CMI, Tokyo

14th – 16th April 2025

The development status of autonomous ships in MEGURI2040 and activities toward implementation in shipping

14th April 2025

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Dr. Hideyuki Ando [2)]

1) Japan Marine Science (NYK Group)

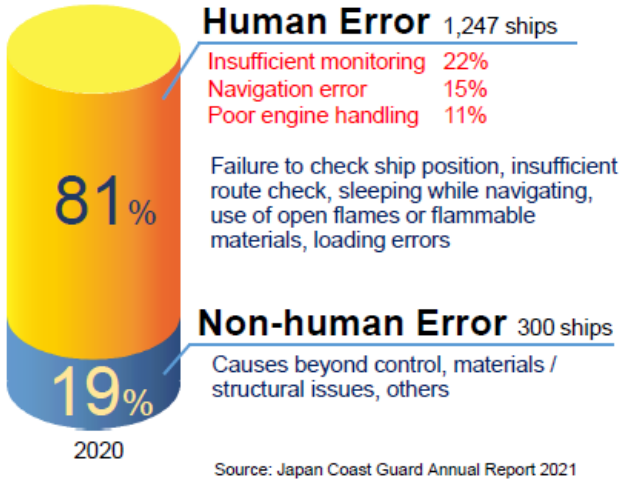
2) MTI (NYK Group)

Outline

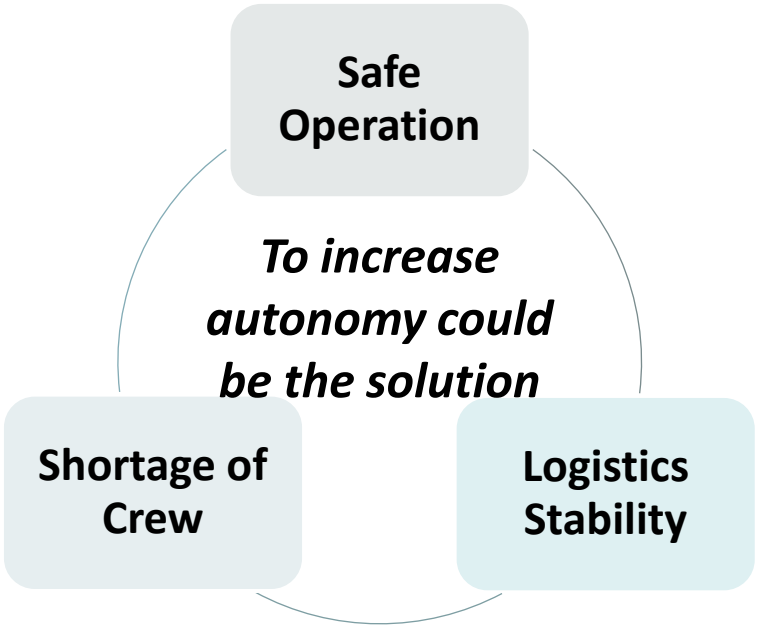
1. **Introduction on MEGURI2040 & DFFAS/DFFAS+ Project**
2. Risk assessment and verification in DFFAS+ Project
3. Summary

Why do we need Autonomous Ships?

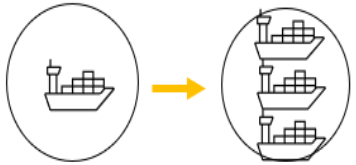
Sustainability of shipping is fundamental for global economy



✓ Navigation accidents are caused mainly by **human errors (abt. 80%)**



Bigger ships with smaller engines



More congestions due to increased ships

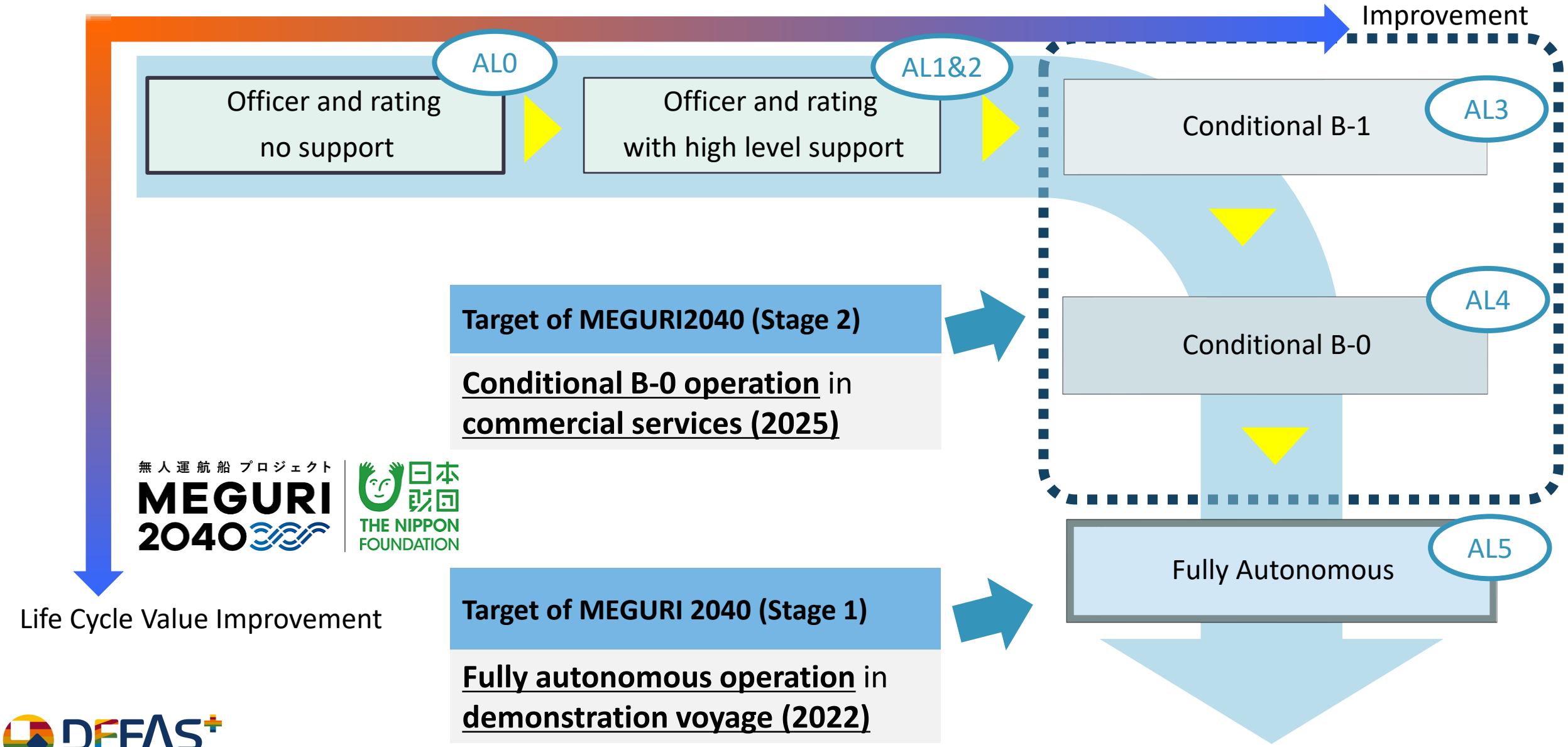
✓ Reduced maneuverability in congested routes
→ **Early action** is important

✓ **Global seafarer shortage 8.8%,** highest ever
✓ **Shortage of seafarers** in Japan's domestic shipping
(by 2040 there will be a 30% shortage of seafarers)

✓ **Future increase in maritime transport demands in each region** (from trucks to shipping and trains)

Ref) M. Unno, Fully Autonomous Ship Project "MEGURI2040" –Project Overview, Dec 4th, IMO MSC 109

