E

MARITIME SAFETY COMMITTEE
106th session
Agenda item 5

MSC 106/INF.4
2 August 2022
ENGLISH ONLY
Pre-session public release: ☒

DEVELOPMENT OF A GOAL-BASED INSTRUMENT FOR MARITIME AUTONOMOUS SURFACE SHIPS (MASS)

Results of demonstration tests of fully autonomous ship navigation on "MEGURI 2040"

Submitted by Japan

SUMMARY	
Executive summary:	This document provides information of demonstration tests of fully autonomous ship navigation on "MEGURI 2040".
Strategic direction, if applicable:	2
Output:	2.23
Action to be taken:	Paragraph 9
Related document:	MSC 106/5/1

Introduction

1 The Nippon Foundation MEGURI 2040 Fully Autonomous Ship Program is leading the world in carrying out demonstration tests of fully autonomous navigation for coastal shipping, and through the success of these tests, seeks to create further opportunities for technological development in this field, promote innovation in Japan's logistics, economy and social platforms, and support related technological development.

The Nippon Foundation MEGURI 2040 Fully Autonomous Ship Program

2 With Japan today experiencing a contracting and aging population, shortages of human resources are emerging in a wide variety of fields. Coastal shipping, with its challenging work environment, is no exception, and with more than half of coastal shipping crew members over the age of 50, this is becoming a major issue. In addition, Japan has roughly 400 inhabited offshore islands, many of which are visited by ships only twice a day, in the morning and evening. Maintaining these offshore routes has therefore become a critical issue in the daily lives of those inhabitants. In addition, human error is said to be involved in 70-80% of maritime accidents, making accident reduction an issue as well.

Meaning of 'MEGURI 2040'

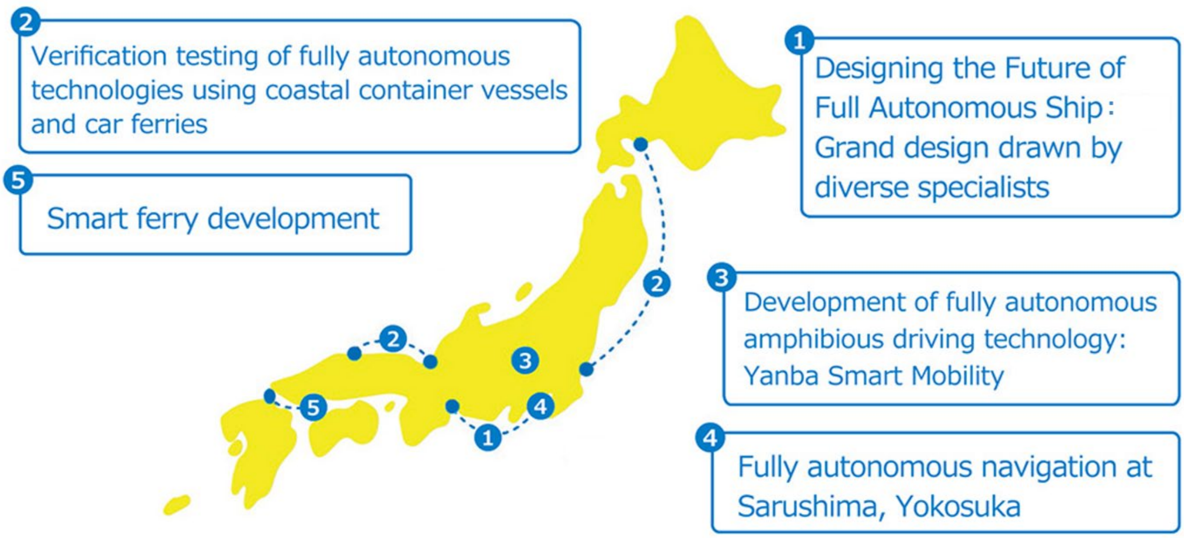
3 Practical implementation of fully autonomous navigation will improve the flow of goods, people, costs, and traffic, thereby creating greater convenience. The program's name conveys the concept of "Improving Japan's circulation," which is seen as the program's main benefit, and the name "MEGURI" is a Japanese word for "flow."

Aiming for practical implementation by 2025

4 Demonstration tests of autonomous driving has been moving forward, primarily in the automotive sector, but sea navigation presents technological challenges in terms of telecommunications infrastructure between land and sea and obstacle avoidance. At the same time, the advanced technologies in areas including the internet of things (IoT), artificial intelligence (AI), and image analysis are making it possible to conduct demonstration tests of autonomous navigation. Therefore, joint technological development by multiple private-sector companies that possess these technologies opens up possibilities for dramatic advances in technological development for fully autonomous navigation.

Demonstration tests at each consortium

5 As of November 2021, the five consortia were in the process of developing new equipment, systems, technologies, and frameworks with a view toward conducting demonstration tests by the end of March 2022. These tests were the world's first demonstrations using large vessels navigating over long distances through congested sea lanes.



Results of Demonstration Tests of Fully Autonomous Ship Navigation

6 In demonstration tests by four consortia with five ships, which were conducted in the coastal area of Japan under the Nippon Foundation MEGURI 2040 Fully Autonomous Ship Program, autonomous navigation including "collision avoidance" and "berthing and unberthing" has been achieved. Some milestones are shown as below.

.1 autonomous navigation in a congested sea area (roughly 500 ships pass each day), using the container ship **SUZAKU**.

.2 autonomous navigation under rough weather and sea condition together with mooring operations using a drone, using the container ship **MIKAGE**.

.3 autonomous navigation in long distance of 750 kilometres over roughly 18 hours, using the large car ferry **SUNFLOWER SHIRETOKO**.

.4 autonomous navigation (automated navigation from departure to docking), using the small passenger ship **SEA FRIEND ZERO**.

.5 autonomous port berthing and unberthing using turning and reversing movements as well as autonomous navigation under high-speed (up to 26 knots), using the large car ferry **SOLEIL**.

7 The obtained key knowledges through demonstration tests are shown below.

.1 Autonomous Navigation System (ANS) which had been installed in demonstration ships can be broken down into three functions: situation awareness (i.e. detection and integration), decision for collision avoidance (i.e. analysis and planning) and action (i.e. control and actuation). ANS consists of combination with existing technologies and new technologies. New technologies are, for example, applied to route planning for collision avoidance and ship motion controlling in the low-speed range.

.2 Operational Design Domain (ODD) of every ANS installed in demonstration ships were clarified in advance. ODD means the range of operation that ANS can work properly, in this paper.

.3 Human Machine Interface (HMI) for ANS status monitoring and override/fallback by the crew/operator of demonstration ships had been provided.

.4 Remote monitoring had been applied by 3 consortia and remote control had been applied by one consortium, because the necessary human intervention should be changed depending on the Concept of Operation (CONOPS) of MASS.

8 The information of following Demonstration Tests set out in the annexes:

.1 Designing the Future of Full Autonomous Ship: Grand design drawn by diverse specialists;

.2 Verification testing of fully autonomous technologies using coastal container vessels and car ferries;

.3 Fully autonomous navigation at Sarushima, Yokosuka; and

.4 Smart ferry development.

Action requested of the Committee

9 The Committee is invited to note of the information regarding Demonstration Tests of Fully Autonomous Ship Navigation on "MEGURI 2040", including the annexes.

