NYK approach for autonomous ship – current status and way forward –

12th November 2020

Capt. Satoru Kuwahara (Japan Marine Science Inc.)

Dr. Hideyuki Ando (MTI Co., Ltd)

Capt. Koji Kutsuna (MTI Co., Ltd)

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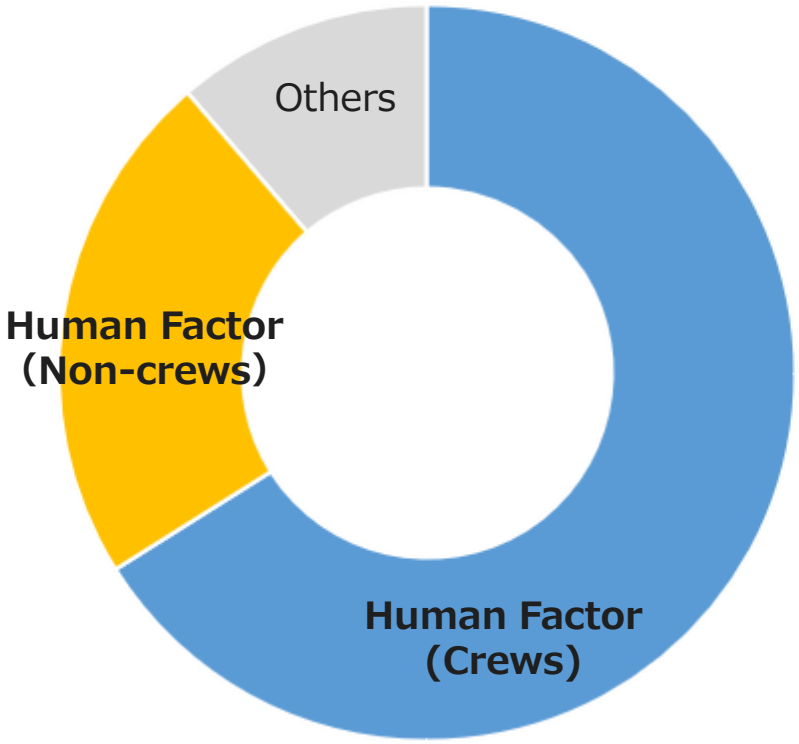
Contribution of autonomous ship (short term)

Cause of navigation incidents



90% of incident causes relate to Human Factor

Gains by automation and high level support

Customer reliability

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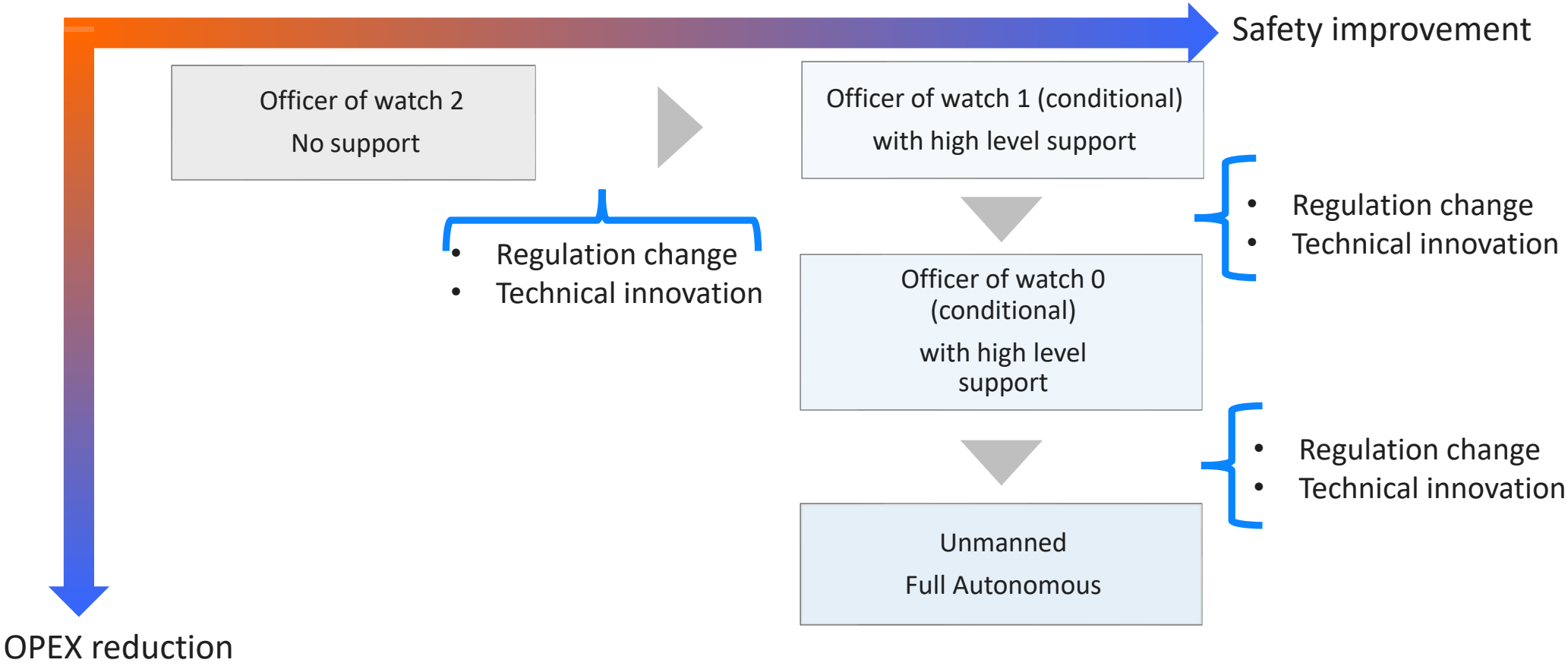
Contribution of autonomous ship (mid & long term)



- **In the meantime, loss reduction and customer reliability are targets**
- **In long run, OPEX reduction can be expected**

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NYK approach for Autonomous Ships

Objective

- Improve safety (reduce the number of accident)
- Reduce workload

What do we need ?