Autonomous navigation roadmap and target of MEGURI2040 Stage 1&2



* AL0 – 5 refers autonomy level (AL) definition by Lloyd's Register, Cyber-enabled ship, 2016

DFFAS Project in MEGURI2040 Stage 1

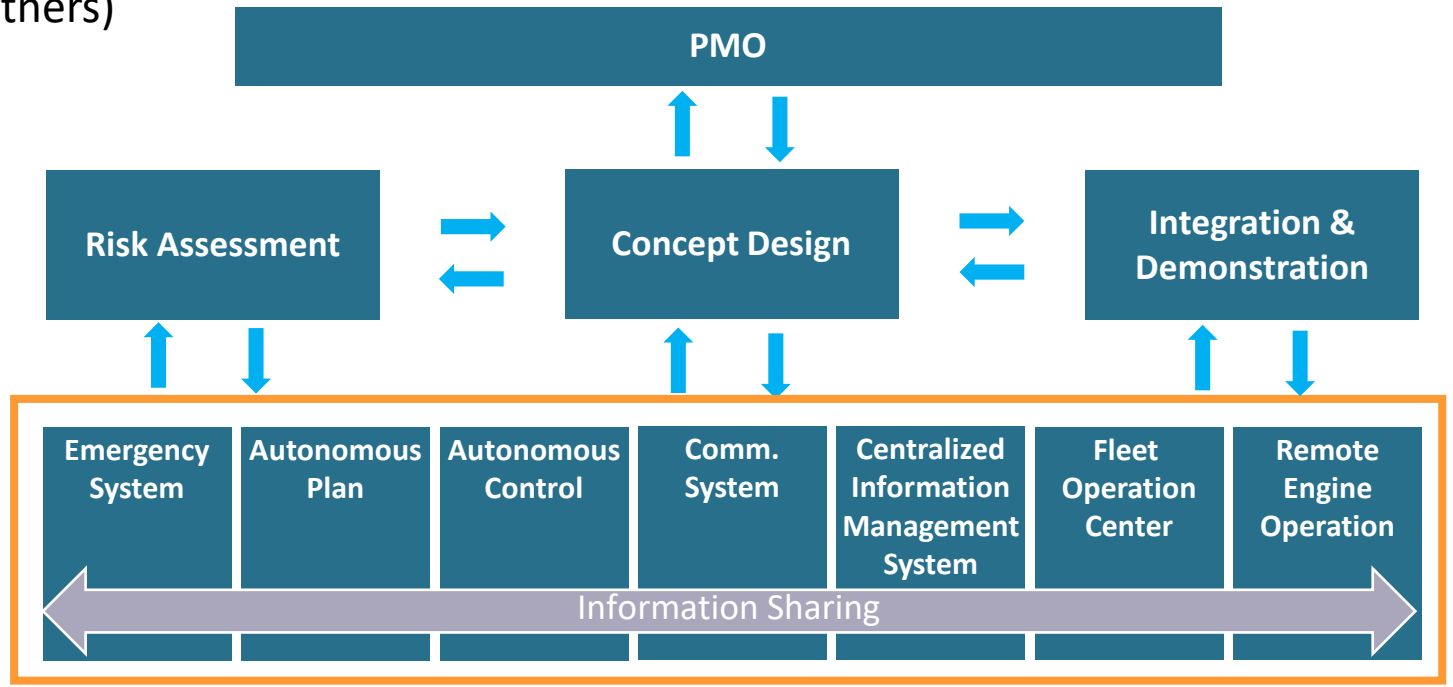
DFFAS (Designing the Future of Fully Autonomous Ship)

- **Target**
  - Demonstration of fully autonomous ship navigation under MEGURI2040
- **DFFAS consortium members & partners**
  - Consortium: 30 organizations (domestic)
  - Total: 60+ organizations (including global partners)
- **Schedule**
  - Feb 2020 – Mar 2022 (abt. 2 years)

Target ship and route	Container ship “Suzaku”, 749GT Tokyo bay – Ise bay

Project Director
Capt. Satoru Kuwahara

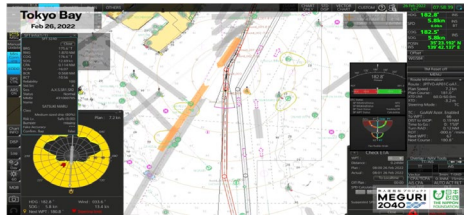
Organization of DFFAS Project



DFFAS System Overview

DFFAS

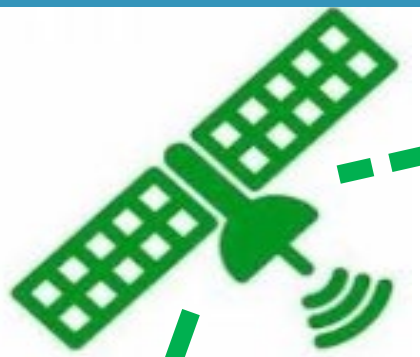
Onboard system
(autonomous functions)



Telecommunication system
(3 satellites and 1 terestrial communication line, information management & control)

DFFAS

MEGURI 2040



Land-based system
(land-based support functions)

Integrated Display Block
(ship information collection, monitoring & analysis)
(engine remote monitoring, control & anomality detection)

Emergency Response Block
(remote operation function)

DFFAS+ Designing the Future of Fully Autonomous Ships

Results of DFFAS Project (2022)

Demonstration of fully autonomous functions in congested coastal routes in Japan

Port of Tokyo
Incl. Uraga Straight traffic route

FOC
Makuhari

Port of Tsu-Matsusaka
Incl. Irago Straight traffic route in Ise bay

Round trip
424 NM (790km)

