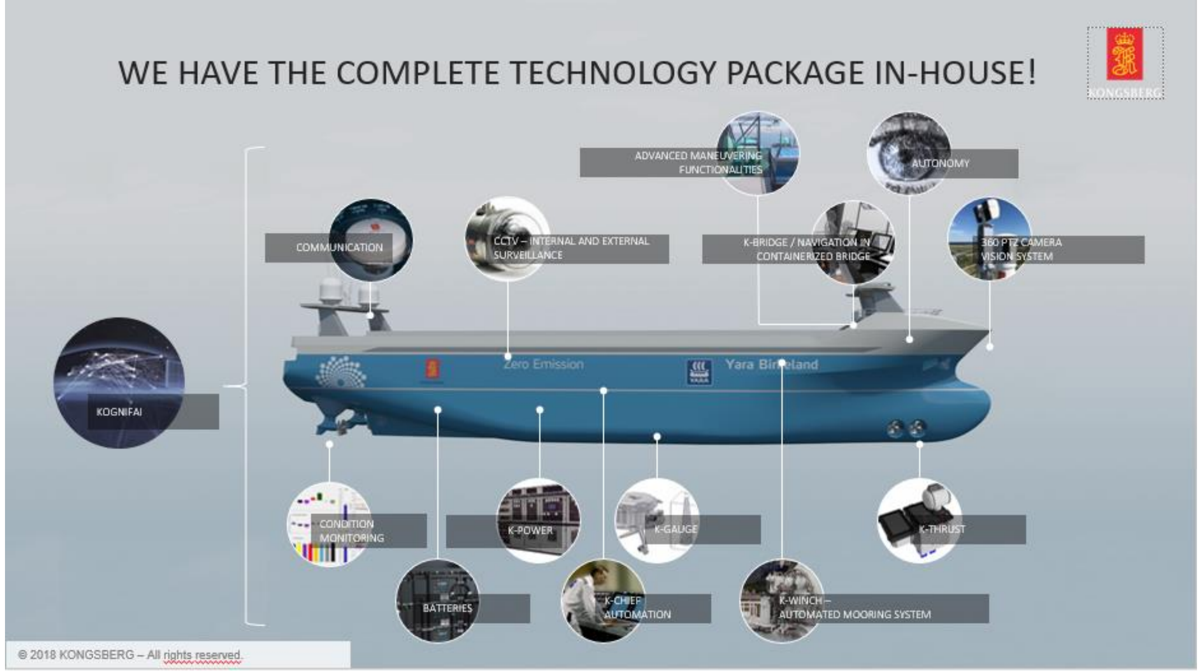
29 sep 2017

The Integration Conundrum

Evolving Understanding of Complexity

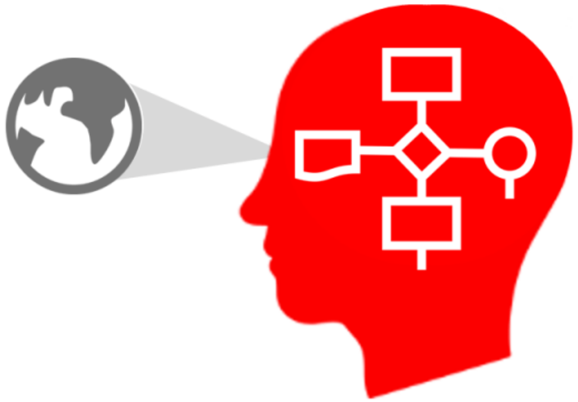




As announced May 9th 2017, Yara and KONGSBERG have partnered to build the world's first autonomous and fully electric container vessel. "Yara Birkeland", named after Yara's founder Kristian Birkeland, will enable a reduction of 40,000 road journey's from Yara's Porsgrunn fertiliser plant in southern Norway to the ports of Brevik and Larvik, significantly reducing local NOx and CO2 emissions produced by haulage trucks. The vessel will be delivered and begin first tests and operations early 2019, and conduct fully autonomous operations in 2020.

Mental Model

- The mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states.



"All models are wrong, but some are useful“ G. Box

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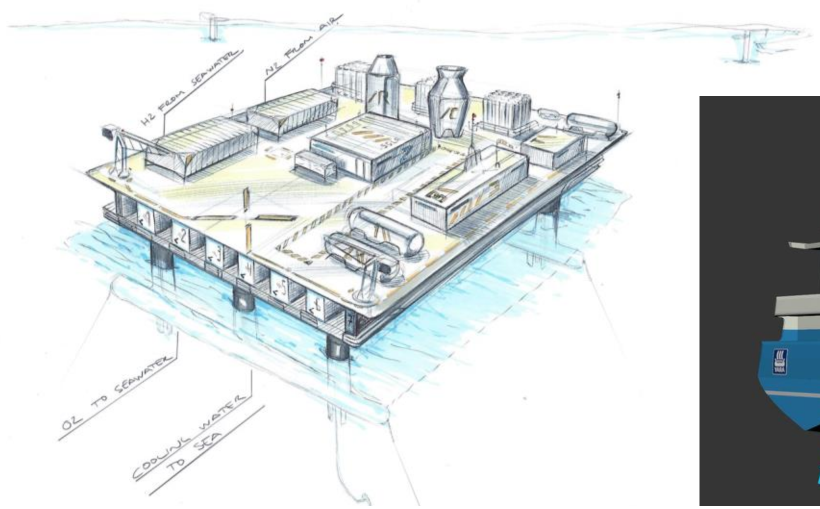
Shared Mental Model