- Advanced support by computer systems (fully utilizing computer power) = Complement human operations
- Additionally, **PPTO** (**P**eople, **P**rocess, **T**echnology and **O**rganization) is important

How to approach ?

- User-centric … Involvement of experienced captains with know-how, skills & experiences to lead technology development process
- Continuous improvement … identify the right issues to solve and improve step-by-step
- Open collaboration with best partners

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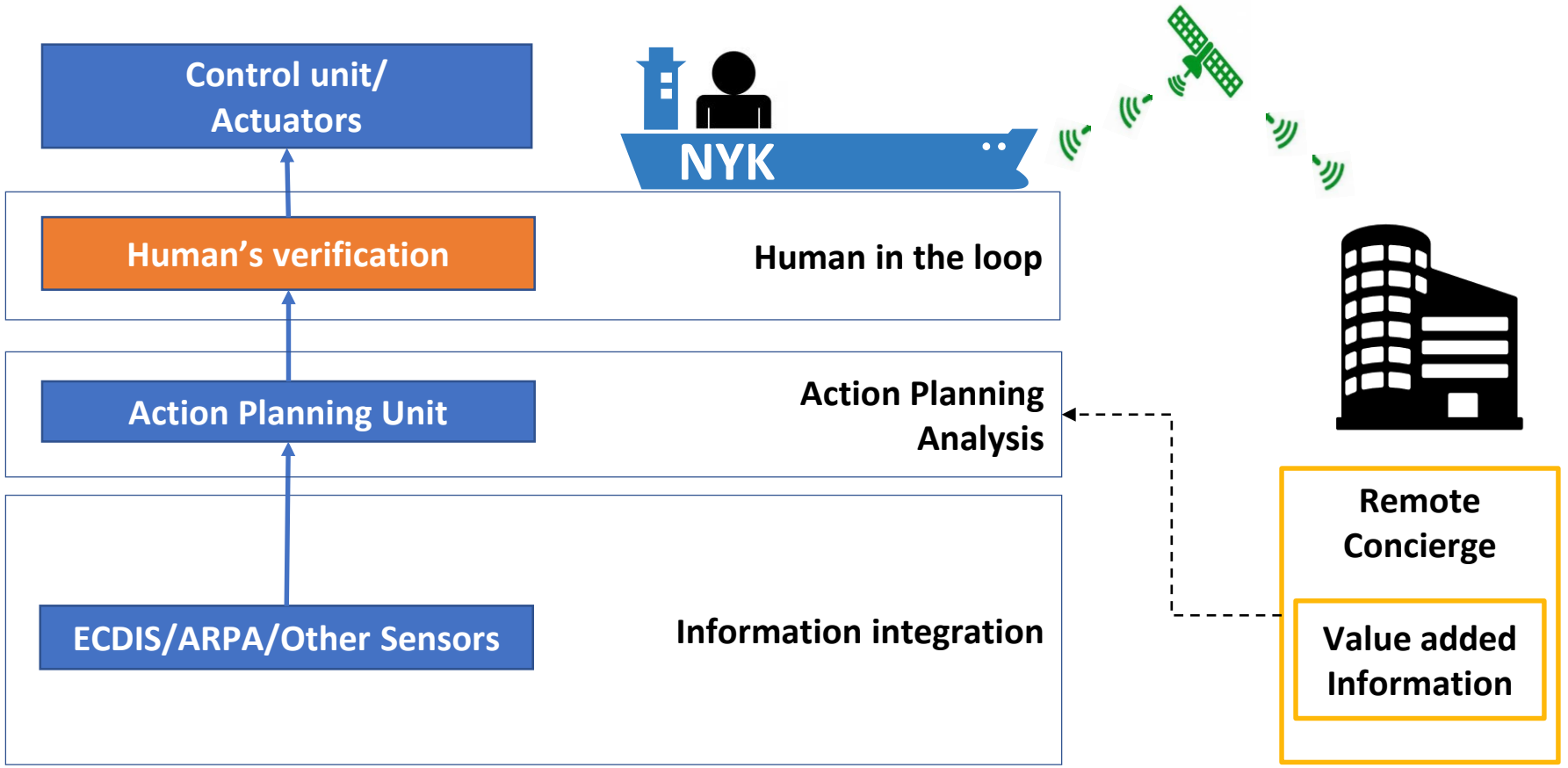
Concept of Action Planning and Execution System (APExS)

- NYK group defines a manned-autonomous system framework as ***Action Planning and Execution System (APExS).***
- We received AiP approval for the concept of APExS from ClassNK in Feb 2020.



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Function of APExS

The APExS targets the decision-making support necessary for seafarers to maneuver vessels and has the following three specific functions.

1. **Anti-collision and anti-aground support:** formulate and present an action plan to prevent collision and aground during voyage. The parameters for the analysis can be different depending on the area (open ocean, coastal area, congested area, or waterway).

2. **Approach support:** formulate and present an action plan for stopping and restarting the boat, e.g., anchoring, berthing, and mooring.

3. **Docking and undocking support:** formulate and present an action plan for docking/undocking including position and attitude adjustment by using various actuators such as main engine, rudder, thruster, and tug's support. This function is the same as the approach support mode for a ship with a docking and undocking capability of its own.