***

ANNEX 1

Results of Demonstration Test of Fully Autonomous Ship Navigation ".1 Designing the Future of Full Autonomous Ship: Grand design drawn by diverse specialists"

Consortium members of Demonstration Test

1 The demonstration test was conducted by a consortium consisting of the following members:

.1 Japan Marine Science Inc. (leader)
.2 Bemac Corporation
.3 Eizo Corporation
.4 Furuno Electric Co., Ltd.
.5 Honda Heavy Industries Co., Ltd.
.6 Ikous Corporation
.7 Japan Hamworthy, Co. Ltd.
.8 Japan Marine United Corporation
.9 Japan Radio Co., Ltd.
.10 Kinkai Yusen Kaisha Ltd 11. Mitsubishi Research Institute, Inc.
.12 Mitsui Sumitomo Insurance Company, Ltd.
.13 Miura Co., Ltd.
.14 MTI Ltd.
.15 Nabtesco Corporation
.16 Nihon Shipyard Co., Ltd.
.17 Nippon Telegraph and Telephone Corporation
.18 Nippon Yusen Kabushiki Kaisha
.19 NTT Communications Corporation
.20 NTT Docomo, Inc 21. NX Shipping Co., Ltd.
.22 Pluszero Co., Ltd.
.23 Sanwa Dock Co., Ltd.
.24 Sky Perfect JSAT Corporation
.25 Sunflame Co., Ltd.
.26 Suzuyo Marine Co., Ltd.
.27 Tokio Marine & Nichido Fire Insurance Co., Ltd.
.28 Tokyo Keiki Inc.
.29 Weathernews Inc.
.30 YDK Technologies Co., Ltd.

Results of Demonstration on a Container ship

2 The demonstration test of a fully autonomous container ship and its Fleet Operation Centre for emergency monitoring and operation carried out from 26 February to 1 March. The test, using the container ship **SUZAKU**, demonstrated the sea route between Tokyo Bay and Ise Bay for the first time the use of a comprehensive fully autonomous navigation system (including remote control and land support) for a container ship operating in a congested sea area.

3 This successful demonstration test was of an operating system developed by the Designing the Future of Full Autonomous Ship (DFFAS) Consortium, made up of 30 companies from diverse fields using an open innovation framework. In the test, the **SUZAKU** (95 meters, 749 gross tonnage) navigated a 790 km round-trip route, departing from and returning to, Tokyo Bay by way of Ise Bay using a comprehensive fully autonomous navigation system, including remote operation from the Fleet Operation Centre in Chiba Prefecture.

4 Roughly 500 ships pass through Tokyo Bay each day, compared with roughly 40 through the Panama Canal and roughly 320 through the Straits of Malacca and Singapore. This successful demonstration in a highly congested area verified a high level of technological development that represented a significant step toward practical implementation. In addition to addressing the issues of aging crew and crew shortages facing the coastal shipping industry and the social issue of reduction in accidents, remote operation from land can be expected to introduce new work styles for industries and increase labour capacity for onboard crew.

5 With an eye toward full-scale implementation, the DFFAS Consortium developed a comprehensive fully autonomous navigation system with repeated risk assessments carried out from the design stage. The system has three primary components: (1) a ship-side navigation system that controls autonomous functions from the ship; (2) a land-side system that monitors and supports the ship from shore, including remote ship-handling functions; and (3) an information and communications system that enables stable communication between the ship and land.

6 The Fleet Operation Centre marks a particular advance, allowing fully autonomous navigation at sea with tracking from land of functions normally performed by crew, including the monitoring of weather and sea conditions, traffic flow, and the ship's equipment. In emergency situations, the system can switch to remote operation from the Fleet Operation Centre, ensuring the overall system's safety and stability.

7 The more information of DFFAS Consortium for Fully Autonomous Ship Project is provided in the appendix.

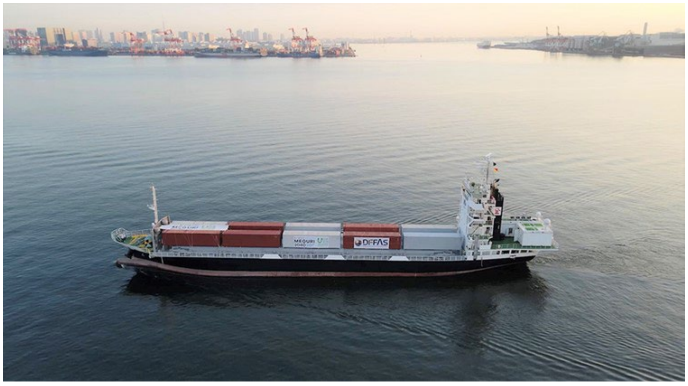


Figure 1: Container ship "SUZAKU"


Figure 2: Remote operation at the FOC

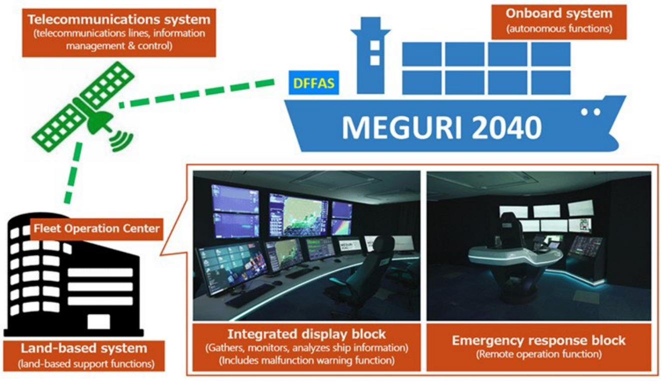


Figure 3: Overview of the DFFAS comprehensive fully autonomous navigation system

APPENDIX

DFFAS Consortium for Fully Autonomous Ship Project

DEVELOPMENT and DEMONSTRATION OF AUTONOMOUS SHIP in JAPAN

28th April 2022

DFFAS Consortium Approach for Design, Development and Demonstration of Fully Autonomous Navigation Ship