System Concept

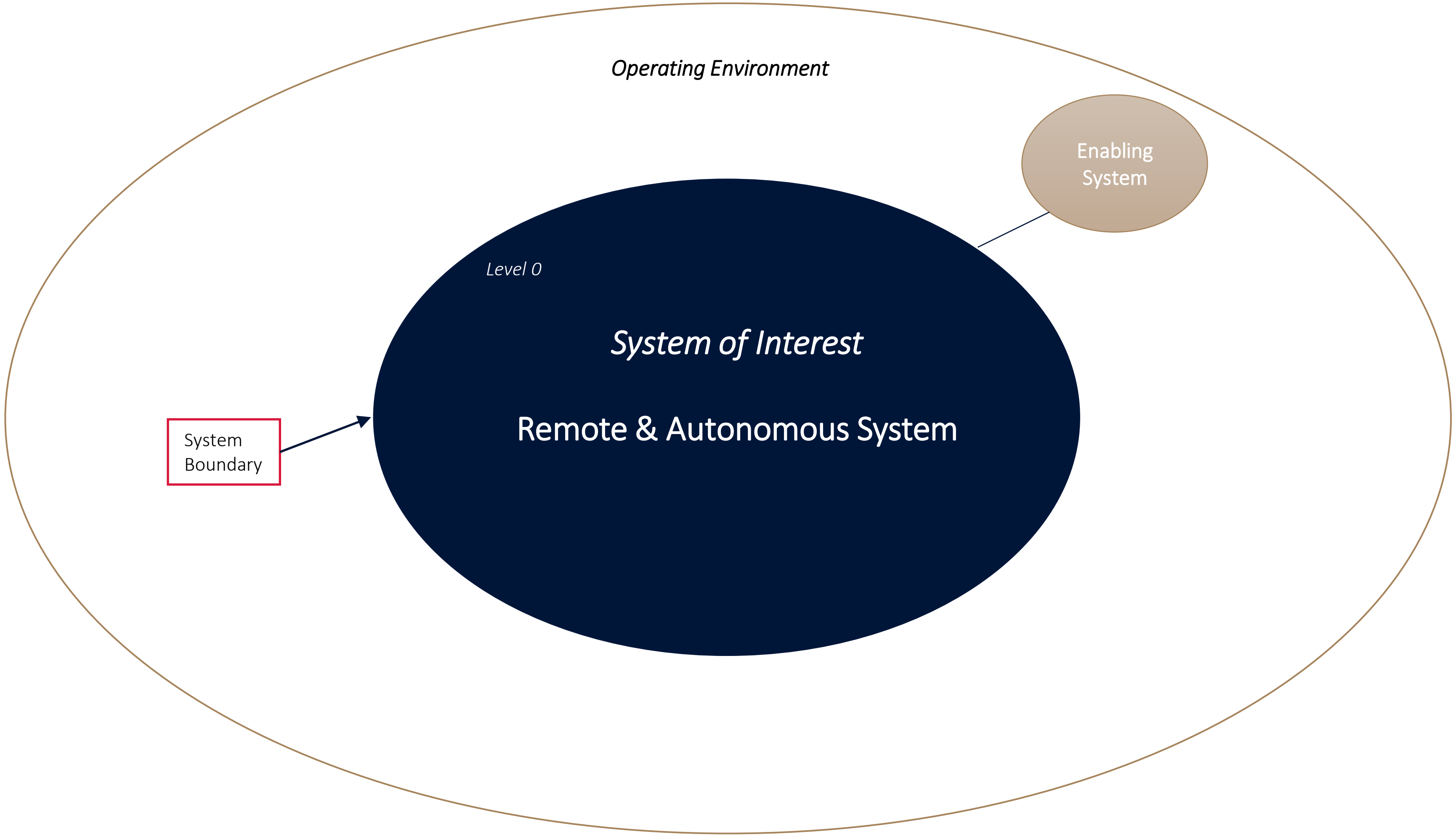


Need to express system concept behavior and facilitate communication

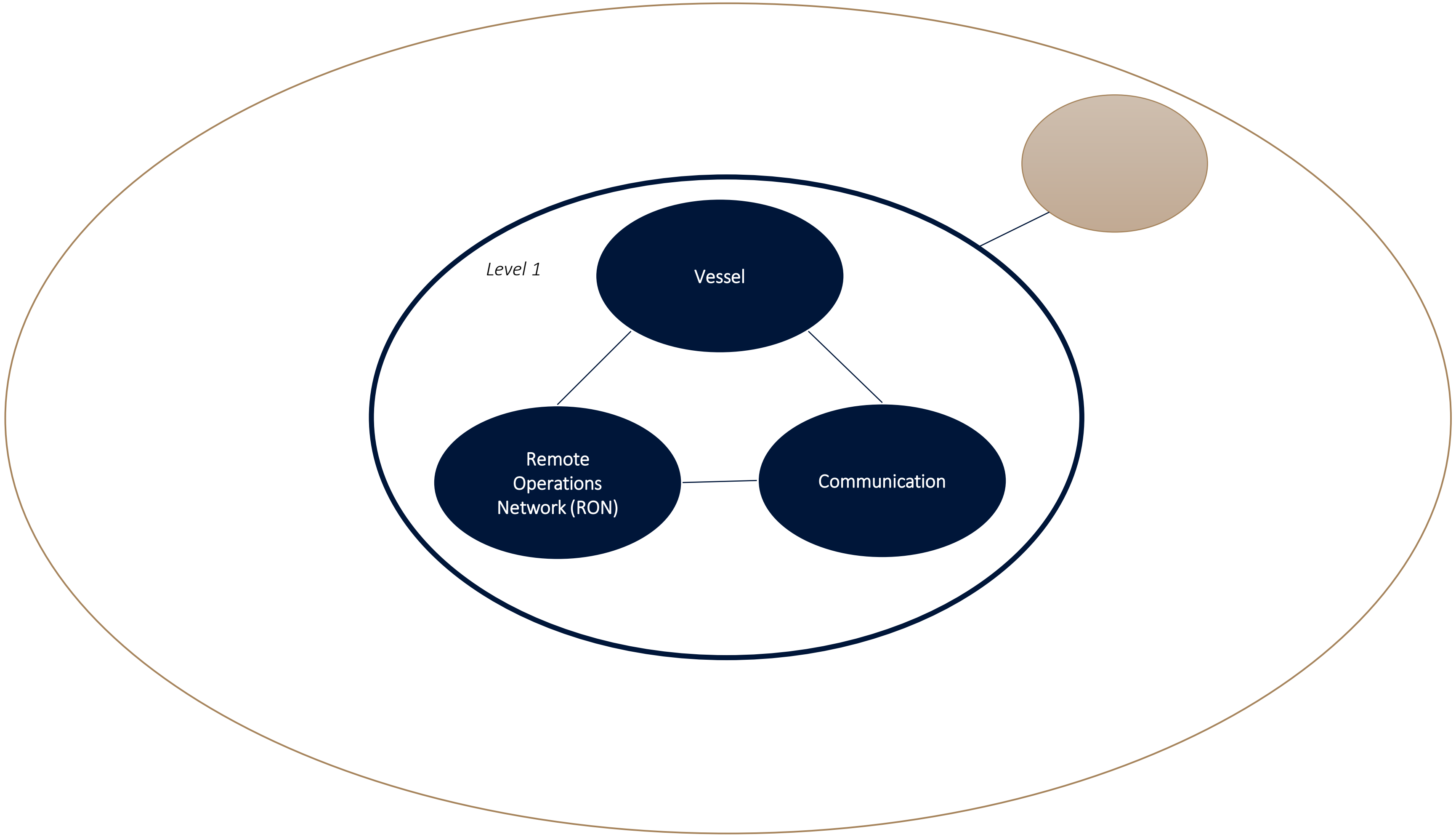
Shared Mental Model

System Concept

Systems Thinking



System of Systems



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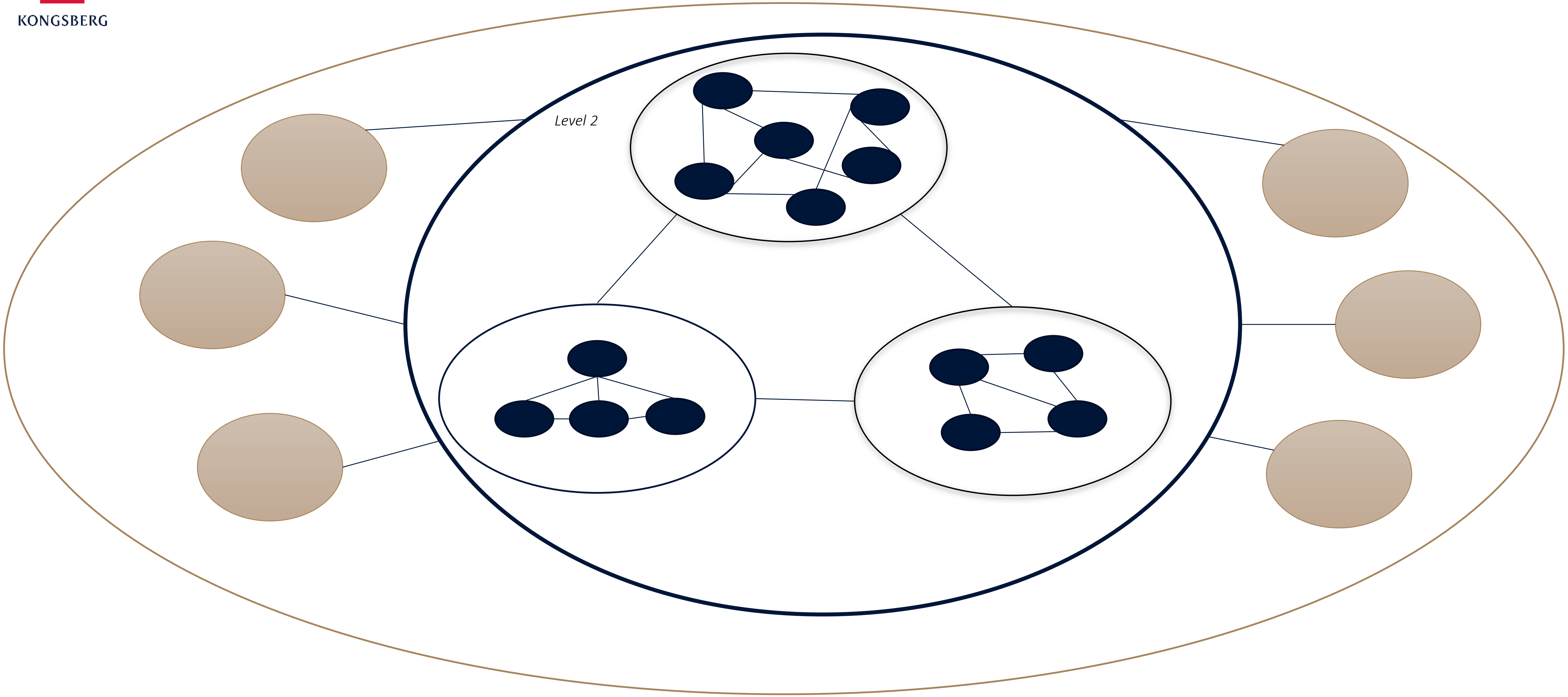