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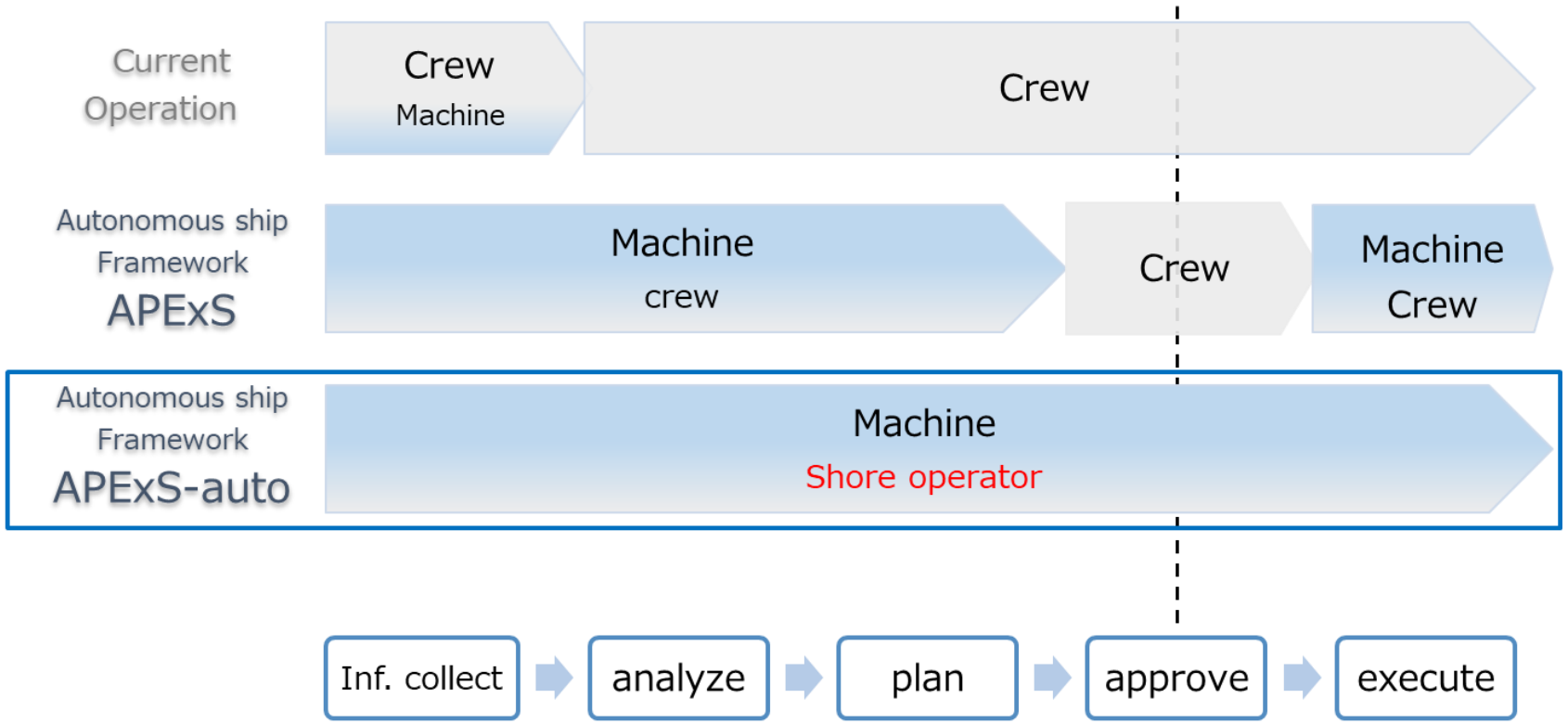
APExS-auto: Autonomous Ship Framework for full autonomous ship

- APExS-auto is the new framework that evolved from APExS
  - Machine carries out a series of navigation tasks, including approval.
  - Remote operators support the machine



- DFFAS project aims to receive AiP for APExS-auto: systematized concept design & procedures are required.

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Design approach : MBSE (Model Based Systems Engineering)

- Autonomous ship is considered as System of Systems (SOS)
  - Each system is huge
  - Each system has a deep hierarchy
  - Each system interacts with another system complicatedly

- Approach: MBSE (Model-Based Systems Engineering)
  - All partners can access and update the common design model
  - All partners use the latest (common) model to develop the system

- MBSE models are frequently described by SysML.
  - SysML: System Modelling Language

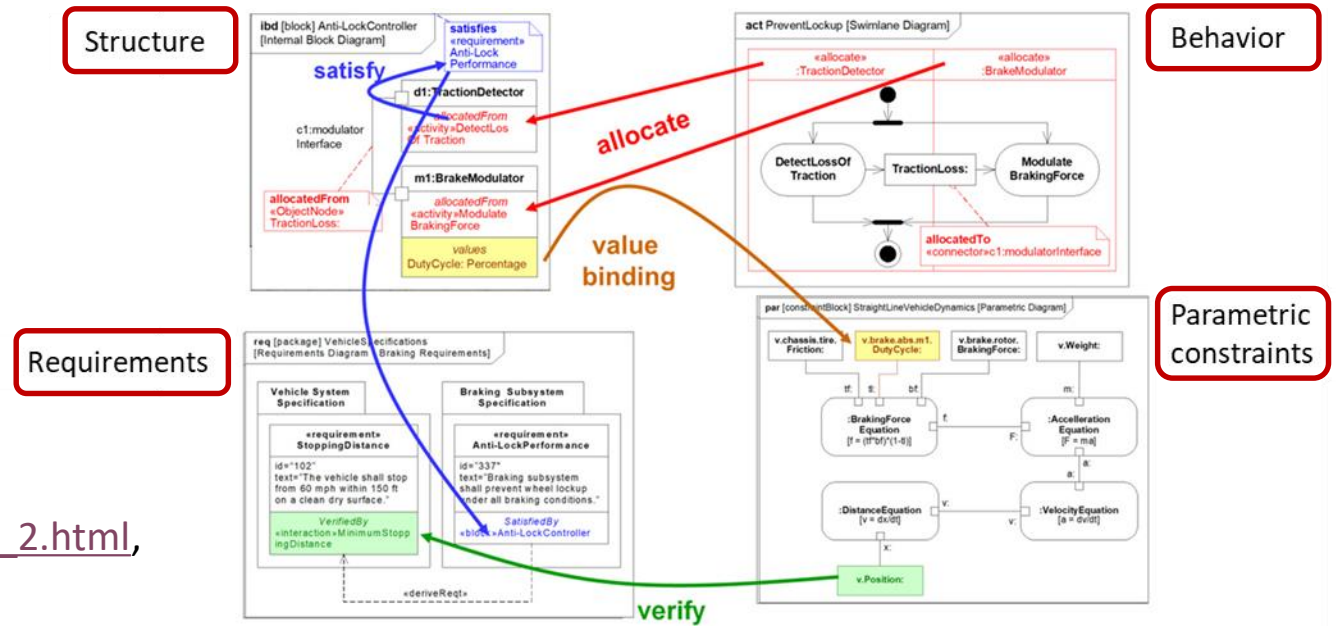

Figure: MBSE components and relations
Reference)
https://techfactory.itmedia.co.jp/tf/articles/1804/13/news002_2.html,
(original in Japanese)

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CONOPS (Concept of Operations)

- CONOPS: Concept of Operations
  - A ConOps is a user-oriented document that describes system characteristics for a proposed system from the user's viewpoint.
  - The ConOps document is used to communicate overall quantitative and qualitative system characteristics to the user, buyer, developer, and other organizational elements (for example, training, facilities, staffing, and maintenance).