無人運航船プロジェクト MEGURI 2040

日本財団 THE NIPPON FOUNDATION

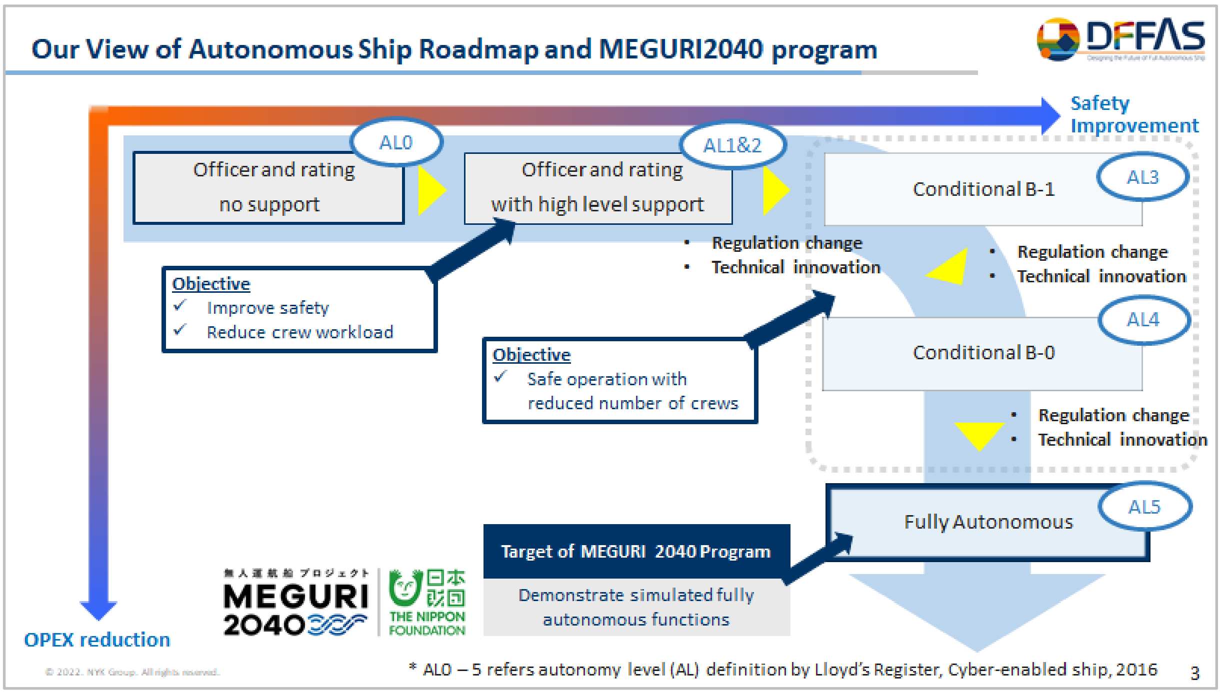
DFFAS Designing the Future of Full Autonomous Ship

NYK GROUP

Outline

1. **Introduction of DFFAS Project**
2. System overview
3. System design and development process
4. Demonstration
5. Summary

 2



Ambition of DFFAS Project in MEGURI 2040 Program

- ***Challenge***

  To solve labor shortage in the domestic shipping industry, which has supported Japanese domestic logistics with social implementation of fully autonomous ship technology

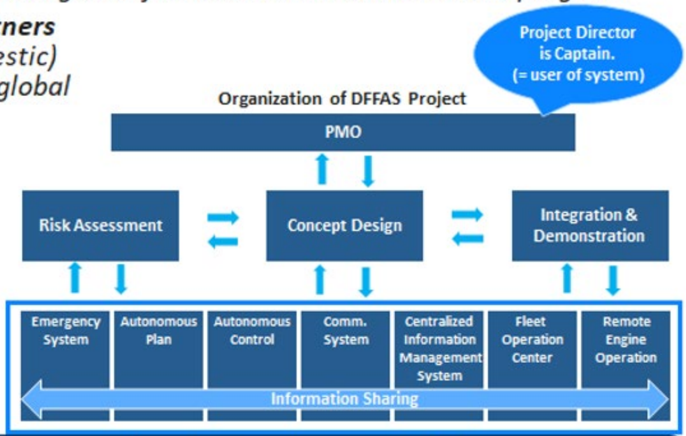
- ***Goal***

  Developing technologies that will lead to the future through Open Innovation, with a view to long-term industrial growth, and envisioning a Grand Design for autonomous ship in Japan and around the world.

4

DFFAS Project (Designing the Future of Full Autonomous Ship)

- ***Target***
  Demonstrate fully autonomous ship navigation functions under MEGURI 2040 program
- ***DFFAS consortium members & partners***
  Consortium: 30 organizations (domestic)
  Total: 60 + organizations (including global partners)
- ***Schedule***
  Feb 2020 – Mar 2022 (abt. 2 years)



Background target: Develop open architecture & open process for autonomous ship design, development, construct, commission and operation for to realize social implementation of autonomous ships for all AL levels.

 5

NYK GROUP

Outline

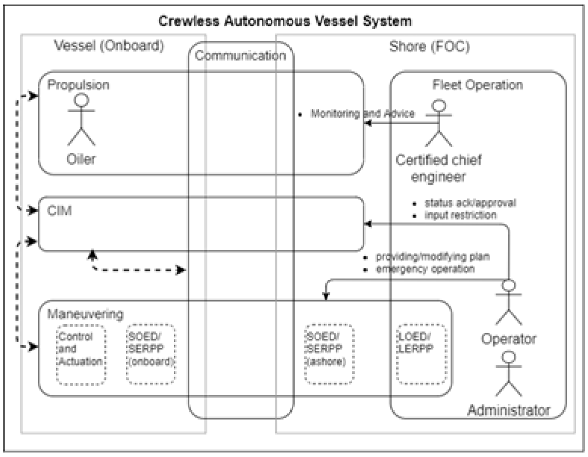
1. Introduction of DFFAS Project
2. **System overview**
3. System design and development process
4. Demonstration
5. Summary

 6

Definition of system requirements with deep domain knowledge

To formulate the conceptual design of an autonomous navigation system, two deep knowledge domains, the master mariners' and chief engineers' knowledge of the operational domain and the manufacturers' knowledge of the technical domain, are essential.

Master mariners and chief engineers, who are well versed in ship operations, lead the project, define the concept of operations (ConOps), design autonomous ship navigation system and perform a risk assessment, for eliciting system requirements together with engineers of manufactures and system specialists by using Model-Based Systems Engineering (MBSE) approach.



High level concept description by using use case diagram

7

DFFAS System Composition and System Status Definition

Subsystem	Main Function	
Maneuvering	• Collecting Information around Own Ship • Planning Collision Avoidance Actions	• Controlling Actuator • Monitoring & Operating DFFAS System remotely
Propulsion	• Collecting Information of Engine Condition	• Monitoring & Operating Engine Equipment remotely
Communication	• Achieving Communication between Ship & Fleet Operation Center (Shore)	• Monitoring Communication Quality
Fleet Operation Center System	• Collecting a Wide Variety Information from Shore & Ship (Weather, Traffic etc.)	• Planning a Long-Term Voyage Plan
Centralized Information Management System	• Collecting Condition of other Subsystems • Judgement the Status of DFFAS System	• Feedback the Determined Status of DFFAS System to each Subsystem

Status	Definition
Normal	System is running without any intervention by crew or fallback from shore
Active Monitoring	System is running under the verification by operator at shore
Remote Fallback	System is running under fallback operations by operator at shore
Independent Fallback	System is running under fallback operations by system on vessel

System status definition:
The definition of the whole system status is based on degree of engagement by human on shore and necessity of fallback operation.