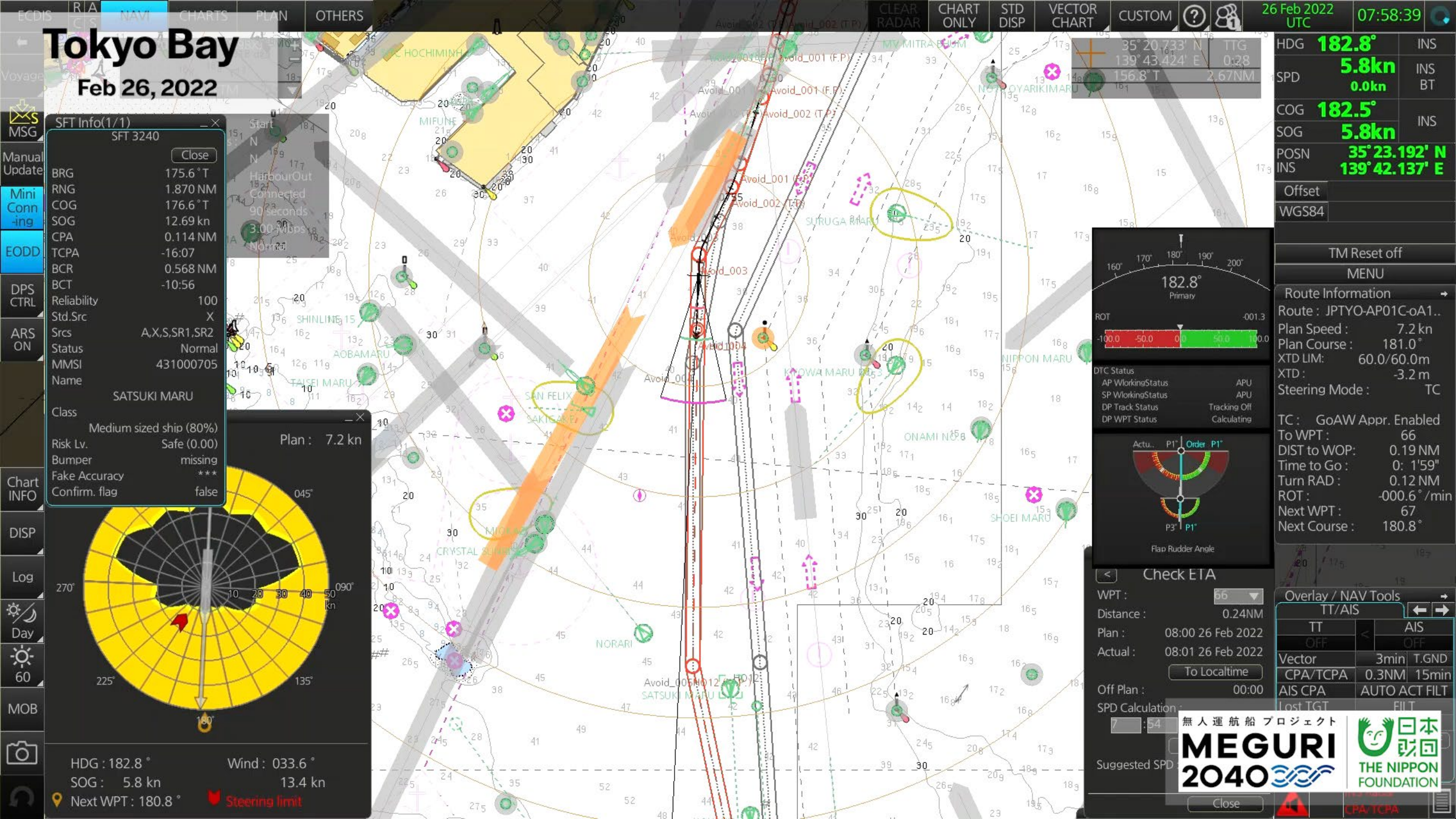
26-27 Feb 2022

28 Feb – 1 Mar 2022

Containership ”Suzaku”, 749GT with fully autonomous functions

Achieved 98.5% of fully autonomous navigation in the demonstration voyage

無人運航船プロジェクト MEGURI 2040 | THE NIPPON FOUNDATION | DFFAS Designing the Future of Full Autonomous Ship


ECDIS
NAVI
CHARTS
PLAN
OTHERS
CLEAR RADAR
CHART ONLY
STD DISP
VECTOR CHART
CUSTOM
26 Feb 2022 UTC
07:58:39
Tokyo Bay
Feb 26, 2022
MSG
Manual Update
Mini Conn -ing
EODD
DPS CTRL
ARS ON
Chart INFO
DISP
Log
Day
60
MOB
SFT Info(1/1)
SFT 3240
Close
BRG 175.6 °T
RNG 1.870 NM
COG 176.6 °T
SOG 12.69 kn
CPA 0.114 NM
TCPA -16:07
BCR 0.568 NM
BCT -10:56
Reliability 100
Std.Src X
Srcs A,X,S,SR1,SR2
Status Normal
MMSI 431000705
Name
SATSUKI MARU
Class
Medium sized ship (80%)
Risk Lv. Safe (0.00)
Bumper missing
Fake Accuracy ***
Confirm. flag false
Plan : 7.2 kn
045°
090°
135°
180°
225°
270°
10 20 30 40 50 kn
HDG : 182.8 °
SOG : 5.8 kn
Next WPT : 180.8 °
Wind : 033.6 °
13.4 kn
Steering limit
HDG 182.8° INS
SPD 5.8kn INS
0.0kn BT
COG 182.5° INS
SOG 5.8kn
POSN 35°23.192' N
INS 139°42.137' E
Offset
WGS84
TM Reset off
MENU
Route Information
Route : JPTYO-AP01C-oA1..
Plan Speed : 7.2 kn
Plan Course : 181.0°
XTD LIM: 60.0/60.0m
XTD : -3.2 m
Steering Mode : TC
TC : GoAW Appr. Enabled
To WPT : 66
DIST to WOP: 0.19 NM
Time to Go : 0: 1'59"
Turn RAD : 0.12 NM
ROT : -000.6°/min
Next WPT : 67
Next Course : 180.8°
182.8°
Primary
ROT -001.3
DTC Status
AP WorkingStatus APU
SP WorkingStatus APU
DP Track Status Tracking Off
DP WPT Status Calculating
Flap Rudder Angle
Check ETA
WPT : 66
Distance : 0.24NM
Plan : 08:00 26 Feb 2022
Actual : 08:01 26 Feb 2022
To Localtime
Off Plan : 00:00
SPD Calculation
Suggested SPD
Overlay / NAV Tools
TT/AIS
TT AIS
OFF OFF
Vector 3min T.GND
CPA/TCPA 0.3NM 15min
AIS CPA AUTO ACT FILT
Lost TGT FILT
Close
CPA/TCPA
無人運航船プロジェクト
MEGURI 2040
THE NIPPON FOUNDATION

DFFAS+ Consortium for MEGURI2040 Stage 2

- In MEGURI2040 Stage 2, 53 companies form the DFFAS+ Consortium
- Project period: October 2022 to March 2026 (3.5 years)
- Total grants: 50 mil. USD granted from the Nippon Foundation

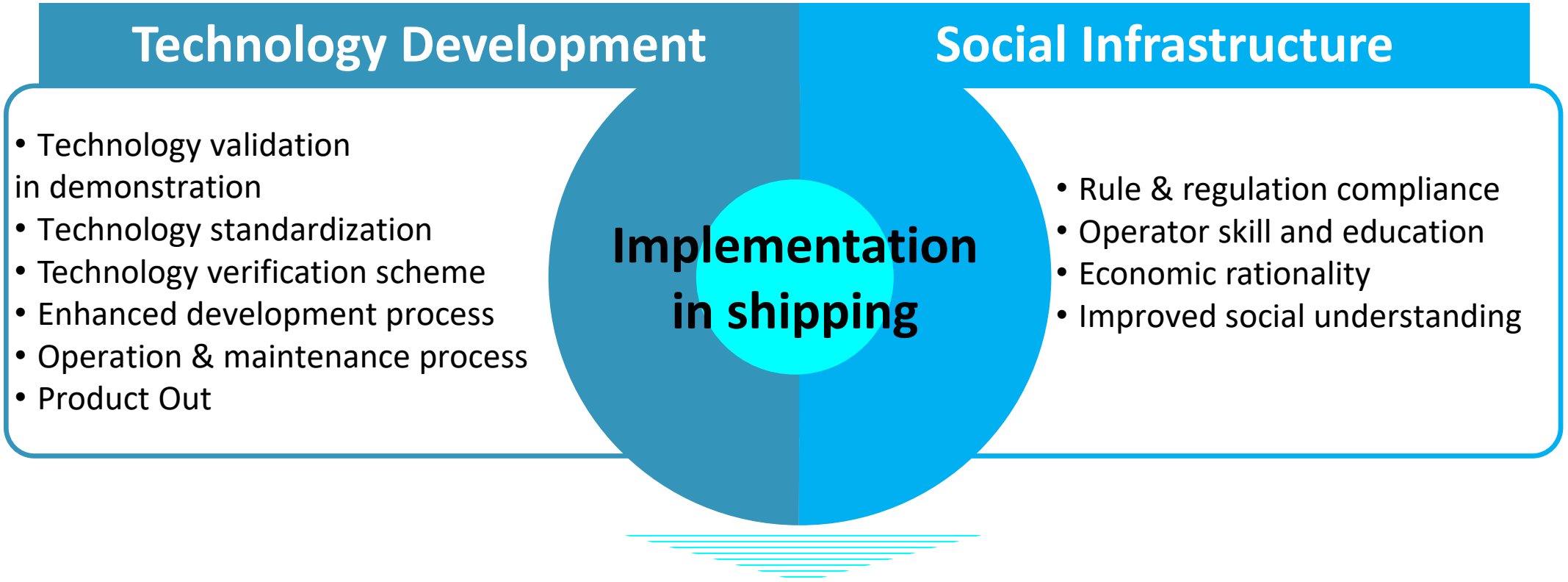
DFFAS+ Designing the Future of Fully Autonomous Ships

Demonstration in MEGURI2040 Stage 2

Demonstration of 4 autonomous ships in commercial operations with support from 2 Remote Operation Centers(ROC).