  (IEEE Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document)

- CONOPS of DFFAS project, an autonomous ship project in Japan, is composed of:
  - Component: Sub-system structure
    - Maneuvering
    - Propulsion
    - Power Management
    - Communication
    - Fleet Operation Center
    - Central Information Management
  - Philosophy: Double/Single fault redundancy
  - Assumption
  - ODD and MRC model
  - DFFAS system specification
  - Definitions
  - Threshold in operation

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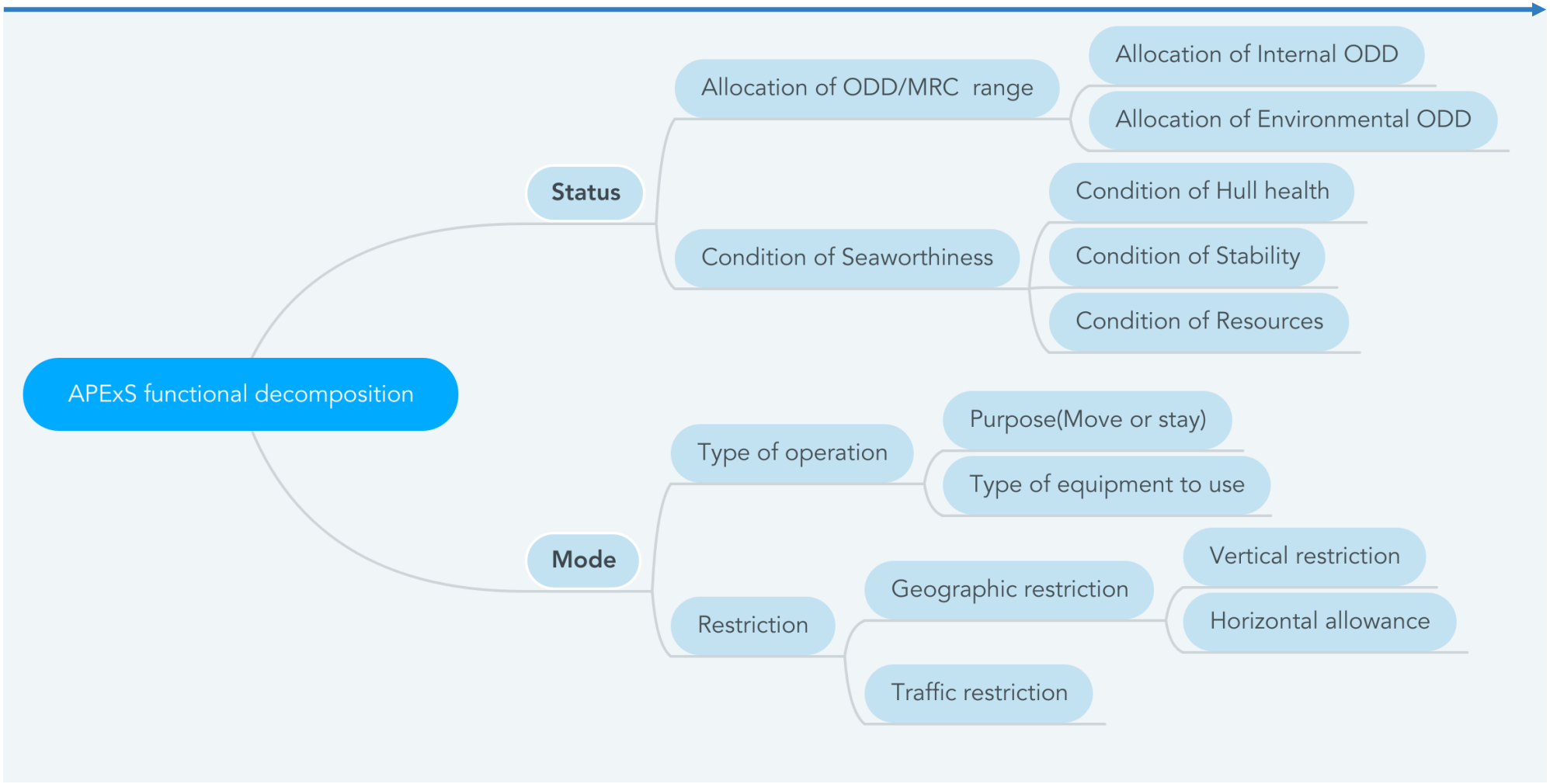
Clarification of system requirements

- To clarify requirements of autonomous ship system as SoS, we use functional layer decomposition approach.