Complex System of Systems



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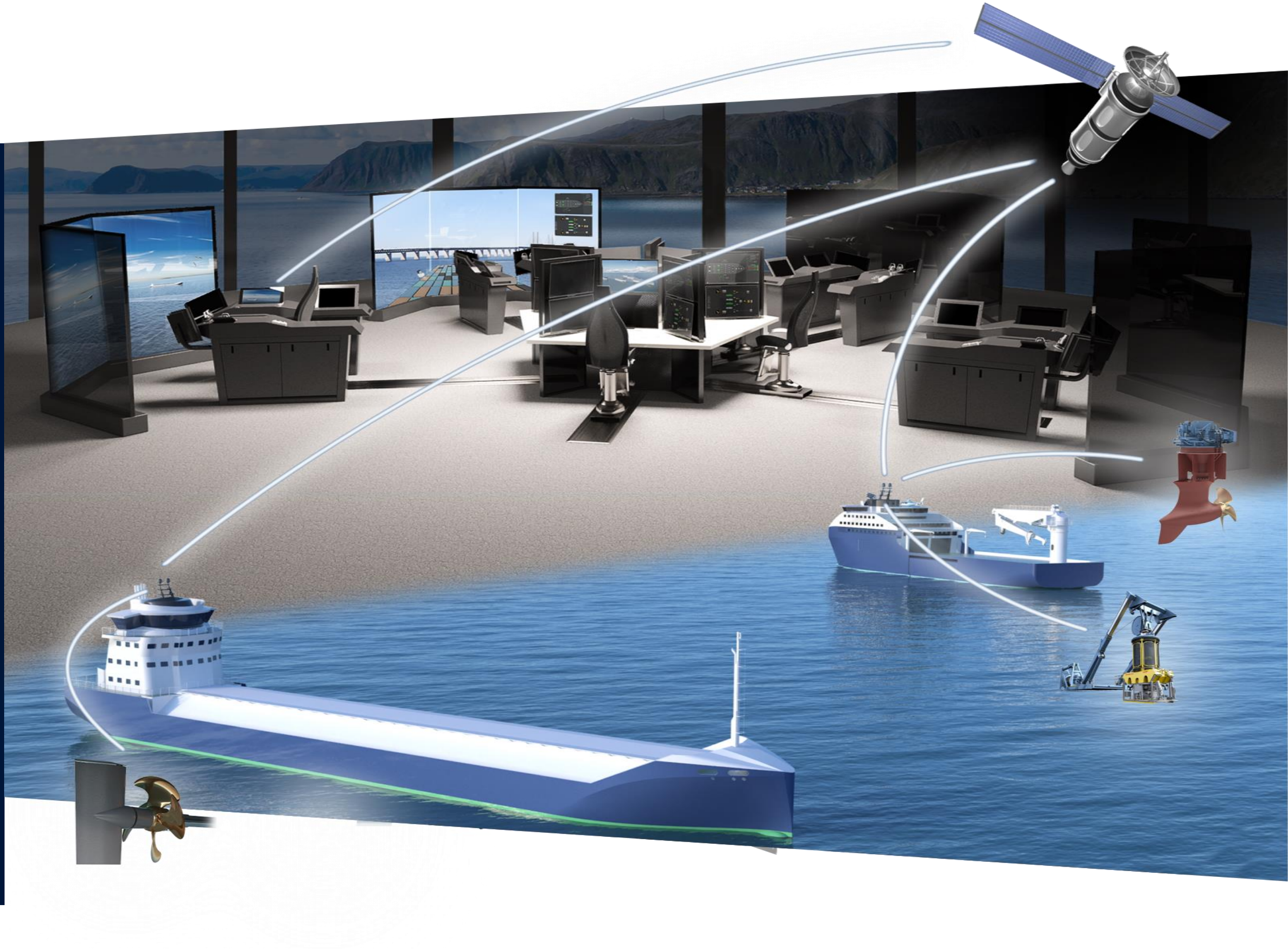
Manage Complexity

- What information do we need to define for Remote & Autonomous Systems?
- How do we structure the information?
- How do we manage the information efficiently?