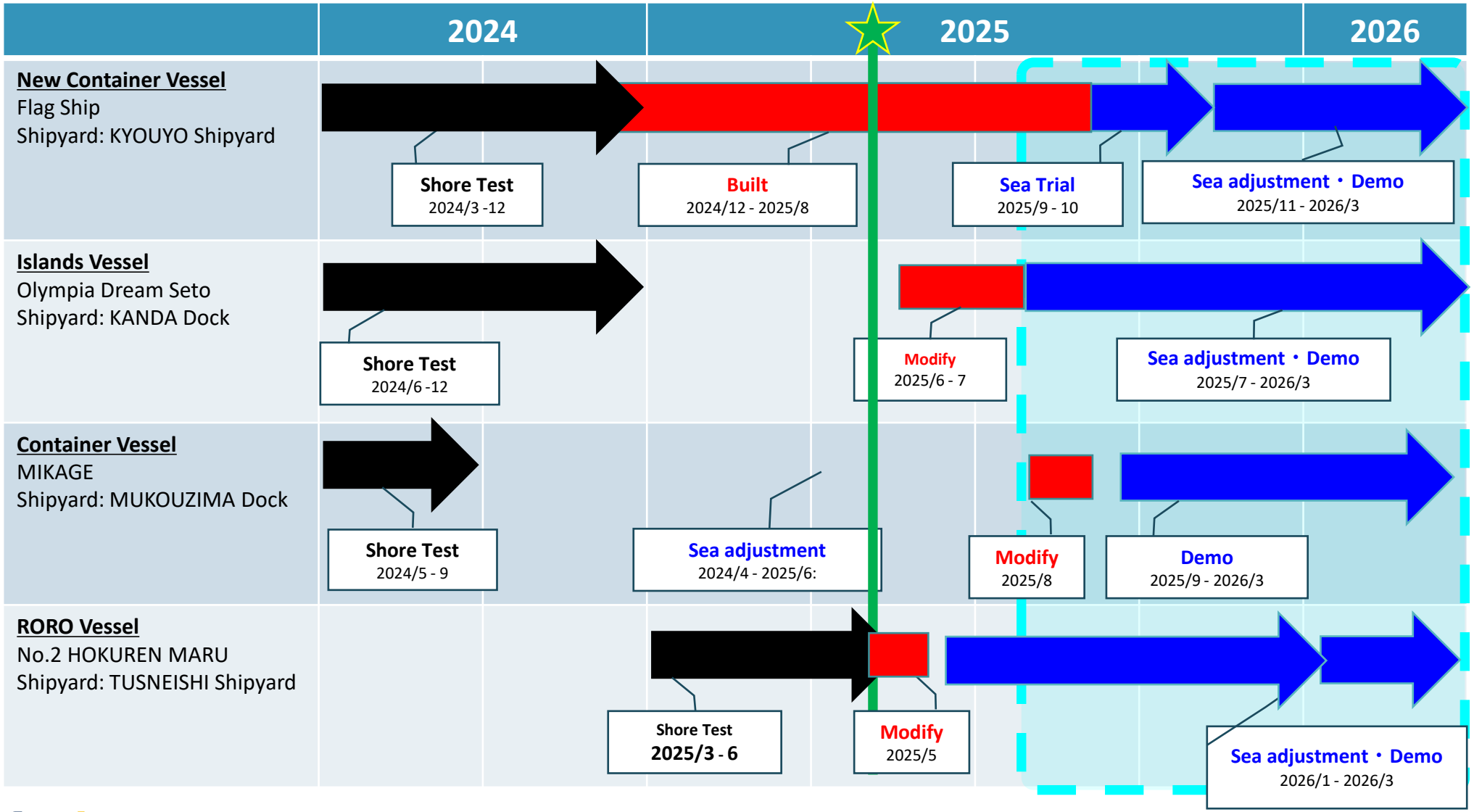
Period	Type, name, size & operation area	Ship	Companies
Nov 2025 - (5 months)	Newly built Container Vessel (about 7,800GT/Coasting area)	(Delivery in Sep 2025)	**MTI (Lead)** Ikous, Japan Marine Science, JMU, Furuno Electric, BEMAC, Tokyo Keiki, Nabtesco, Sunflame, Mitsui E&S Shipbuilding, Space Compass, JRCS, TerasakiElectric, NaikoMirai, WNI, EIZO
June 2025 - (9 months)	Island Vessel OLYMPIA DREAM SETO (942GT/ Smooth water area)		**Japan Marine Science (Lead)** Ryobi Ferry, Mitsui E&S Shipbuilding, Mitsubishi Shipbuilding, Furuno Electric
Oct 2025 - (6 months)	Container Vessel MIKAGE (749GT/Coasting area)		**Mitsui O.S.K. (Lead)** Imoto Lines, Furuno Electric, Mitsui E&S Shipbuilding
Sep 2025 – (a few voyages)	RO-RO Vessel No.2 HOKUREN MARU (11,413GT/ Limited major coasting area)		**Kawasaki Kisen (Lead)** Kawasaki KinkaiKisen, Japan Radio, YDK

Target of DFFAS+ Project in MEGURI2040 Stage 2



- Autonomous navigation demonstrations in commercial operations on various ship types (2 container ships, 1 passenger ship, 1 RoRo ship) will be conducted.
- Long term practical use of the autonomous navigation systems → Non-technical issues need to be considered, such as human-machine interface, comfortable work environment, crew familiarizations and trainings.