Functional decomposition



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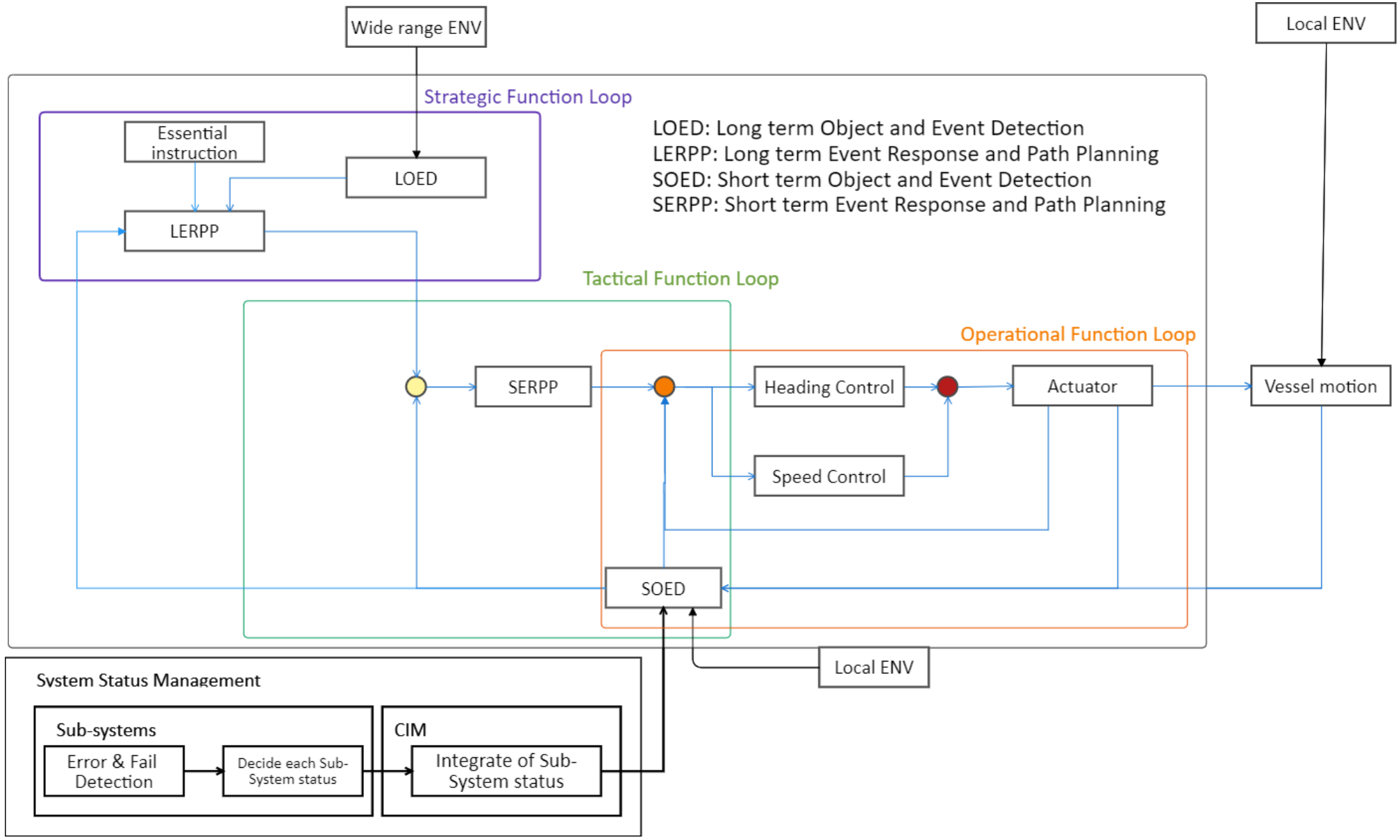
System model



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Operational Design Domain (ODD)

- ODD should consist from Internal ODD and External ODD
  - IODD: ODD which depends on condition of internal factors(Working condition of equipments)
  - EODD: ODD which depends on environmental factors (weather, sea state, etc.)

e.g. EODD representation example - Station Capability of Dynamic Positioning System wind envelope:

wind direction & speed
in which the vessel can
keep position and heading

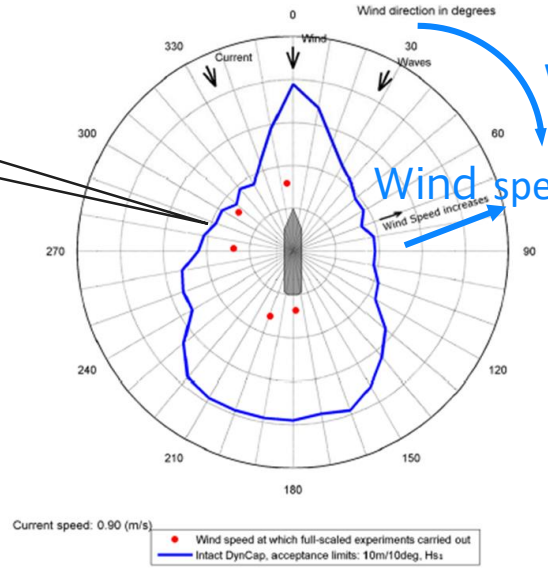

Figure 9: DynCap wind envelope for the design condition, comparison between experiments and simulations

Reference)
DynCap –
Full scale validation of a vessel's station-keeping capability analysis
Øyvind Smogeli, Dong Trong Nguyen, Kristoffer Eide, Luca Pivano, DYNAMIC POSITIONING CONFERENCE, October 13-14, 2015

- MRC (Minimal Risk Condition): a condition in which the system can change to desired status in case of deviation from ODD (=fallback).
- **MRC is minimal requirement for autonomous system.**

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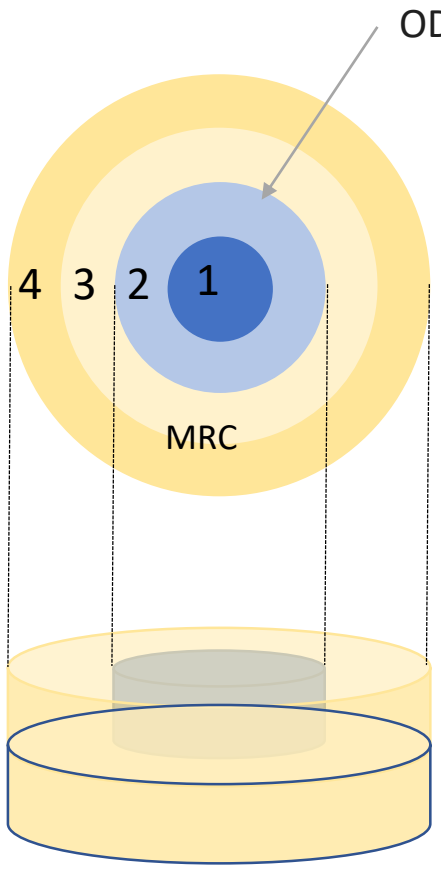
System state and MRC model

- MRC (Minimal Risk Condition)
  - Conditions in which the system can change to desired status in case of deviation from ODD (=fallback).