Introduction to R&A Architecture



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Defining R&A Architecture

Systems Thinking Principles

Table 1. A Set of Systems Principles. (SEBoK Original)

Name	Statement of Principle
Abstraction	A focus on essential characteristics is important in problem solving because it allows problem solvers to ignore the nonessential, thus simplifying the problem (Sci-Tech Encyclopedia 2009; SearchCIO 2012; Pearce 2012).
Boundary	A boundary or membrane separates the system from the external world. It serves to concentrate interactions inside the system while allowing exchange with external systems (Hoagland, Dodson, and Mauck 2001).
Change	Change is necessary for growth and adaptation, and should be accepted and planned for as part of the natural order of things rather than something to be ignored, avoided, or prohibited (Bertalanffy 1968; Hybertson 2009).
Dualism	Recognize dualities and consider how they are, or can be, harmonized in the context of a larger whole (Hybertson 2009).
Encapsulation	Hide internal parts and their interactions from the external environment (Klerer 1993; IEEE 1990).
Equifinality	In open systems, the same final state may be reached from different initial conditions and in different ways (Bertalanffy 1968). This principle can be exploited, especially in systems of purposeful agents.
Holism	A system should be considered as a single entity, a whole, not just as a set of parts (Ackoff 1979; Klir 2001).
Interaction	The properties, capabilities, and behavior of a system are derived from its parts, from interactions between those parts, and from interactions with other systems (Hitchins 2009 p. 60).
Layer Hierarchy	The evolution of complex systems is facilitated by their hierarchical structure (including stable intermediate forms) and the understanding of complex systems is facilitated by their hierarchical description (Pattee 1973; Bertalanffy 1968; Simon 1996).
Leverage	Achieve maximum leverage (Hybertson 2009). Because of the power versus generality tradeoff, leverage can be achieved by a complete solution (power) for a narrow class of problems, or by a partial solution for a broad class of problems (generality).
Modularity	Unrelated parts of the system should be separated, and related parts of the system should be grouped together (Griswold 1995; Wikipedia 2012a).
Network	The network is a fundamental topology for systems that forms the basis of togetherness, connection, and dynamic interaction of parts that yield the behavior of complex systems (Lawson 2010; Martin et al. 2004; Sillitto 2010).
Parsimony	One should choose the simplest explanation of a phenomenon, the one that requires the fewest assumptions (Cybernetics 2012). This applies not only to choosing a design, but also to operations and requirements.
Regularity	Systems science should find and capture regularities in systems, because those regularities promote systems understanding and facilitate systems practice (Bertalanffy 1968).
Relations	A system is characterized by its relations: the interconnections between the elements. Feedback is a type of relation. The set of relations defines the network of the system (Odum 1994).
Separation of Concerns	A larger problem is more effectively solved when decomposed into a set of smaller problems or concerns (Erl 2012; Greer 2008).
Similarity/Difference	Both the similarities and differences in systems should be recognized and accepted for what they are (Bertalanffy 1975 p. 75; Hybertson 2009). Avoid forcing one size fits all, and avoid treating everything as entirely unique.
Stability/Change	Things change at different rates, and entities or concepts at the stable end of the spectrum can and should be used to provide a guiding context for rapidly changing entities at the volatile end of the spectrum (Hybertson 2009). The study of complex adaptive systems can give guidance to system behavior and design in changing environments (Holland 1992).
Synthesis	Systems can be created by “choosing (conceiving, designing, selecting) the right parts, bringing them together to interact in the right way, and in orchestrating those interactions to create requisite properties of the whole, such that it performs with optimum effectiveness in its operational environment, so solving the problem that prompted its creation” (Hitchins 2009: 120).
View	Multiple views, each based on a system aspect or concern, are essential to understand a complex system or problem situation. One critical view is how concern relates to properties of the whole (Edson 2008; Hybertson 2009).

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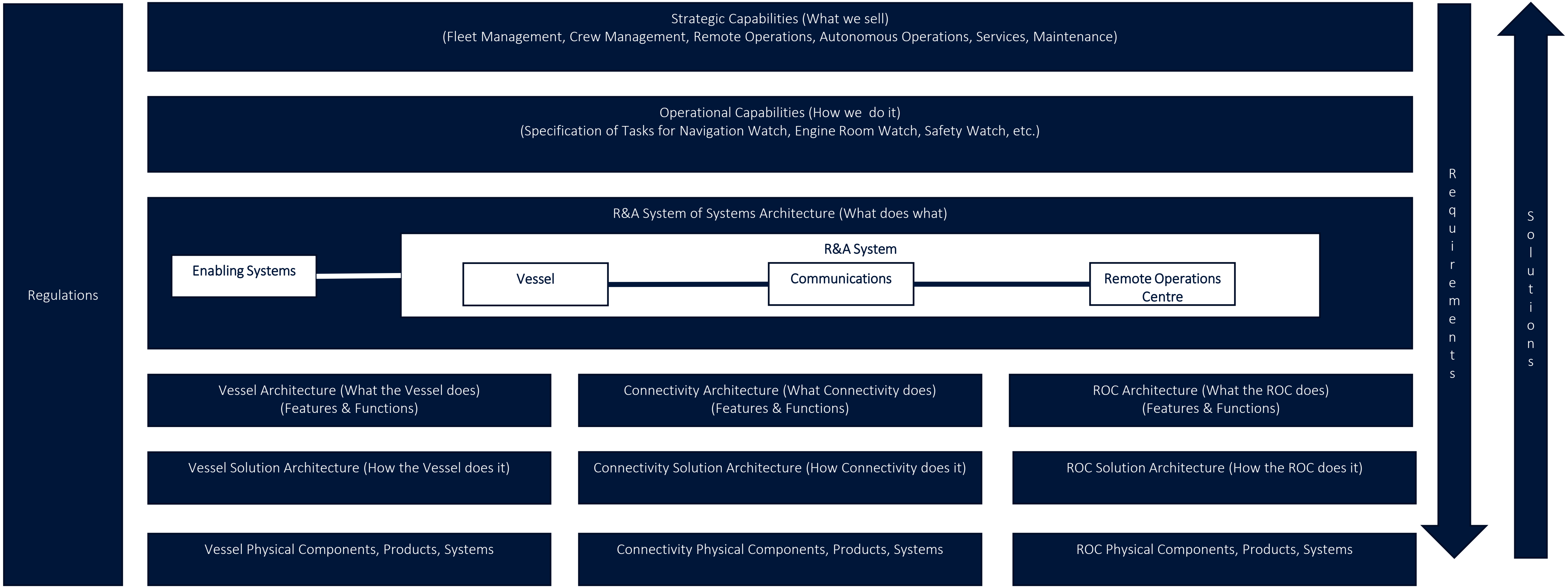
The Big Picture