DFFAS+ Project - Schedule



Outline

1. Introduction on MEGURI2040 & DFFAS/DFFAS+ Project
2. **Risk assessment and verification in DFFAS+ Project**
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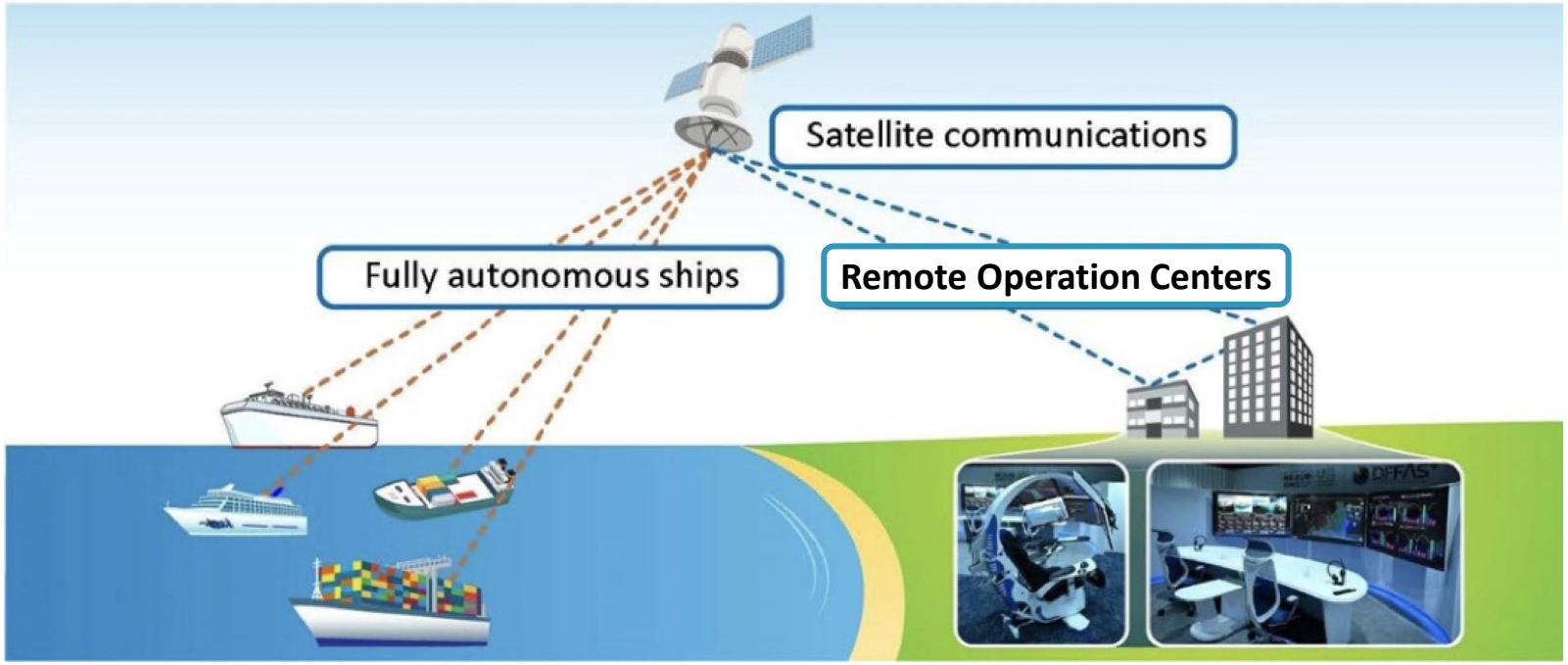
DFFAS+ Autonomous System Overview – the Key additional functions



The Key additional functions

Navigation
- New sensors
- Integrator
- Planner
- Controller

Others
- Status management
- Data recording
- Cyber security

Machinery
- Abnormalities detection

ROC
- Voyage planning
- Engine & power plant remote monitoring

Modified based on Ref) T. Nakashima, et. al, Addressing systemic risks in autonomous maritime navigation: A structured STPA and ODD-based methodology, Reliability Engineering & System Safety, Volume 261, September 2025

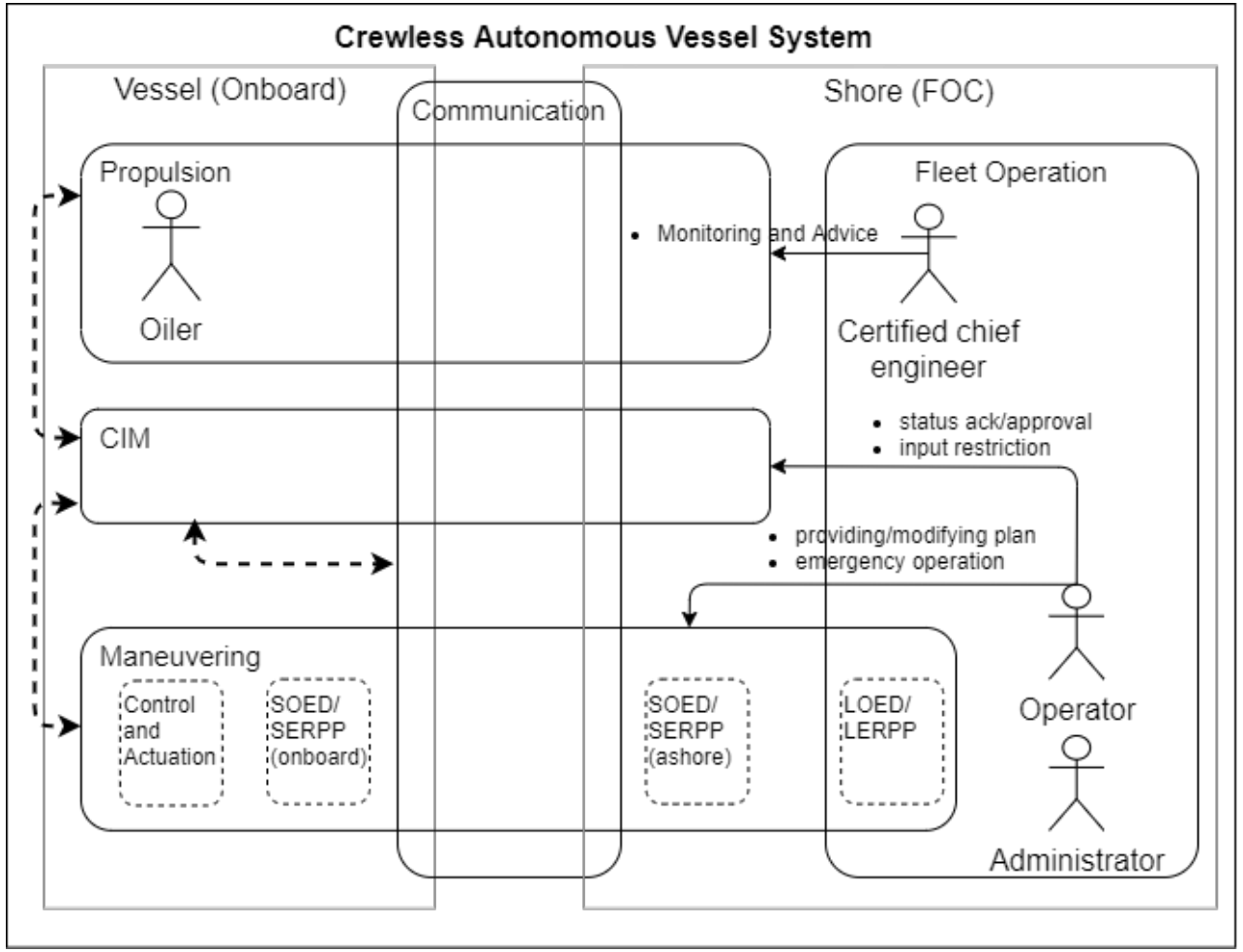
Definition of system requirements in ConOps

Define Concept of Operations (ConOps)

- Master mariners and chief engineers, who are well versed in ship operations, define the ConOps in cooperation with engineers of manufacturers and system engineering specialists.
- For eliciting system requirements Model-Based Systems Engineering (MBSE) and risk assessment, such as STPA, are used.

Key features of ConOps

- Ship specifications
- Who, When, What, How
- Operational Design Domain (ODD)
  - Environmental conditions
- Functional Requirements
- Rules and regulations