- System state and MRC model

  e.g. Maneuvering sub-system case
  - System state changes by internal/external conditions
  - System operation is confirmed by:
    - Certified crew @ 2, 3
    - Certified equipment @ 1, 2, 3, 4
    - OOW on duty @ 2, 3
    - Actuator @ 2, 3, 4
    - Hull health @ 1, 2, 3



1. Normal
2. Active monitoring
3. Failed: Remote FB
4. Failed: independent FB

Outside MRC

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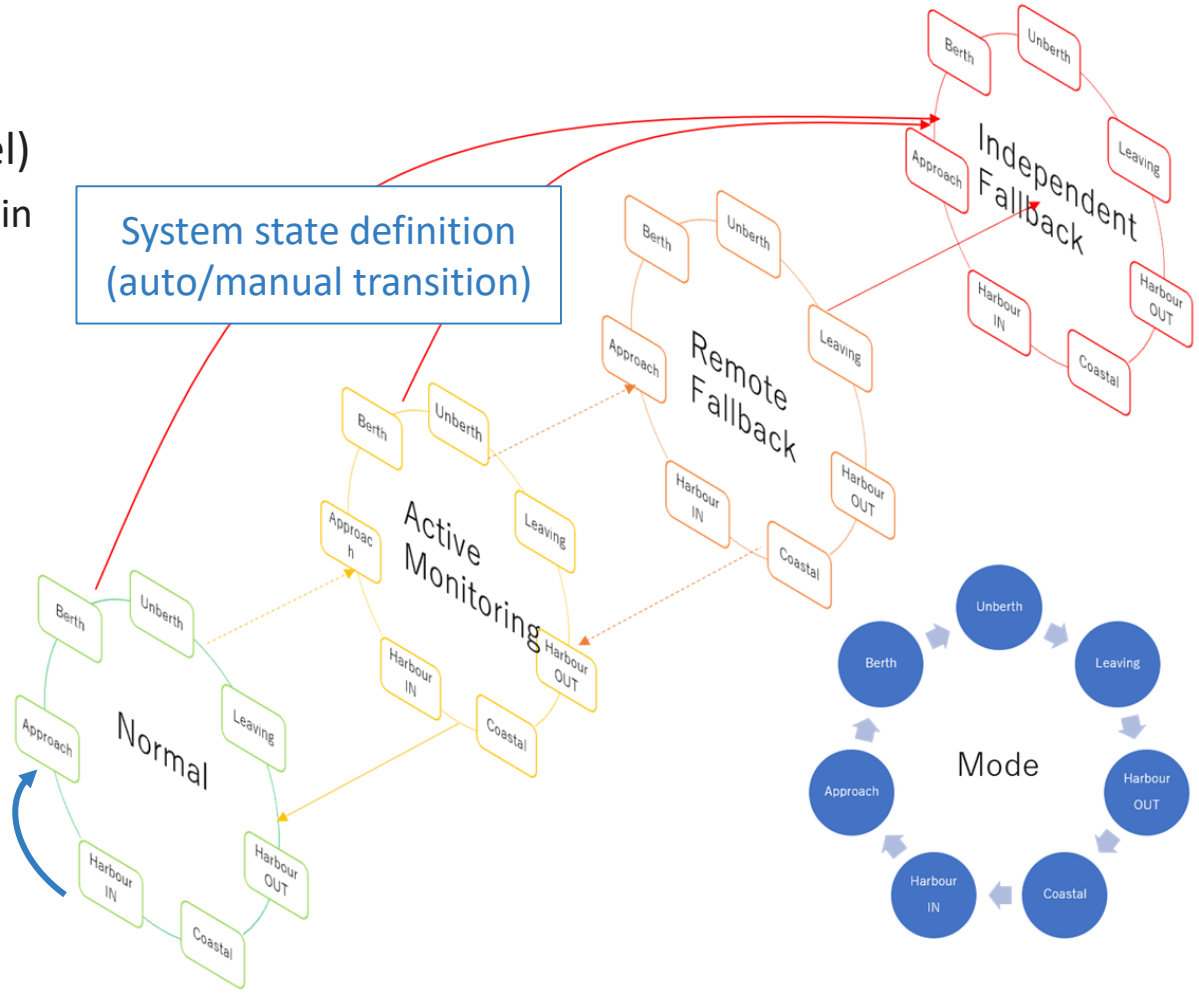
System behavior definition & fallback framework

- In maneuvering sub-system, status and mode are defined as below:
  - Status: Normal, Active Monitoring, Remote Fallback, Independent Fallback
  - Mode: classification of voyage (unberth to berth)

- Fallback framework (designed in accordance with MRC model)
  - Definitions: alternative actions to minimize risk which will be used in abnormal (=deviating from ODD) conditions
  - Framework: system status and required operations
    - Remote fallback: F/B operation by shore operator
    - Independent fallback: F/B operation on vessel
    - Active monitoring: system requires verification by shore operator

System state definition
(auto/manual transition)



Mode within system state:
Classification of voyage (unberth to berth)