8

Task category, Executor and Location

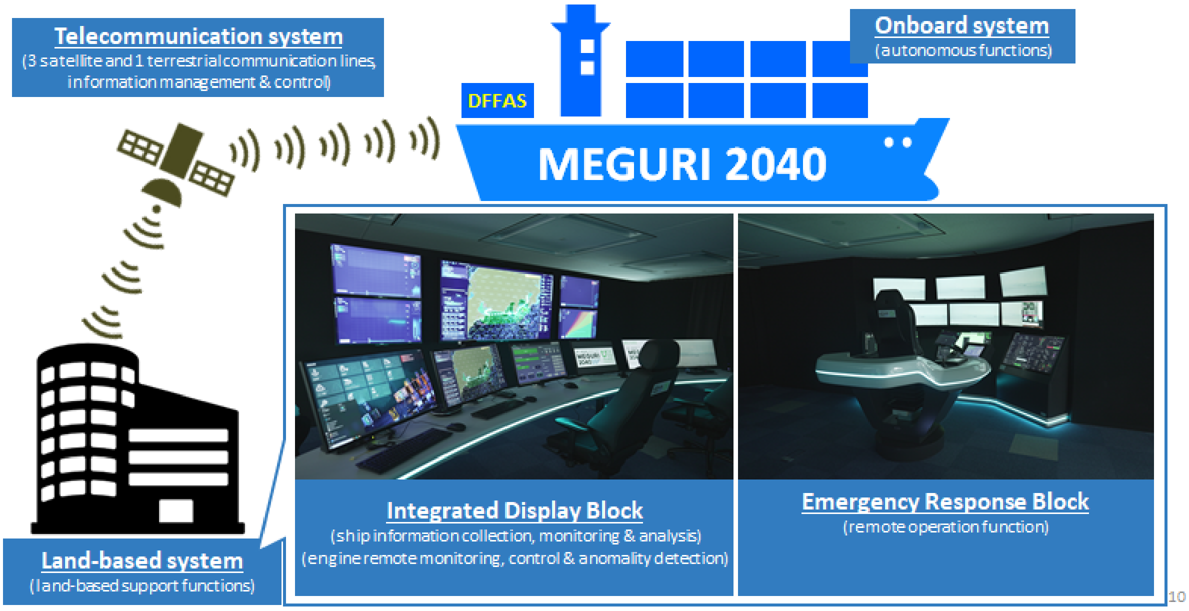
Task		Executor	Location
Situation Awareness (Detection)	Long Term Object & Event Detection (LOED)	Machine, Human	Shore
	Short Term Object & Event Detection (SOED)	Machine	On board
Decision Making (Integration / Analysis / Planning)	L-Event Response & Path Planning (LERPP)	Machine Human (Including / Restriction, Approval)	Shore
	S-Event Response & Path Planning (SERPP)	Machine	On board Shore (Status: AM / RFB)
		Human	Shore (Status: AM / RFB)
	CIM	Machine	On board
		Human (Operation for System Status)	Shore
Execution (Control / Actuation)	DTC and Propulsion	Machine	On board
(Independent) Fallback		Machine	On board

CIM: Centralized Information Management
DTC: Drive Train Controller

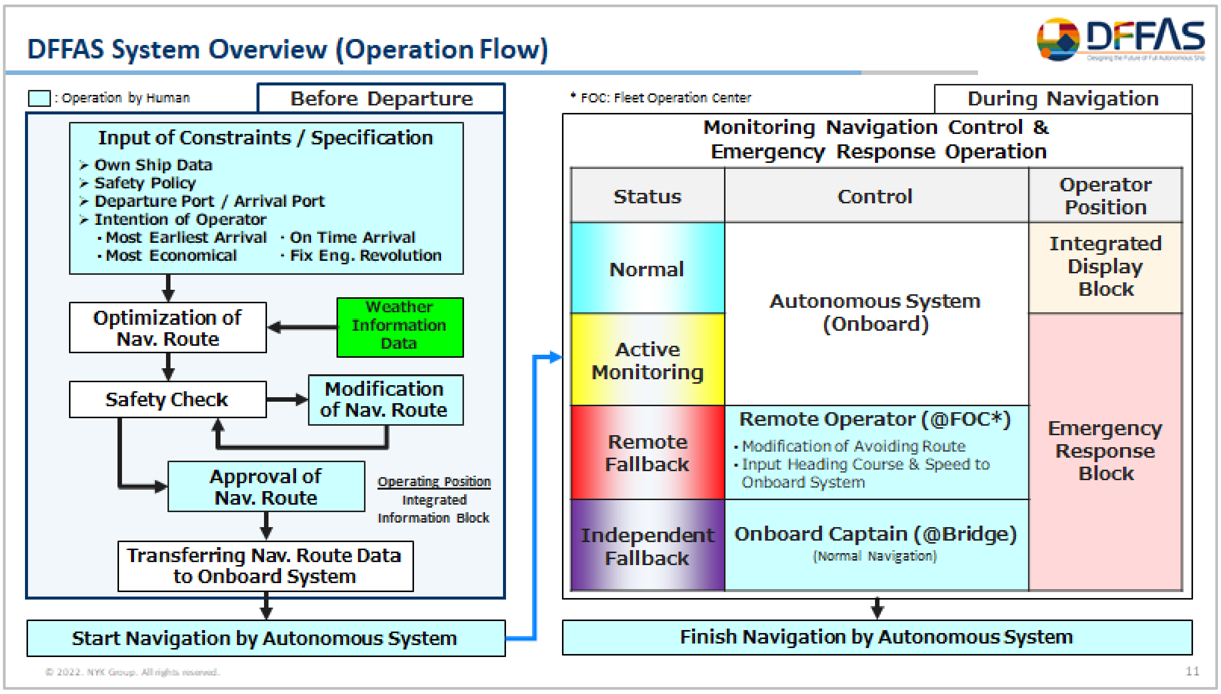
Ref) MTI, APExS-auto system overview, DFFAS PJ, MARCH 2022