High level system conceept description by using use case diagram

Navigation mode for classifying sea areas

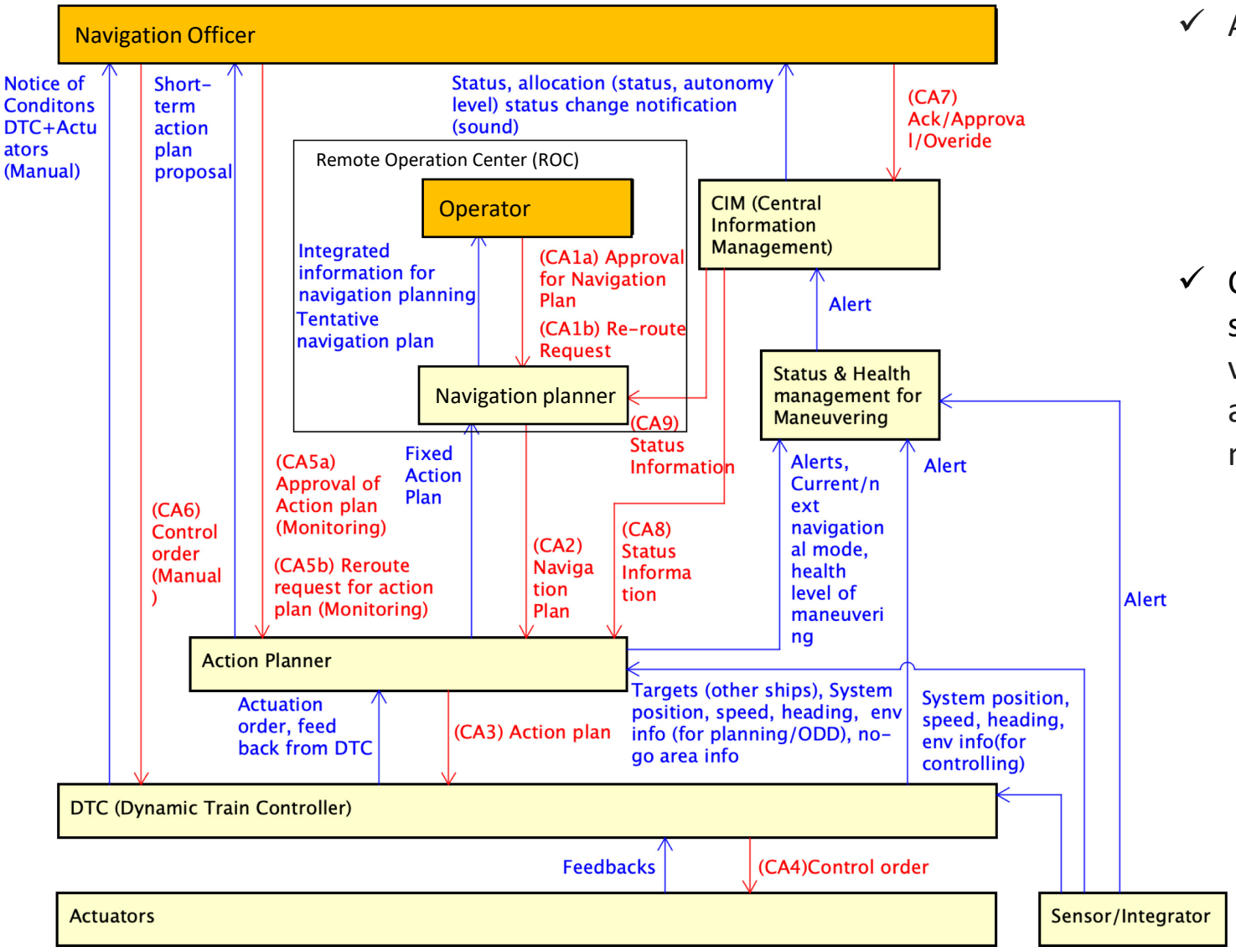
- System configuration could be different depend on navigation mode.

Table 4. Navigational mode used in DFFAS Plus project.

Navigational mode	Definition
Unberthing	Attitude control, unberthing operations
Leaving	Attitude control, speed control possible (speed: lower than upper limit at the operation and/or area)
Harbor Out	Track control, speed control possible (speed: from 0 knots to upper limit of the ship)
Coastal	Track and speed control possible if speed is above the operational minimum (avoiding auxiliary blower cycling) and below the ship's maximum
Ocean	Track control
Harbor In	Track control, speed control possible (speed: from 0 knots to upper limit of the ship)
Approaching	Attitude control, speed control possible (speed: lower than upper limit at the operation and/or area)
Berthing	Attitude control, berthing operations

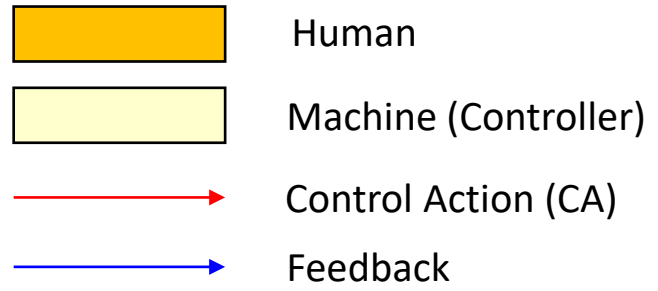
Ref) T. Nakashima, et. al, Addressing systemic risks in autonomous maritime navigation: A structured STPA and ODD-based methodology, Reliability Engineering & System Safety, Volume 261, September 2025

Example) Control structure of the maneuvering subsystem



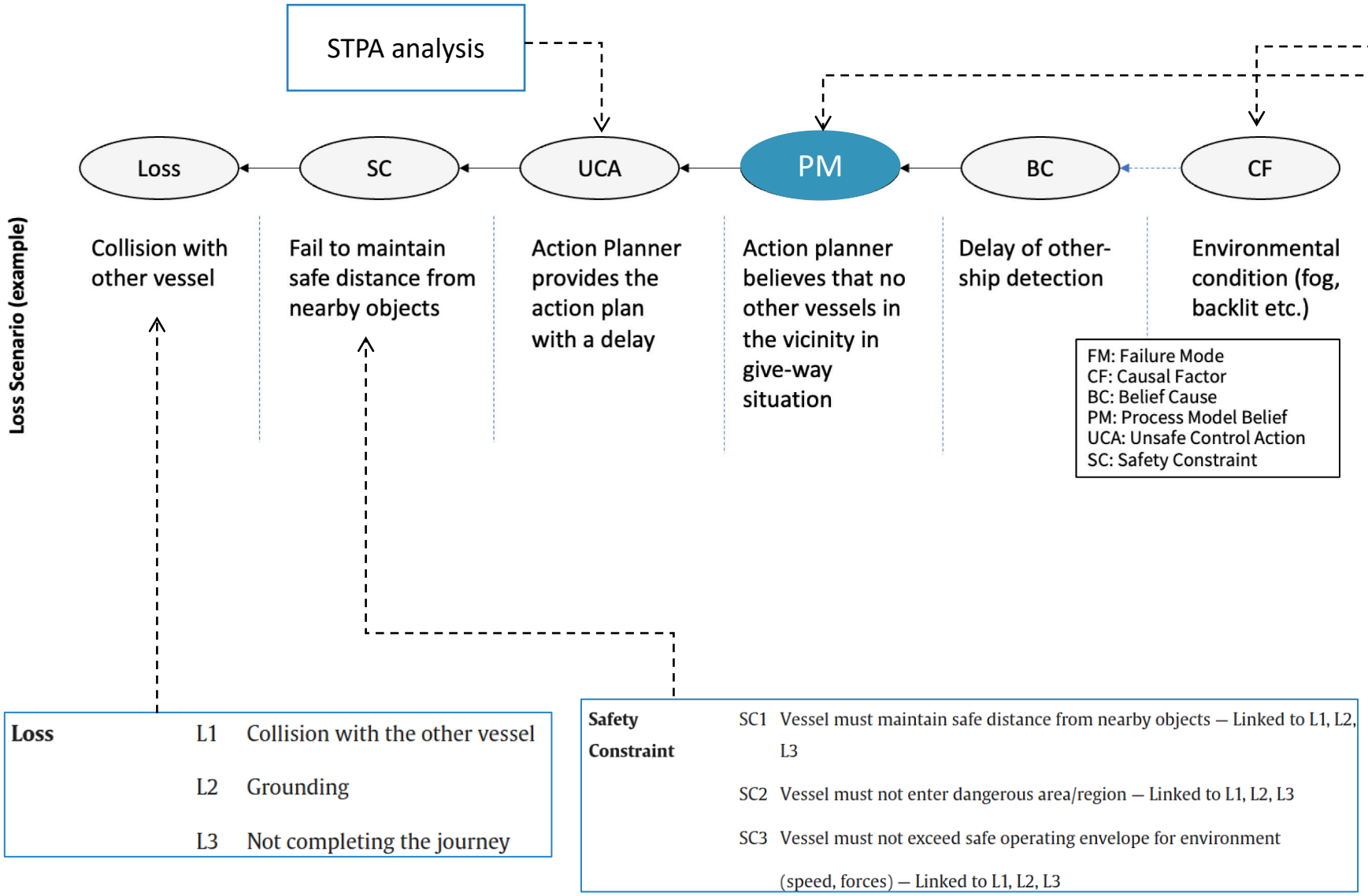
- ✓ Autonomous navigation statuses:
  - ☐ Fully Autonomous
  - ☐ Monitoring (by navigation officer)
  - ☐ (normal) Track Control
  - ☐ Manual operation.