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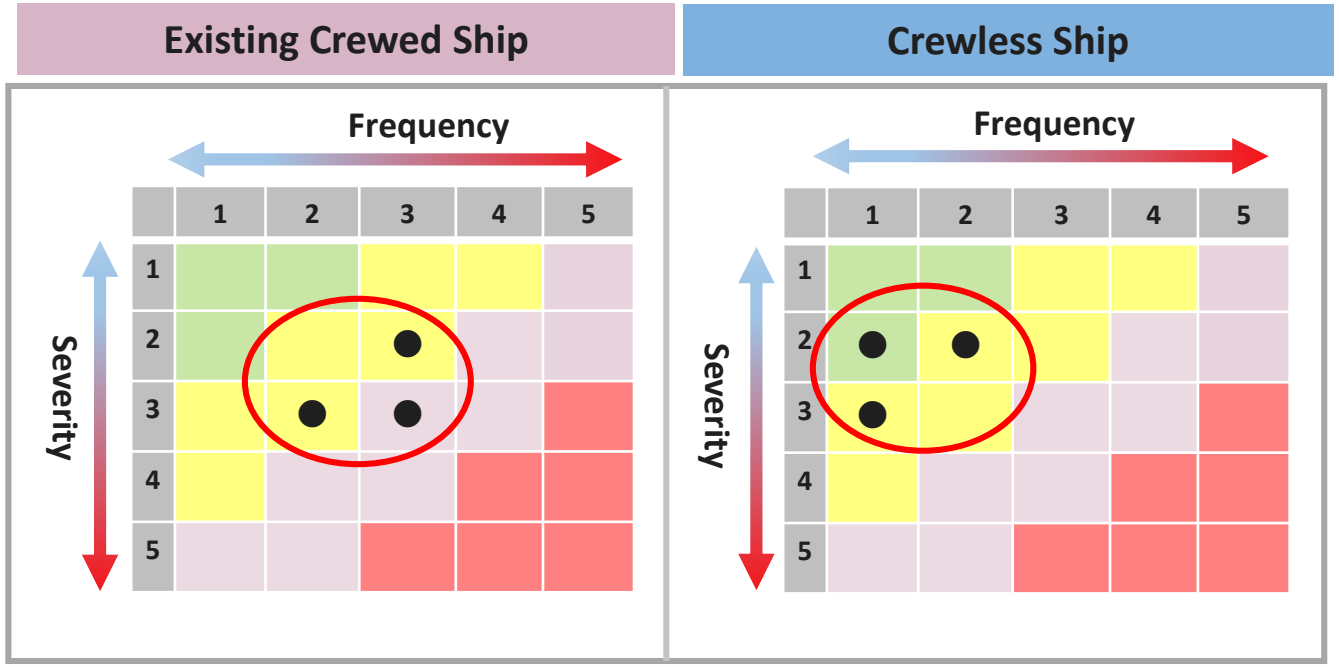
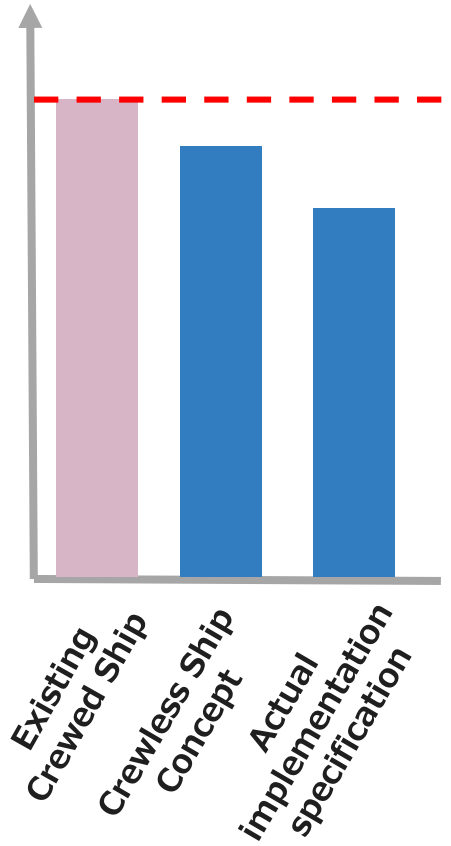
Proof of safety equivalence (in case of regulation change is requested)

- **Existing crewed ships** is the comparison target to evaluate safety equivalence.
- Both crewless ship concept and actual implementation specification should be as safe as or better than existing crewless ships. That is, it will be confirmed that **their risk does not exceed existing ships**.



※In accordance with FOR THE APPROVAL OF ALTERNATIVES AND EQUIVALENTS AS PROVIDED FOR IN VARIOUS IMO INSTRUMENTS （MSC.1/Circ.1455）



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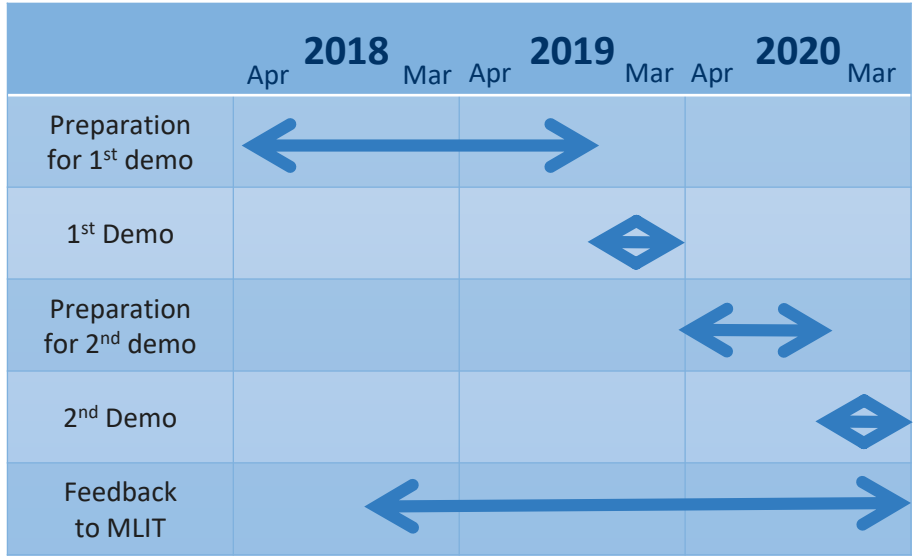
Remote Operation Demonstration Project in Japan t/w MLIT

- Objective: Demonstrate Remote Operation Concept
- Target ship: Tug boat “Yoshino Maru” (Shin-Nippon Kaiyosha)
- Period: 2018.4 – 2021.3
- Project members: company name (role)
  1. MTI (project coordinator/concept design)
  2. JMS (project coordinator/simulator)
  3. NYK (project coordinator/ship owner)
  4. IKOUS (ship owner)
  5. Furuno Electric (navigation equipment)
  6. Japan Radio (navigation equipment)
  7. Tokyo Keiki (navigation equipment)
  8. BEMAC (DPS)
  9. Keihin Dock (shipyard)
  10. Mitsubishi Shipbuilding (engineering)
  11. Sky Perfect JSAT (satellite communication)
  12. NTT DoCoMo (4G/5G network)
  13. NTT (system provider)
  14. Niigata Power Systems(propulsion)
  15. ClassNK (verifier)
  16. NMRI (risk assessment)



1st demonstrations was conducted in January 2020.
The send demonstration will be conducted in the next winter..