Enterprise Framework



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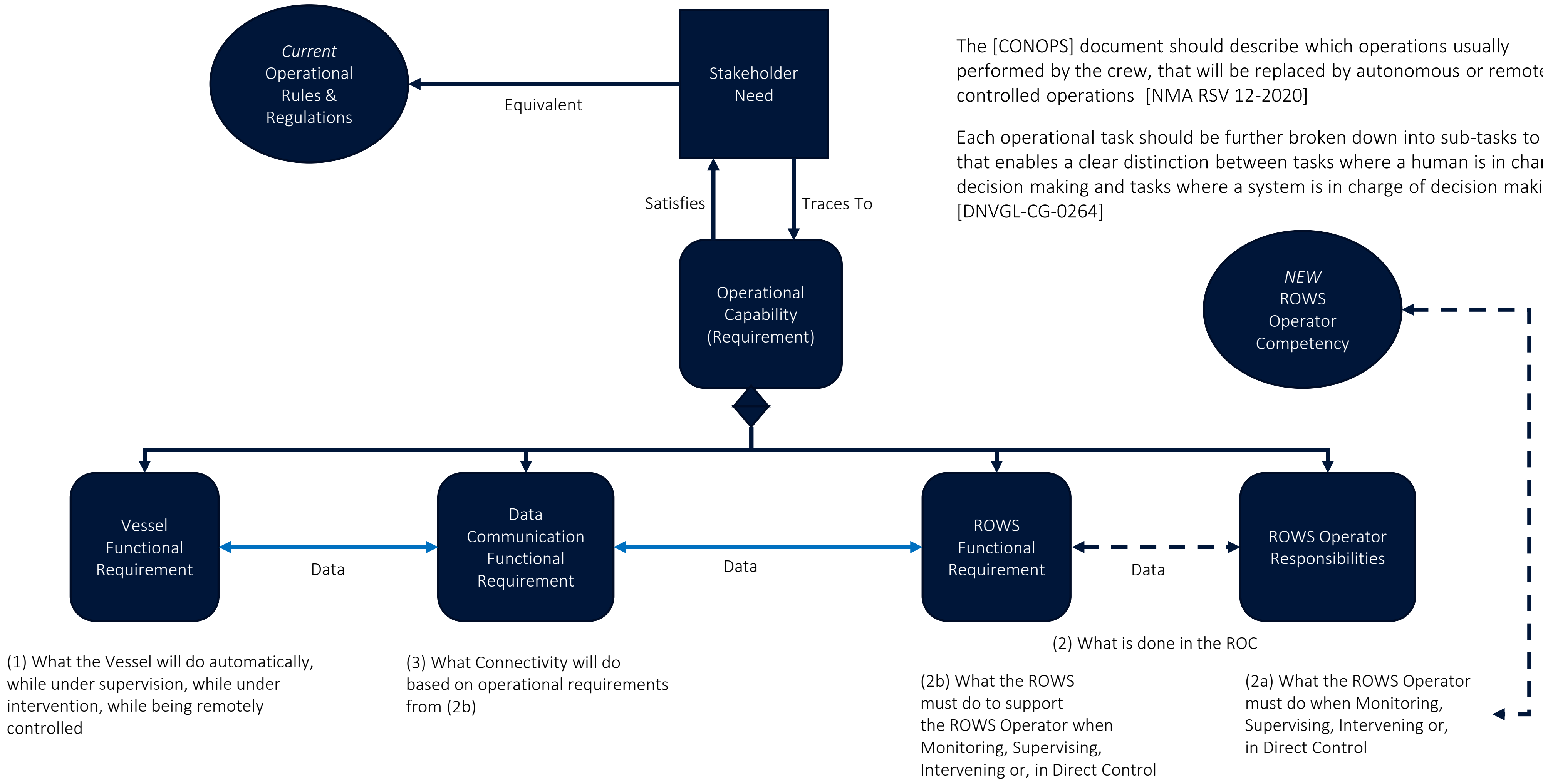
«equivalent or better…»

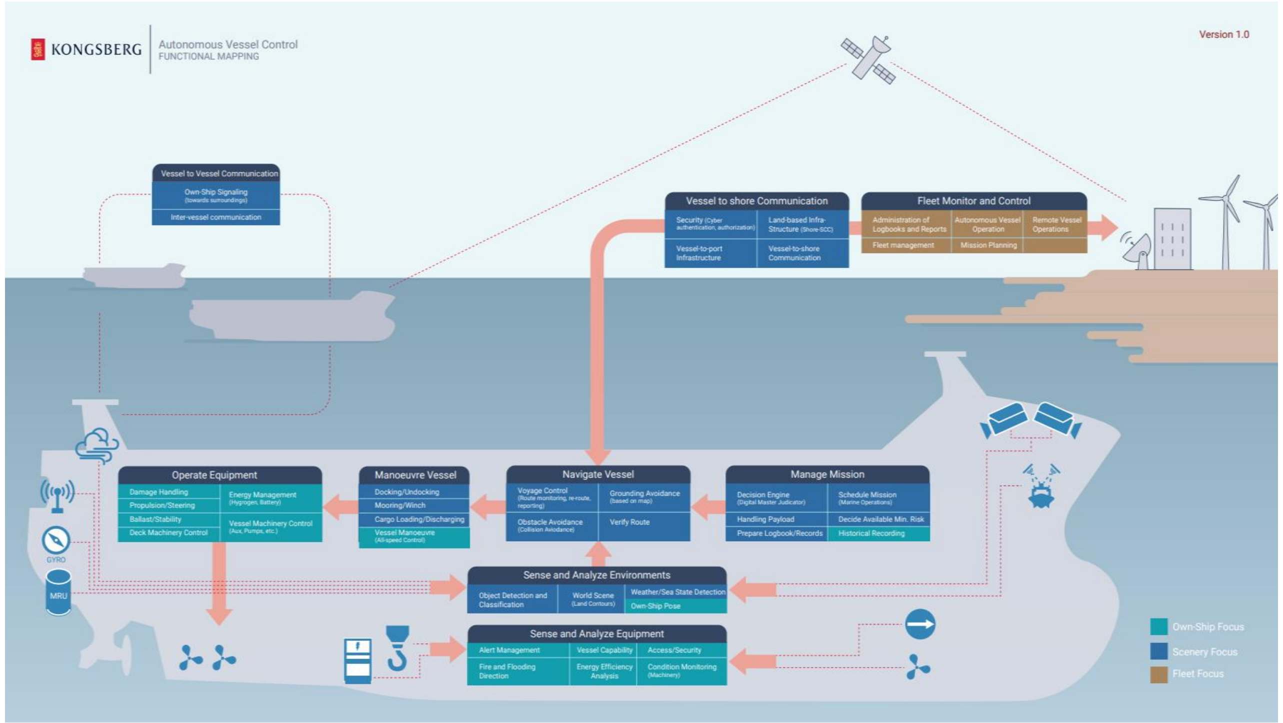
The [CONOPS] document should describe which operations usually performed by the crew, that will be replaced by autonomous or remotely controlled operations [NMA RSV 12-2020]