- ✓ Control structure changes depend on navigation status, layer of control task, short- or long-term voyage planning, navigation mode, etc. To run risk assessment and to extract loss scenario, each case need to be considered.



Modified based on Ref) T. Nakashima, et. al, Addressing systemic risks in autonomous maritime navigation: A structured STPA and ODD-based methodology, Reliability Engineering & System Safety, Volume 261, September 2025

Image of loss scenario extraction by using STPA



Identified Process Model Discrepancies

- ✓ Estimation of other vessels' or obstacles' positions
- ✓ Estimation of own ship's control performance
- ✓ Estimation of other vessels' behaviors
- ✓ Estimation of the status of internal modules
- ✓ Estimation of the role of the ship or system
- ✓ Estimation regarding the provided control signals
- ✓ Estimation of communication environment
- ✓ Estimation of override or switch timing
- ✓ Estimation of the other control process or operational environment

These PM discrepancies need to be checked & verified by using simulation tests

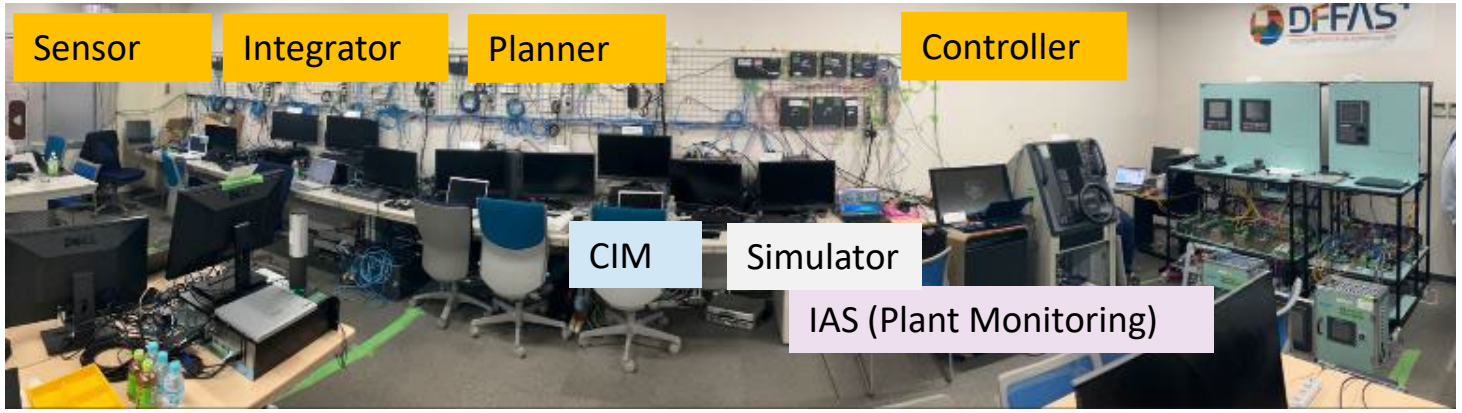
Modified based on Ref) T. Nakashima, et. al, Addressing systemic risks in autonomous maritime navigation: A structured STPA and ODD-based methodology, Reliability Engineering & System Safety, Volume 261, September 2025

Example loss scenario from STPA

Table 7
Sample loss scenarios from STPA.

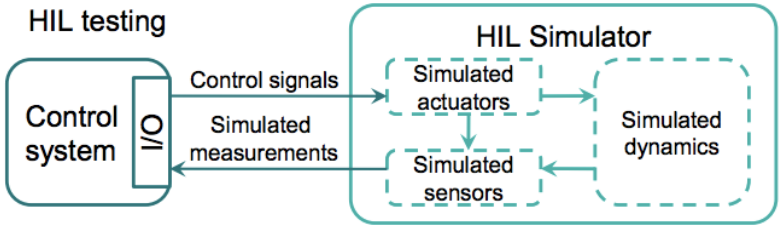
LSID	UCA	Context	Process Model	Belief Cause	Causal Factor
3P1–1	Action Planning Module provides an action plan to approach other ships and/or land to DTC (Drive Train Controller), leading to a distance close to other ships and/or land [SC1]	Other ships, obstacles and/or land are around own ship	Action Planning Module does not recognize other ships or land around the own ship, or recognize in a different position	The ship's position and attitude information deviates from the true value (Process model variable: Own ship - Position)	Failure/performance reduction of own ship sensors and communication routes (not detected)
3P1–2	Action Planning Module provides an action plan to approach other ships and/or land to DTC (Drive Train Controller), leading to a distance close to other ships and/or land [SC1]	Other ships, obstacles and/or land are around own ship	Action Planning Module does not recognize other ships or land around the own ship, or recognize in a different position	The position and attitude information of other vessels deviates from the true value, or the information of other vessels is missing (Process model variable: Other ship)	Reduced sensor performance due to environmental change, aging deterioration (fog, heavy rain, etc.)

HIL(Hardware In the Loop) test arrangement



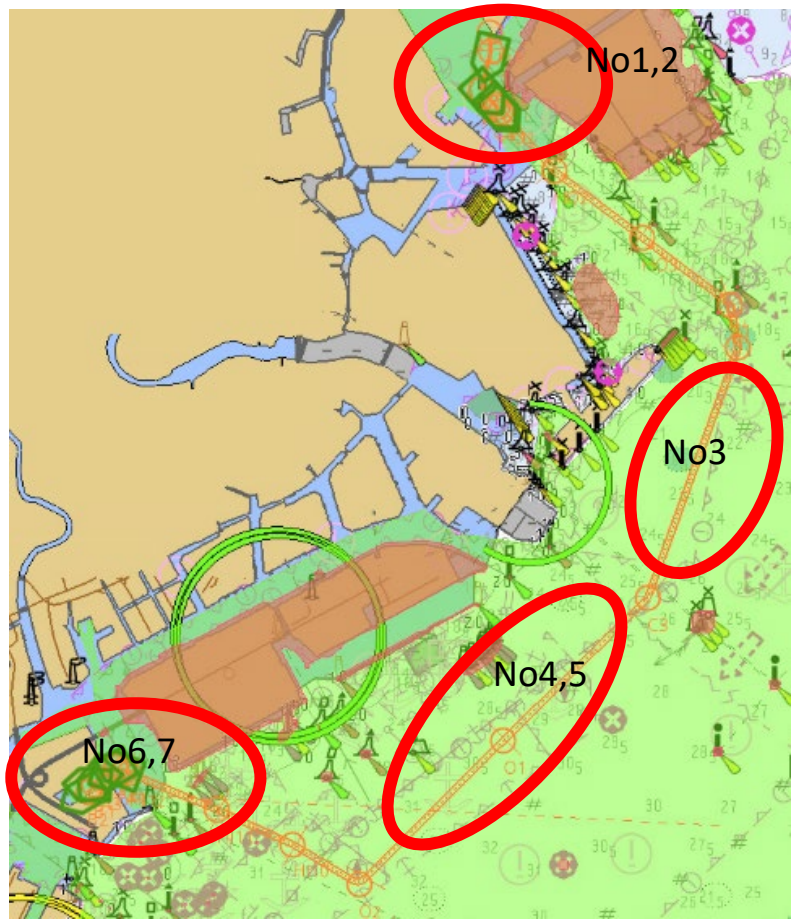
Control system
(Autonomous Navigation System)