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DFFAS Project (Designing the Future of Full Autonomous Ship)

NYK to Participate in Crewless Maritime Autonomous Surface Ship Trial Project

Jun. 15, 2020

-- Efforts toward practical crewless maritime autonomous surface ships by 2025 --

NYK and NYK Group companies Japan Marine Science Inc. (JMS) and MTI Co., Ltd. are participating in the Designing the Future of Full Autonomous Ship Project (hereinafter referred to as the DFFAS Project).* Comprising 22 domestic Japanese companies, the project has been decided to be sponsored by the Joint Technological Development Programme for the Demonstration of Unmanned Ships** under the administration of the Nippon Foundation. With the support of the foundation, the DFFAS Project will aim to conduct the world's first successful crewless maritime autonomous surface ship demonstration trial in order to advance the practical use of crewless maritime autonomous surface ships by 2025.

Outline of the DFFAS Project

The DFFAS project aims to realize a domestic coastal shipping business supported by crewless maritime autonomous surface ships. The NYK Group will make full use of the technology and experience so far cultivated in the technological development of maritime autonomous surface ships (MASS) into this project. The DFFAS project will work toward the standardization of technology and the establishment of systems and infrastructure as well. Moreover, the project plans to carry out a long-distance demonstration trial within FY2021 in congested waters using a domestic coastal containership to realize the world's first crewless maritime autonomous surface ship.

無人運航船プロジェクト
MEGURI 2040

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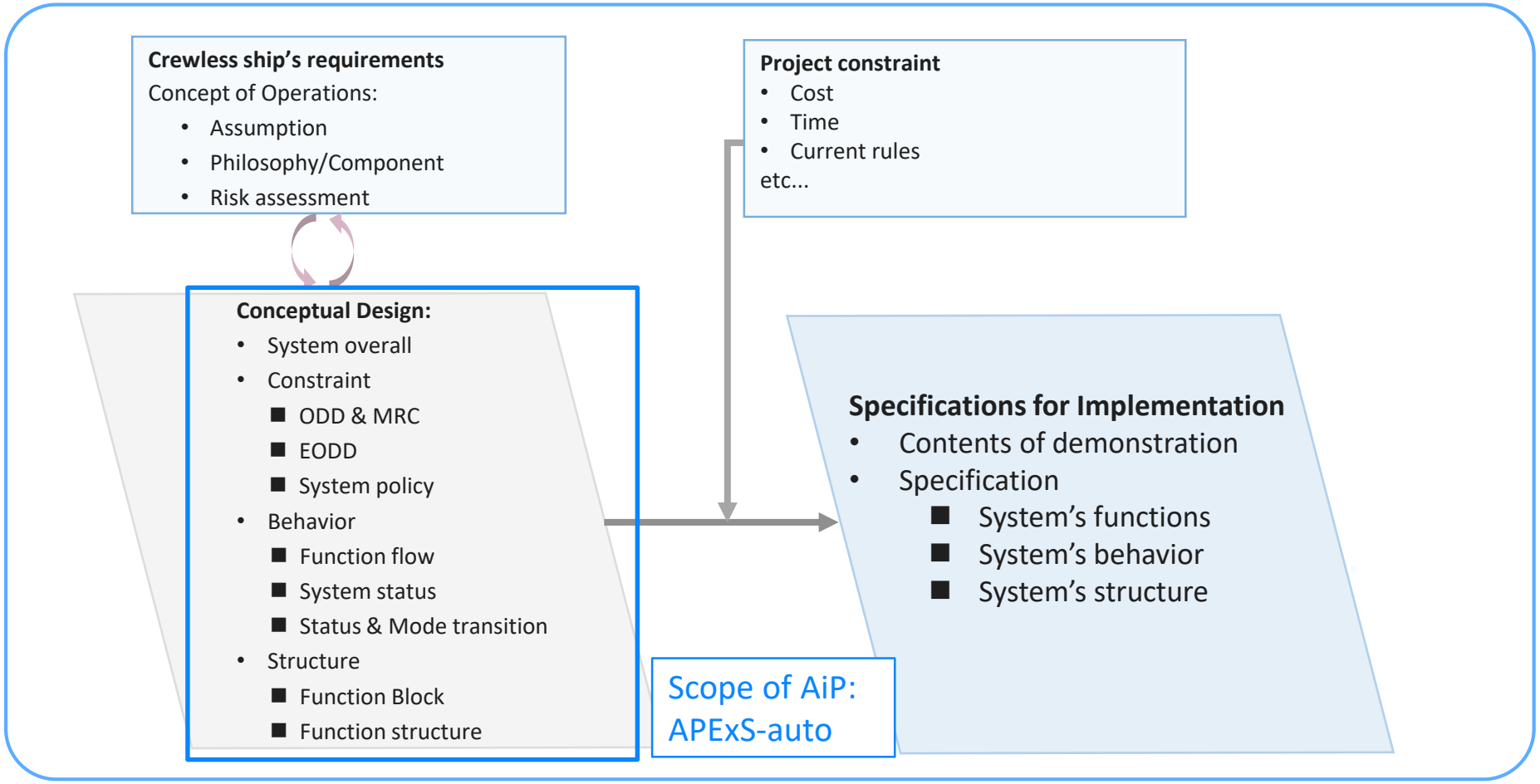
Summary

- In DFFAS Project, we aim at making a proposal for designing autonomous ship as System of Systems.
- We are currently working for to make a conceptual design framework, APExS-auto, evolved from APExS, which receives AiP from ClassNK in Feb 2020.
- In APExS-auto, Model-Based Systems Engineering (MBSE) is used for to share common models to describe SoS among partners

SoS Engineering in DFFAS project



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