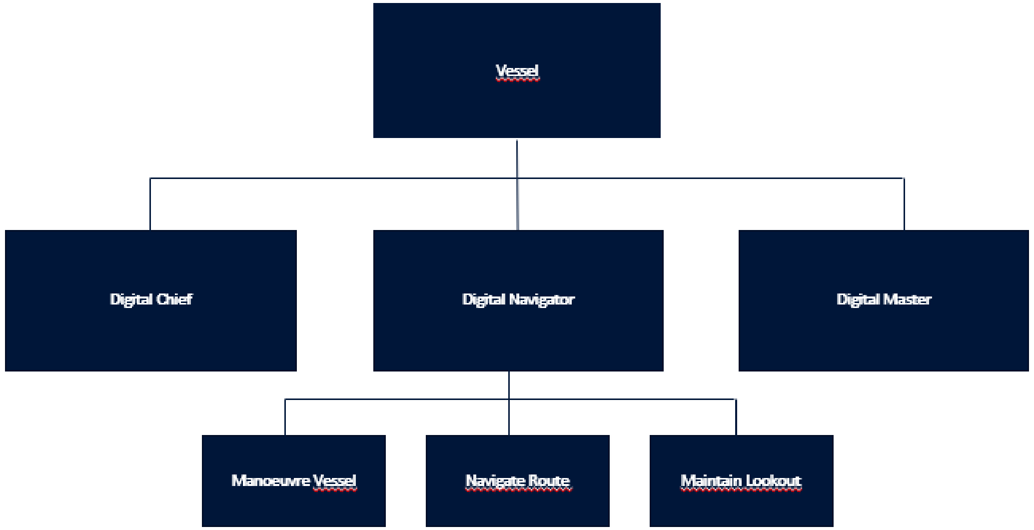
Each operational task should be further broken down into sub-tasks to a level that enables a clear distinction between tasks where a human is in charge of decision making and tasks where a system is in charge of decision making. [DNVGL-CG-0264]



Role-based Architecture

Logical Decomposition Around Operational Roles





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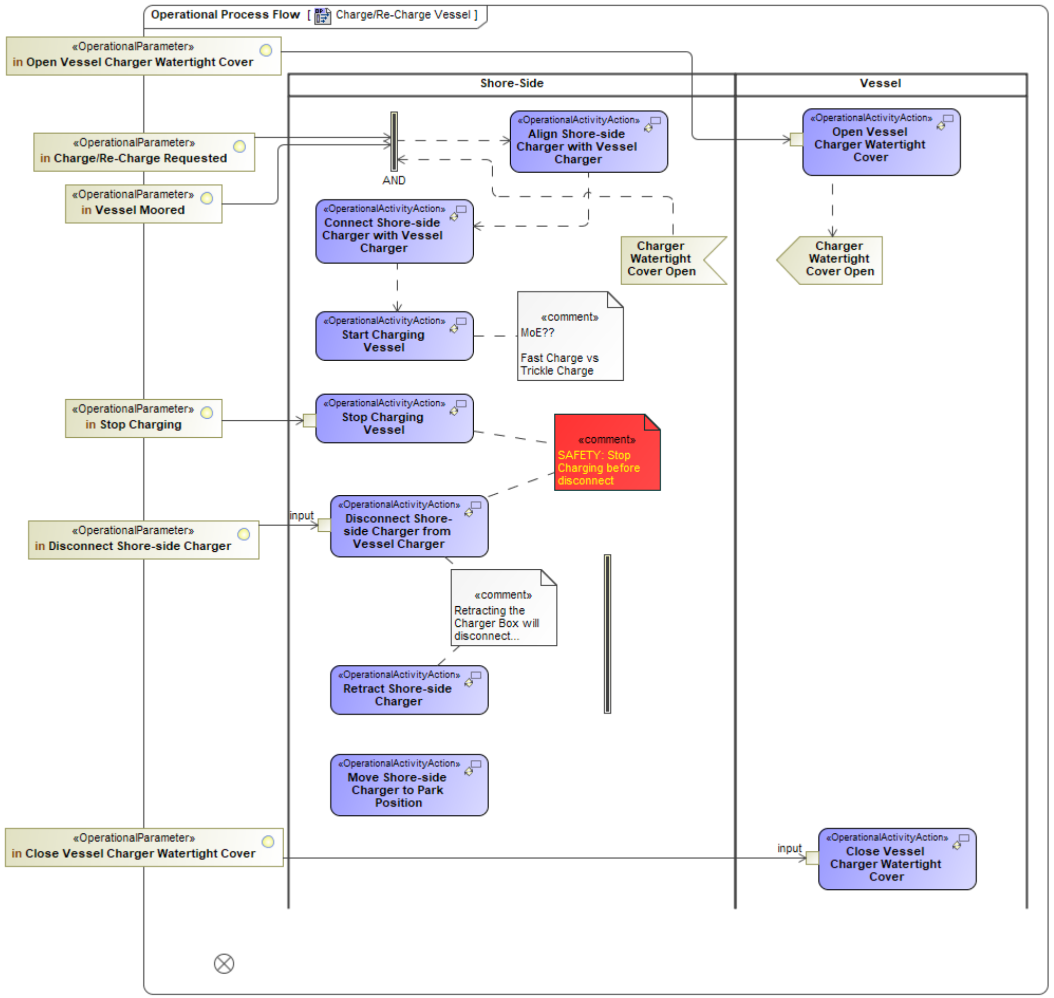
Operational Capabilities

Coordinated through Operational Activities – Allocated to human and/or machine

- Operational Capabilities
  - Perform Pre-mission Checks
  - Perform Post-mission Checks
  - Manage Health
  - Manage Mission
  - Manage MASS Operations
  - Execute Fallback State
  - Control Transfer
  - Manoeuvre Vessel
  - Load Vessel
  - Unload Vessel
  - Operate Equipment
  - Charge/Recharge Vessel
  - Maintain Lookout
  - Navigate Route
  - Communicate
  - Manage Emergency



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R&A Levels of Control

Dynamically Changed during Operation

- Vessel Control Level (VCL)
  - Automatic Execution
    The Vessel Domain determines its own solution and executes the function to achieve the solution without any human intervention.
  - Automatic Conditional Execution
    The Vessel Domain finds one or multiple solutions for the vessel function and request confirmation from the operator to execute the solution.
  - Under Intervention
    The values of properties, parameters or the configuration of a vessel function can be modified by an operator
  - (Directly Controlled)
    The behaviour of the Digital Chief or Operate Equipment domains are influenced by an operator