simulator



Courtesy) DNV, CyberSea

Simulation test scenarios – virtual voyage for HIL test



1. Preparation for navigation
    1. Route transfer from shore
    2. Thruster preparation, offshore route optimization, route monitoring, etc.
2. Maneuvering away from shore
    1. MMS operation
    2. Autonomous navigation start
    3. DTC control Engine/navigation coordination (automatic thruster shutdown)
3. Evasive maneuvers
    1. Normal avoidance (FA/MA)
    2. Fallback
4. Abnormal occurrence
    1. APU stop (equipment running TCS)
    2. 1 GPS unit stopped → 2 GPS units stopped → MRM/MRC operation
5. ODD
    1. EODD over (wind/waves/currents)
    2. Passage of watch area
6. Shore arrival operation
    1. Engine/navigation coordination (automatic thruster start)
    2. Automatic application of berthing route
    3. DTC berthing (including End Of Track control)
    4. End of autonomous navigation → MMS maneuvering
7. Completion of navigation

HIL Test Summary

- Term : Sep. 2024 ~ Mid. Feb. 2025
- Total Test Days : 3days x 10times = 30 days
- Operation time : about 300 hours
- Test Items : 333 items
  - Confirmed 295 items
  - Other items will be confirmed at onboard tests
- Remarks :
  - Briefing to captains and chief engineers on autonomous navigation systems.
  - Interviews with captains and navigators on human-machine interface.

Master of the new built ship

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Roadmap for the goal-based MASS code and EBP

SESSIONS OF MSC	WORK PLAN
MSC 110 (June 2025)	- Consideration of the outcome of the MASS-CG, established at MSC 108 - **Further develop the non-mandatory MASS Code** - Update this road map
MASS-ISWG 4 (2nd half 2025)	- **Further develop the non-mandatory MASS Code**
MSC 111 (May 2026)	- Consideration of the outcome of MASS-ISWG 4 - **Finalization and adoption of the non-mandatory MASS Code** - Invite relevant sub-committees to review the non-mandatory Code - Update this road map
MSC 112 (December 2026)	- Develop a framework for an Experience-building phase (EBP) post adoption of the non-mandatory MASS Code
MSC 1XX (2028)	- **Commence development of the mandatory MASS Code, based on the non-mandatory Code and result from the EBP and review conducted by the relevant sub-committees, and consider amendments to SOLAS (new chapter) for the Code's adoption**
MSC 1XX	- Adoption of the mandatory Code (latest 1 July 2030 for entry into force on 1 Jan 2032)

Ref) IMO MSC 10/WP.8, Annex 2, Page 1, 5 December 2024

- The target of finalization and adoption of the non-mandatory MASS Code is MSC 111 in May 2026
- A framework for experience-building phase (EBP) will be developed in MSC 112 in December 2026

NYK group intends to accumulate experience and data through demonstrations in EBP.

✓ To improve technology, education, process and organization for coming the MASS mandatory code

✓ To share experiences with IMO MSC and other stakeholders to proceed implementation of autonomy in shipping.

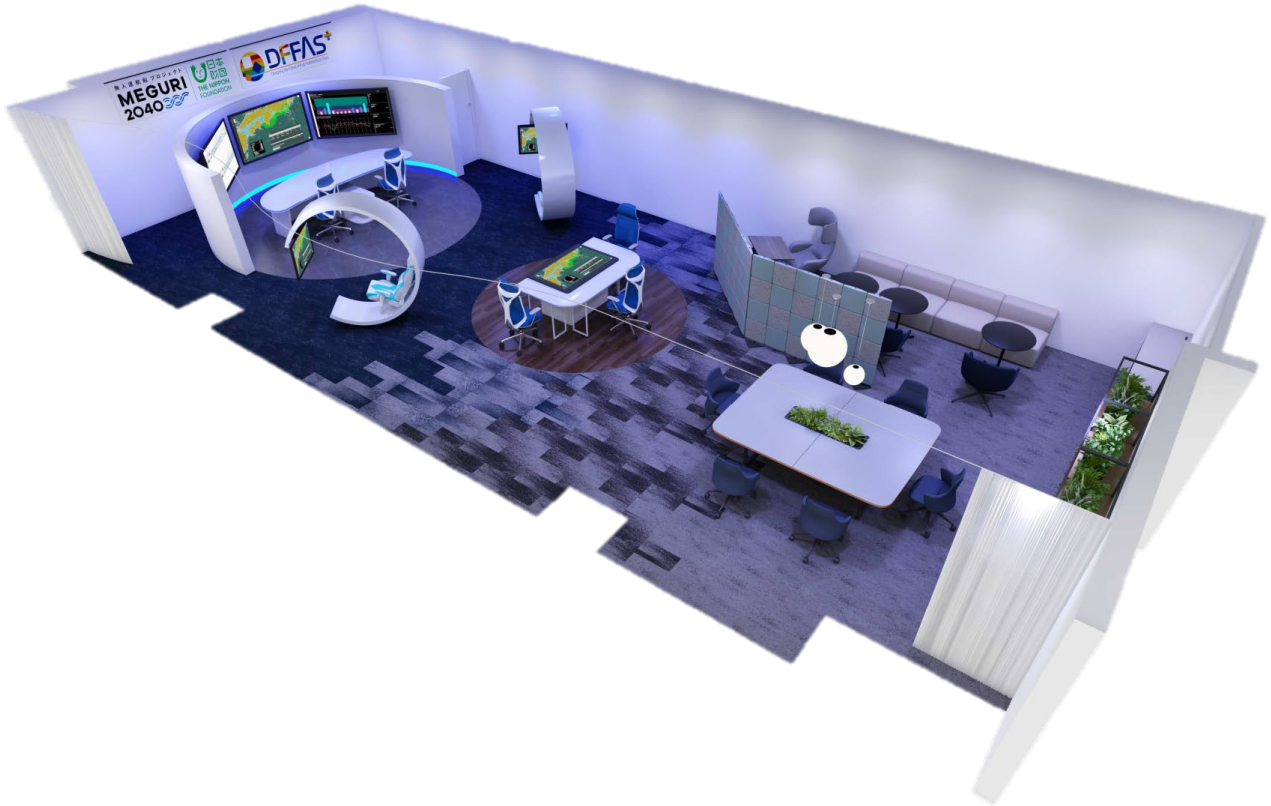
Summary

- In MEGURI2040 Stage 1, we successfully completed a demonstration voyage of DFFAS in 2022 and are currently advancing the DFFAS+ project as Stage 2 for demonstration in this year.

- The DFFAS+ project aims to introduce autonomous navigation systems into shipping and is currently preparing for several months long demonstration in commercial services.

- The DFFAS+ project employs a new risk analysis method STPA based on system control structure and analyze loss scenario that failure potentials lead to accidents. Simulation tests, onboard tests and monitoring after delivery will be conducted based on the analyzed failure potentials.

- Going forward, we believe it is essential to transparently and openly share with legal experts the types of errors that developers anticipate during system development, in order to advance the realization of a safer autonomous system in shipping.



DFFAS+

Designing the Future of Fully Autonomous Ships

Source: DFFAS+ CONSORTIUM

無人運航船プロジェクト

MEGURI 2040

日本財団 THE NIPPON FOUNDATION

Thank you for your listening.