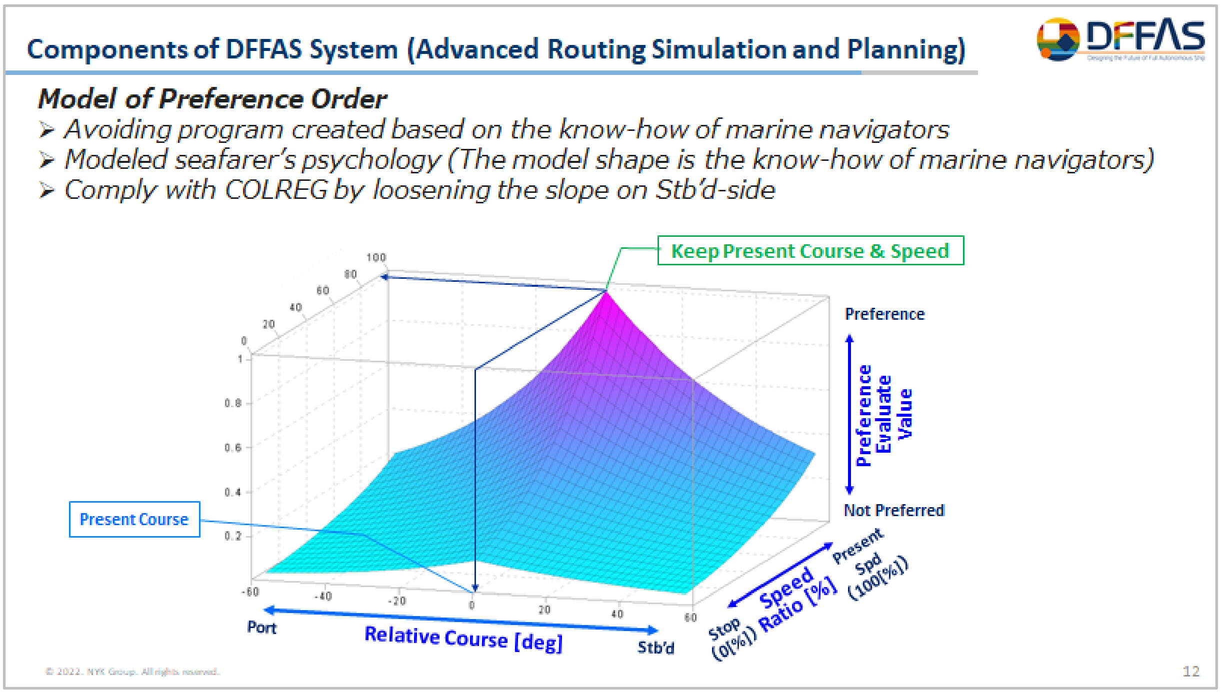
9

DFFAS System Overview



10

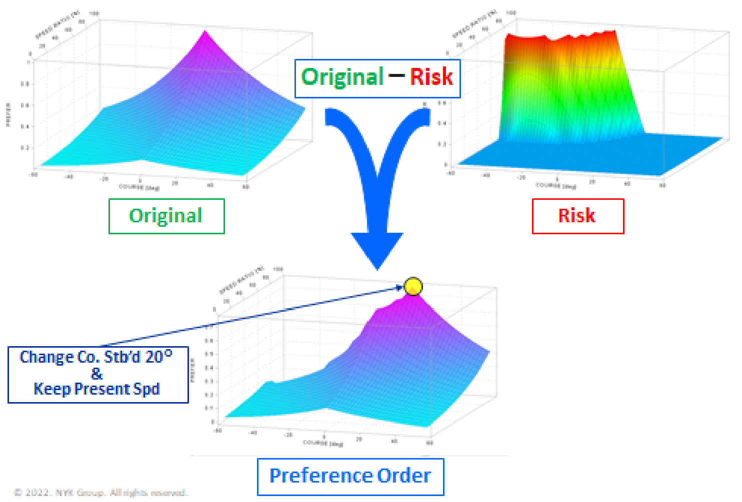

DFFAS System Overview (Operation Flow)
DFFAS
: Operation by Human
Before Departure
Input of Constraints / Specification
➢ Own Ship Data
➢ Safety Policy
➢ Departure Port / Arrival Port
➢ Intention of Operator
・Most Earliest Arrival ・On Time Arrival
・Most Economical ・Fix Eng. Revolution
Optimization of Nav. Route
Weather Information Data
Safety Check
Modification of Nav. Route
Approval of Nav. Route
Operating Position
Integrated Information Block
Transferring Nav. Route Data to Onboard System
Start Navigation by Autonomous System
* FOC: Fleet Operation Center
During Navigation
Monitoring Navigation Control & Emergency Response Operation
Status
Control
Operator Position
Normal
Active Monitoring
Autonomous System (Onboard)
Integrated Display Block
Remote Fallback
Remote Operator (@FOC*)
・Modification of Avoiding Route
・Input Heading Course & Speed to Onboard System
Independent Fallback
Onboard Captain (@Bridge)
(Normal Navigation)
Emergency Response Block
Finish Navigation by Autonomous System
11

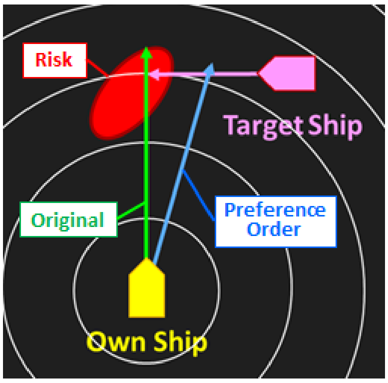

Components of DFFAS System (Advanced Routing Simulation and Planning)
DFFAS
Model of Preference Order
➢ Avoiding program created based on the know-how of marine navigators
➢ Modeled seafarer's psychology (The model shape is the know-how of marine navigators)
➢ Comply with COLREG by loosening the slope on Stb'd-side
Keep Present Course & Speed
Preference
Preference Evaluate Value
Not Preferred
Present Course
Port
Relative Course [deg]
Stb'd
Stop (0[%])
Speed Ratio [%]
Present Spd (100[%])
12

Components of DFFAS System (Advanced Routing Simulation and Planning)

Logic

Calculate Preference Order by subtracting Risk from original.





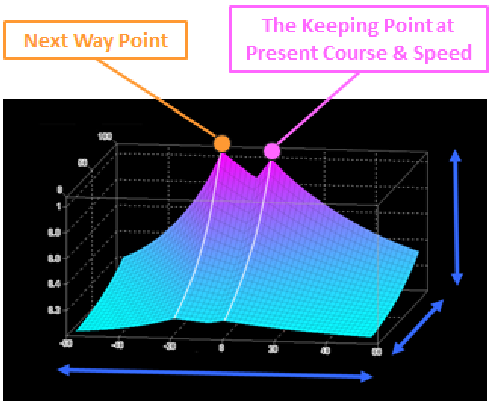
13

Components of DFFAS System (Advanced Routing Simulation and Planning)

In the actual navigation, after avoiding the target ship, it returns to the optimum position. Therefore, the reroute function was equipped by adding the concept of the next way point (set the optimum return point when the next way point is far) to the conventional model.

** If the vessel is navigating on the original route and there is no ship to be avoided, the keeping point at present course & speed and the next way point will be the same.*

Autonomous Navigation using ARS in Tokyo Bay



Situation after avoiding the target ship

14

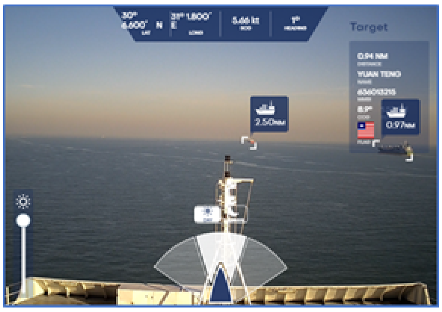
Components of DFFAS System for Supporting Remote Operator

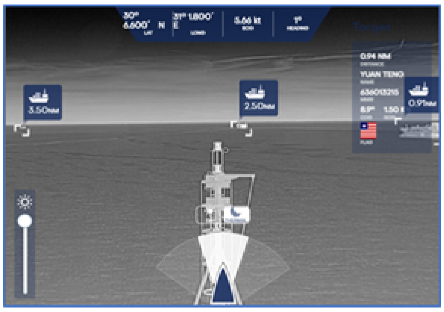
DFFAS

Computer Vision

RECONGNITION (Understanding The Situation around Own Ship) → ANALYSIS → PLAN → JUDGEMENT

Due to human characteristics, it is difficult to collect information at night or when visibility is poor, but we support information collection by making invisible and difficult-to-see targets clearly visible by utilizing image recognition and processing technology.