- Operator Control Level (OCL)
  - Monitoring
    An operator is provided with a read only view of characteristics related to the vessel function.
  - Supervising
    In addition to Monitoring, an operator can approve/disapprove solutions [this may include multiple alternatives] for a vessel function made by the complementary Vessel Domain.
  - Intervening
    In addition to Supervising, an operator can modify the values of properties, parameters or, the configuration related to the complementary vessel function
  - (Direct Control)
    In addition to Intervening, an operator can directly influence the behaviour of all vessel equipment within scope of the Digital Chief domain

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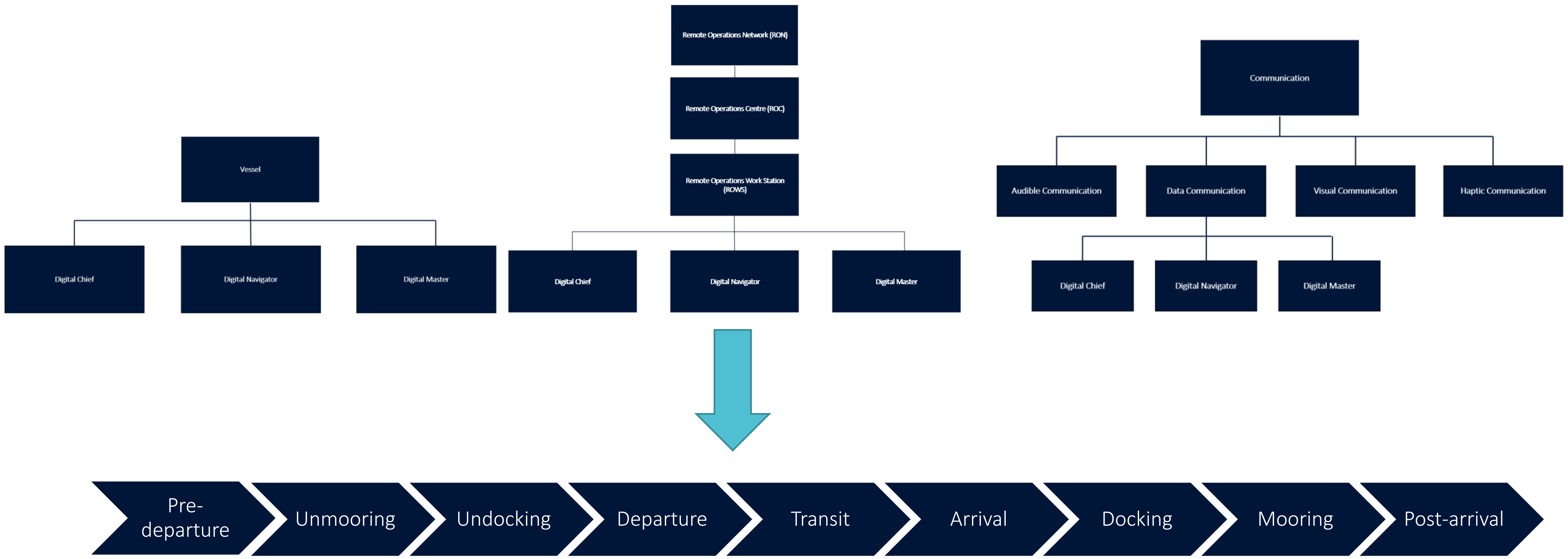
Operational Phases

Decomposition of Operations



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Operational Phases

Reuseable Across R&A Projects

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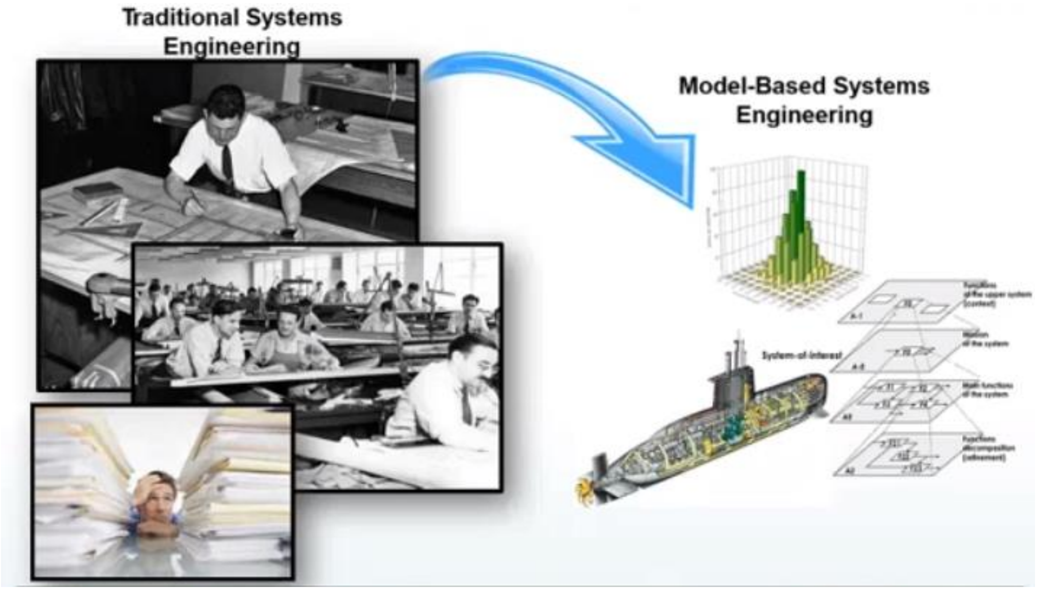
Model-Based Systems Engineering