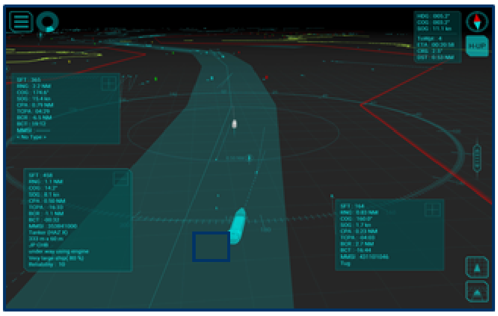
Components of DFFAS System for Supporting Remote Operator

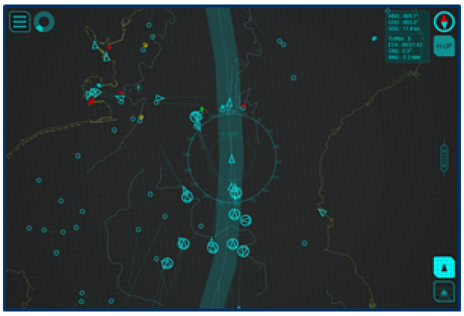
DFFAS

3D Bird View – Virtual Reality

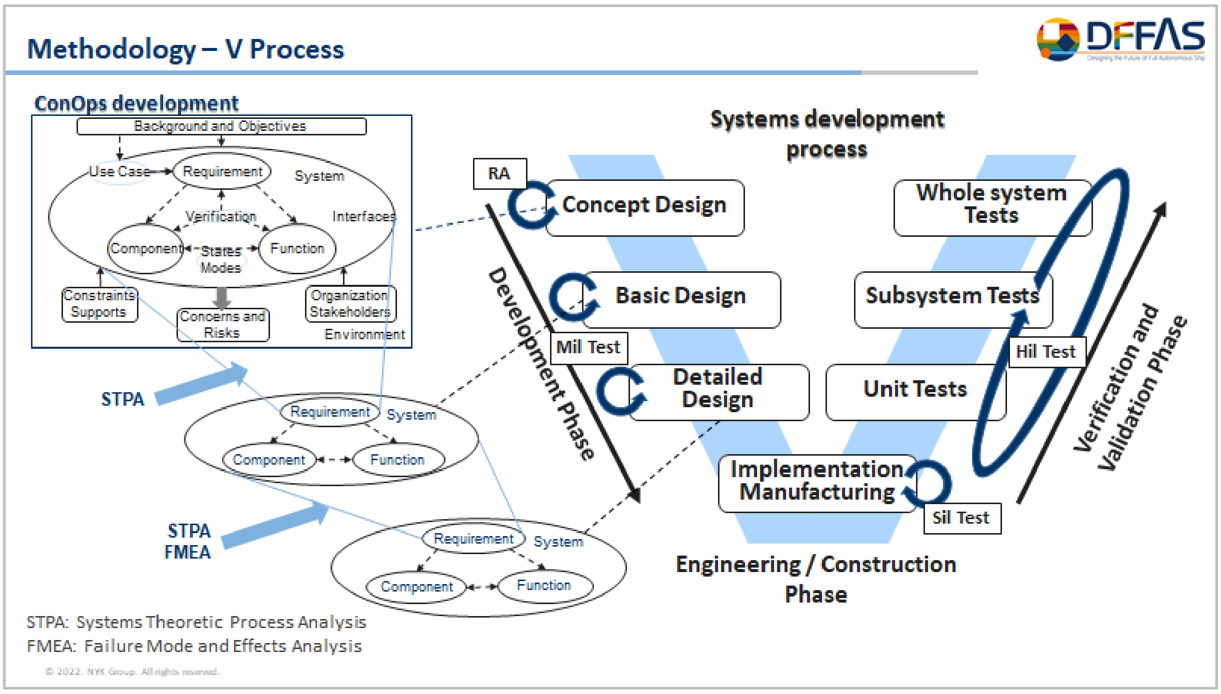
RECONGNITION (Understanding The Situation around Own Ship) → ANALYSIS → PLAN → JUDGEMENT

Supports ship maneuvering strategy planning by grasping the situation around the ship by sensor fusion and providing information in a form that allows the operator to intuitively grasp the situation (complementing the ability to grasp the space).






NYK GROUP
Outline
1. Introduction of DFFAS Project
2. System overview
3. System design and development process
4. Demonstration
5. Summary
© 2016. NYK Group. All rights reserved.
18


Methodology – V Process
DFFAS
ConOps development
Background and Objectives
Use Case
Requirement
System
Verification
Interfaces
Component
States
Modes
Function
Constraints
Supports
Concerns and
Risks
Organization
Stakeholders
Environment
STPA
Requirement
System
Component
Function
STPA
FMEA
Requirement
System
Component
Function
Systems development
process
RA
Concept Design
Basic Design
Mil Test
Detailed
Design
Development Phase
Implementation
Manufacturing
Sil Test
Unit Tests
Subsystem Tests
Hil Test
Whole system
Tests
Verification and
Validation Phase
Engineering / Construction
Phase
STPA: Systems Theoretic Process Analysis
FMEA: Failure Mode and Effects Analysis
© 2022. NYK Group. All rights reserved.

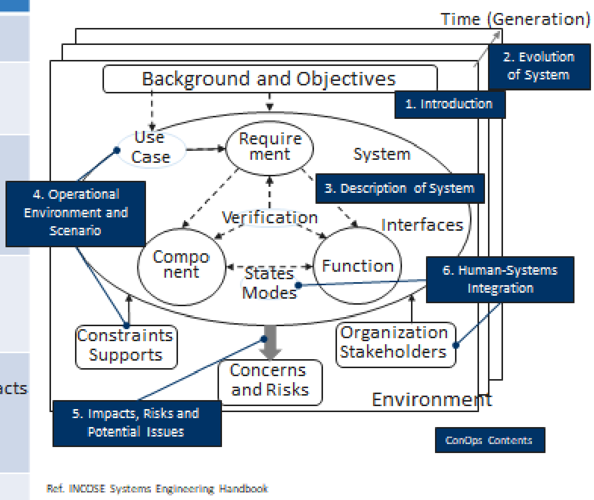
Concept of Operation (ConOps)

DFFAS

ConOps contents for autonomous system

Contents	Description
1. Introduction	• Background • System Scope, Assumption & Constraints
2. Evolution of System	• Justification for changes • Future Roadmap and Status of the envisioned system
3. Description of System	• Needs, Goals & Objectives of the system • Overview Architecture incl. Interfaces (Major System elements & interconnections) • Modes of Operation • Basic Functions (Proposed Capabilities)
4. Operational Environment and Scenario	• Use Cases (Nominal, Off nominal) • Actors/Stakeholders • Operational Scenario • Data flow (input & output of the system)
5. Impacts and Potential Issues	• Operational impacts, Environmental Impacts, Organizational Impacts, Scientific/Technical Impacts • Regulatory Compliance, How to Implement the system
6. Human-Systems Integration	• Human-in-the-loop involvement • Human-machine interface etc.
Appendix	• Glossary, Acronyms, Reference Documents

Required elements for system description



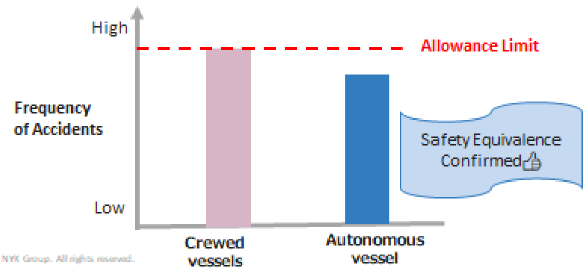
Ref. INCOSE Systems Engineering Handbook

20

Risk Assessment

DFFAS

- *Risk assessment process was done to verify equivalent safety of an autonomous system to existing crewed vessels, according to Guidelines on alternative design and arrangements (by IMO;MSC.1/Circ.1212).*
- *For comparison, frequency of accidents by crewed vessels was calculated using accident investigation data by Japan Transport Safety Board.*
- *Hazards were identified mainly via STPA and the process to accidents caused by the hazards were represented using Bow-Tie method.*
- *It was done to evaluate risk (estimation of accident frequency) and consider additional barriers needed on the Bow-Tie models.*



ConOps
- Goal and Objective
- Assumption
- Safety Constraints

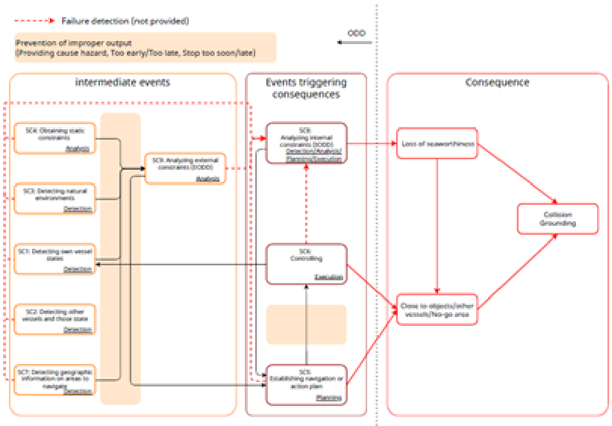
STPA
- Safety Constraints
- Hazard Casual Factor
- UCA (Threat): Violation for Safety Constraints

BowTie
- Threat = UCAs @ STPA control Structure
- Barriers
- Risk Evaluation

Safety Constraints (SC)

- *Violations of Safety constraints (SC) are defined as hazardous events, which should be avoided.*
- *SCs can be considered as the sub-goals to achieve the goal, safety autonomous navigation.*
- *Unsafe control actions were extracted by using STPA analysis and Bow-Tie risk assessments were used to define system requirements.*

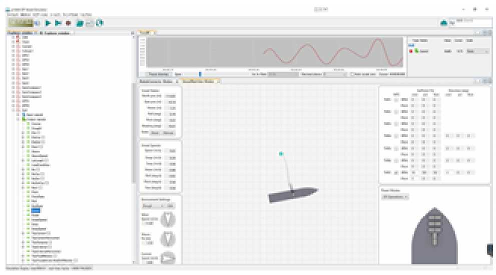
SC	Description
SC1	Own vessel states must be detected: system conditions and sensor-detected values etc.
SC2	Other vessels and those states must be detected: existence and course, heading, speed and positions.
SC3	Natural environments which affect the system must be detected: wind, wave, tidal stream, temperature, etc.
SC4	Static constraints which are essential to achieve voyage must be obtained.
SC5	Navigation and/or action plan must be established.
SC6	Control signal must be calculated based on navigation/action plan.
SC7	Geographic information to navigate must be detected.
SC8	Seaworthiness including condition of equipment and hull must be analysed and actions must be selected based on own status and surrounding environment.
SC9	Dynamic constraints must be analysed based on static constraints and internal/external environment (e.g., short stopping distance, Turning circle).



The autonomous system concept design, APExS-auto, received AiP from ClassNK and BV in March 2022

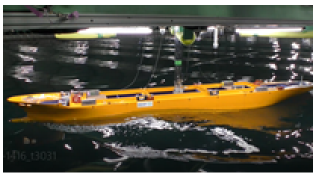
Simulation Tests for to Prevent Potential Failures of Control Systems

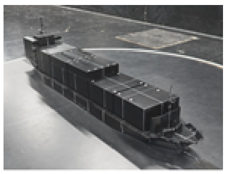
- *Simulation tests are utilized for unit test and system integration test.*
  - *MIL(Model-In-the-loop)*
  - *HIL(Hardware-In-the-loop)*
- *As the base of simulation test, simulation platform CyberSea(DNV) is used.*
- *Vessel dynamic models built as FMU*. FMU parameters of hull, thruster & rudder are calibrated based on model test results and actual ship data at sea trials.*

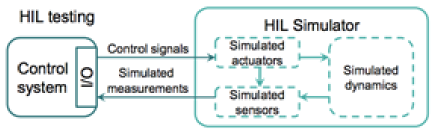


Simulation test platform CyberSea (DNV)

* FMU (Function Mockup Unit)







Ref) DNV Marine Cybernetics Advisory
https://www.dnvgl.com/services/hil-testing-concept-explanation--83385

System Integration Test @ Fleet Operation Center (Jun – Aug 2021)

- *System integration tests were conducted to identify issues before actual installation of the system on the target vessel*
- *All the system/equipment except for some sensors (e.g. radar) are integrated and tested with a virtual ship on CyberSea simulator.*
- *Normal/abnormal situations are tested for coastal navigation, berthing and unberthing scenario*
  - *Normal … 75 sequence*
  - *Abnormal … 34 sequence*
  - *Through voyage … 8 voyages*

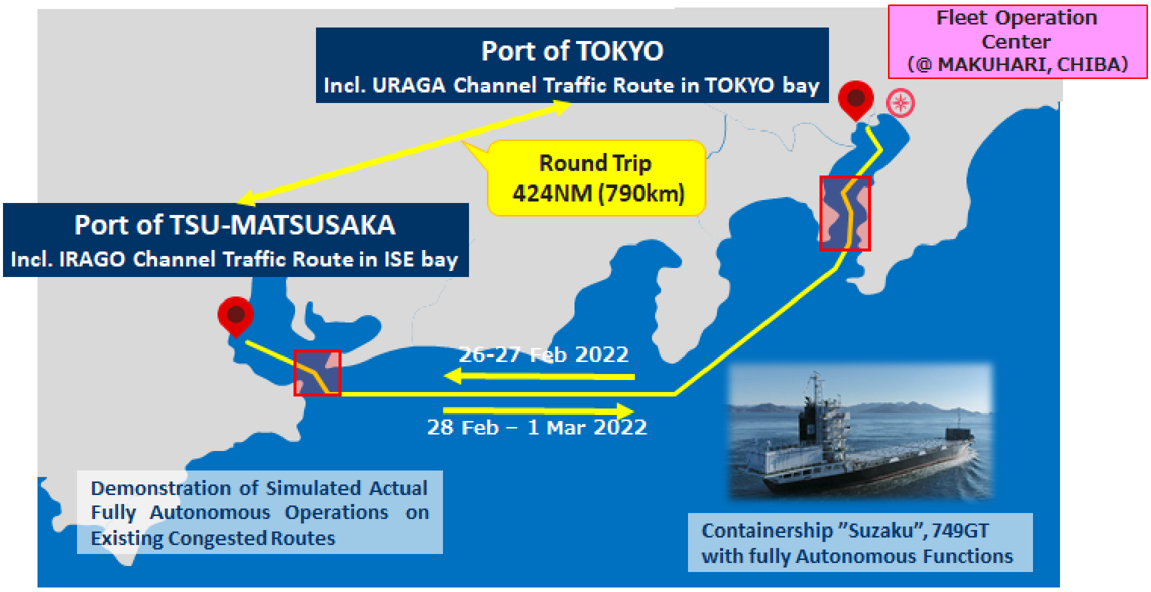
Snapshot of System Integration Test
@ Fleet Operation Center (FOC)

30 items undetected by STPA, FMEA, and unit and coupling tests were corrected prior to loading the system on the vessel.