Key Concepts and Benefits

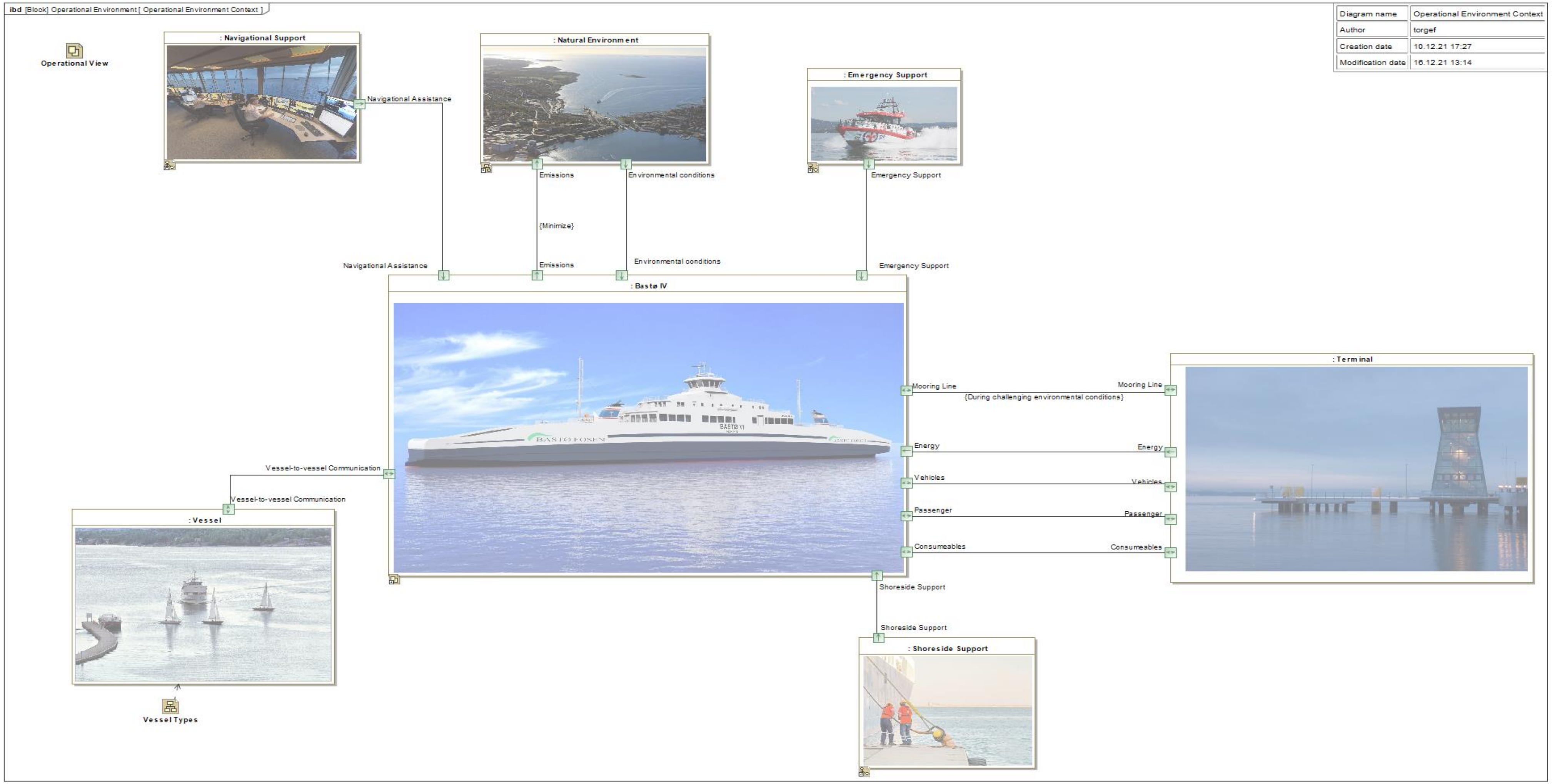
- Single source of truth
- Traceability
- Domain-specific Viewpoints
- Auto-generated documentation
- Maintainable
- Scalable



Aim: Consistent and standardised specification with managed variation for **all** R&A Systems

Context Diagram: Operational Environment & Enabling Systems

SysML used to express Systems Thinking Principles



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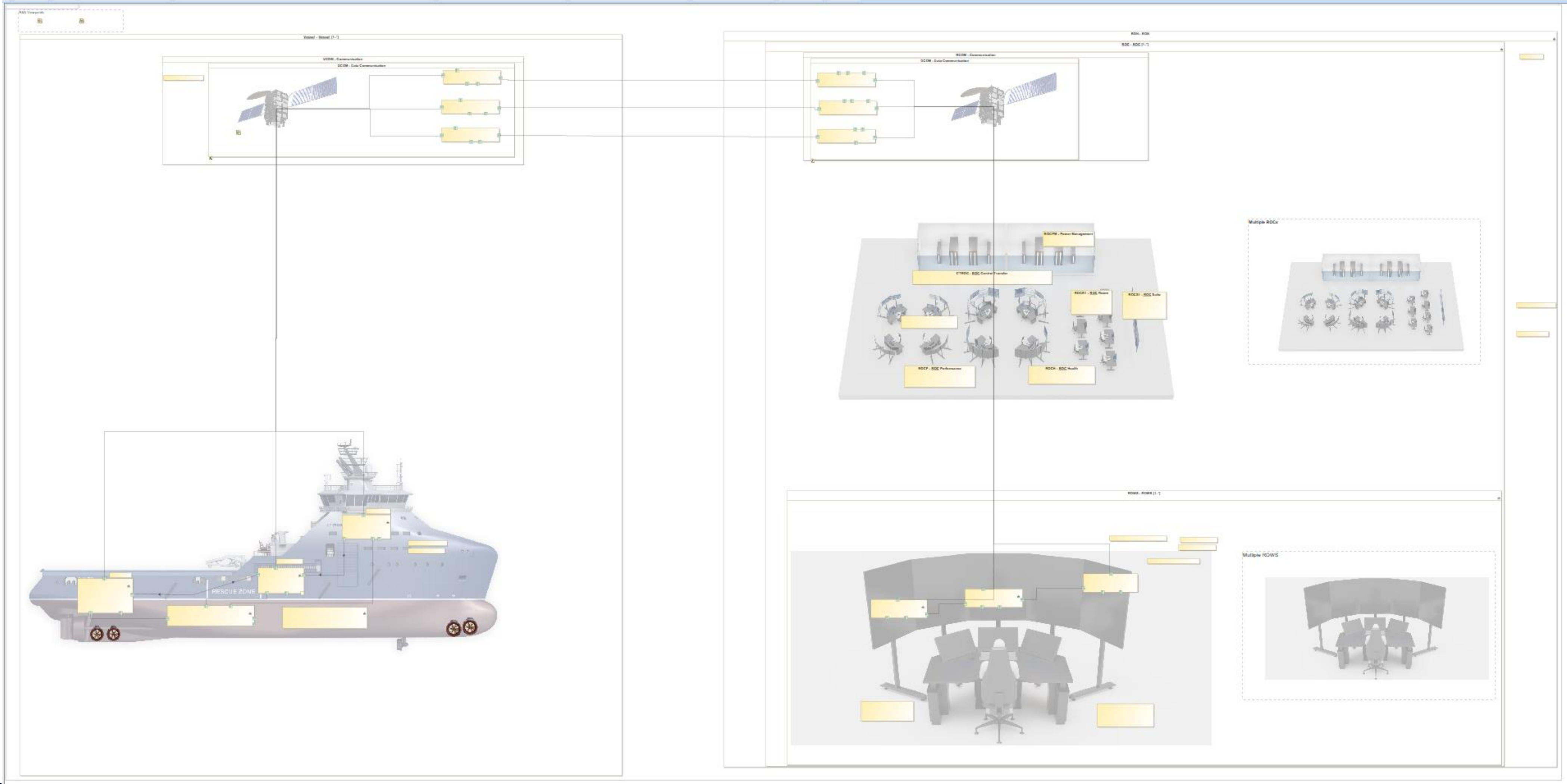
Example: R&A System of Systems

Semantic Relationships Between Systems



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