Outline

1. Introduction of DFFAS Project
2. System overview
3. System design and development process
4. **Demonstration**
5. Summary

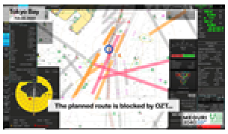
Demonstration Voyages in Feb & Mar 2022



26

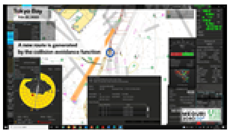
Example of Collision Avoidance using ARS* in Tokyo Bay

*Advanced Routing Simulation & Planning



7:59:16 AM

- The planned route is blocked by Obstacle Zone of Target (OZT) of other surrounding ships.

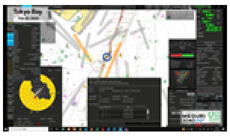


8:00:04 AM

- A new route is generated by the collision avoidance function
- The new route is automatically approved by the system under supervision by shore captain.

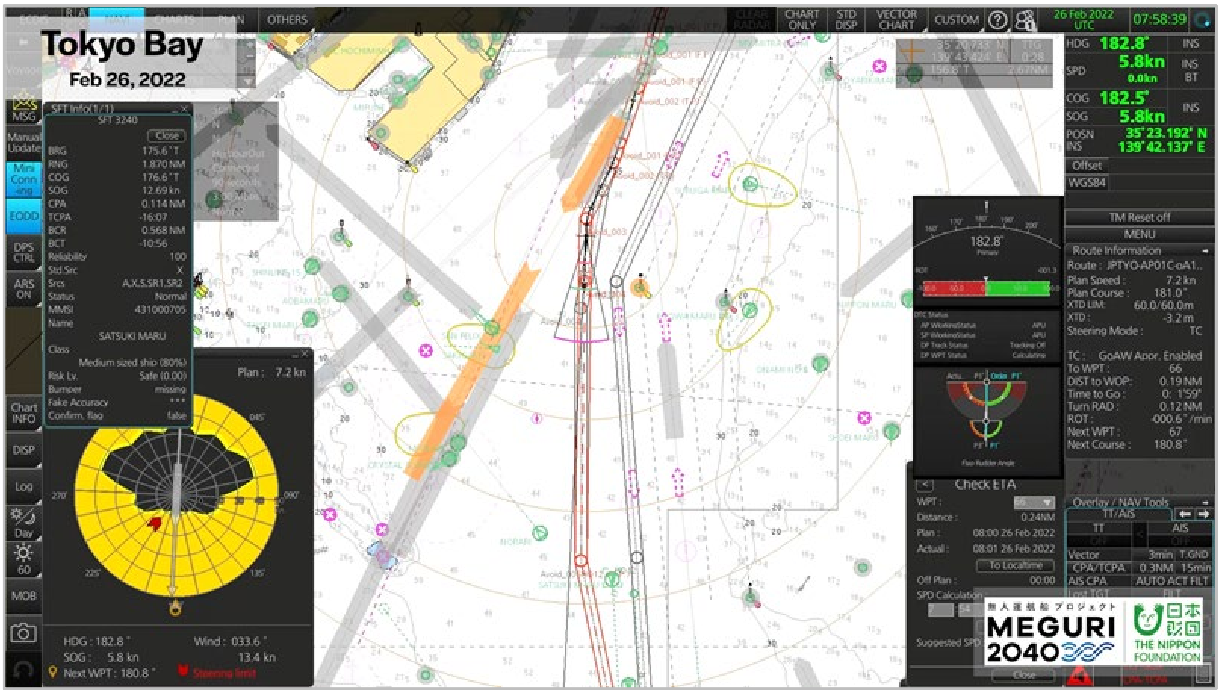
8:01:09 AM

- The new route is not blocked by OZTs and the vessel automatically track the new route.



8:01:53 AM

- The collision avoidance function generates a slightly modified new route due to occurrence of another OZT
- The new route is automatically approved by the system under supervision by shore captain.



Results of demonstration voyages

- ***Westbound (26 - 27th Feb. 2022)***
  Port of Tokyo → Port of Tsu-Matsusaka off

  Distance: 207.5NM (384.3KM)
  Sailing time: 20h10m
  Hours of autonomous operation: 19h39m
  Ave. Speed: 10.3kt
  Actions for collision avoidance: 107 times
  **** Number of avoiding ships were not countable***

Percentage of autonomous operation

97.4%

- ***Eastbound (28th Feb. - 1st Mar. 2022)***
  Port of Tsu-Matsusaka off → Port of Tokyo

  Distance: 216.4NM (400.8KM)
  Sailing time: 19h38m
  Hours of autonomous operation: 19h34m
  Ave. Speed: 11.0kt
  Actions for collision avoidance: 34 times
  **** Number of avoiding ships were not countable***

Percentage of autonomous operation

99.7%

29

NYK GROUP

Outline

30

Summary

DFFAS

- *The DFFAS (Designing the Future of Fully Autonomous Ships) Consortium, which consists of more than 60 partners from Japan and overseas, is working on the Fully Autonomous Ship Program "MEGURI 2040" promoted by The Nippon Foundation. Its purpose is to solve the social problem of labor shortage facing Japan. To that end, we are working on the goal of developing an autonomous navigation system and implementing it in society.*
- *During the demonstration voyage in February 2022, we successfully conducted the first in the world to conduct long-distance voyages in congested areas with unmanned ship operations.*
- *In the development of the system, we are using MIL (Model-In-the-Loop) and HIL (Hardware-In-the-Loop) for verification & validation of the system to build system quality and improve the productivity of the development process.*
- *We are convinced that the various insights gained through this development process and the engineering methods introduced, such as model-based design and model-based development, are very important that the maritime industry should utilize them for tackling further complex systems.*

31


DFFAS
Designing the Future of Full Autonomous Ship
Source: DFFAS CONSORTIUM
無人運航船プロジェクト
MEGURI 2040
日本財団
THE NIPPON FOUNDATION
Legal Disclaimer
No part of this document shall be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of NYK Line.
© 2016. NYK Group. All rights reserved.

***

ANNEX 2

Results of Demonstration Test of Fully Autonomous Ship Navigation ".2 Verification testing of fully autonomous technologies using coastal container vessels and car ferries"

Consortium members of Demonstration Test

1 The demonstration test was conducted by a consortium consisting of the following members:

.1 Mitsui O.S.K. Lines, Ltd. (leader)
.2 Furuno Electric Co., Ltd.
.3 Mitsui E&S Shipbuilding Co., Ltd.
.4 A.L.I. Technologies Inc.
.5 MOL Marine & Engineering Co., Ltd.
.6 MOL Ferry Co., Ltd.
.7 Imoto Corporation
.8 Imoto Lines, Ltd.

Results of Demonstration on a Container ship

2 The demonstration test, carried out on January 24-25 in 2022, a fully autonomous domestic container ship **MIKAGE** navigated a 270 km sea route from Tsuruga, Fukui Prefecture, to Sakaiminato, Tottori Prefecture. In addition to being the first time for an operating container ship to use a fully autonomous navigation system, the test marked the first use of drones for mooring operations (securing the vessel to a wharf with ropes). The fully autonomous ship navigation system, drone-assisted mooring operations, an automated berthing and unberthing system and augmented reality (AR) navigation system for monitoring from land developed for this project are expected to contribute to greater ship safety and reduce crew workloads.

3 Container ships of roughly the **MIKAGE**'s size (749 gross tonnage) play an important role in coastal transport in Japan, accounting for roughly 10% of coastal vessels in operation. At the same time, the length of their voyages combined with crew shortages places a significant burden on crew members. This successful demonstration of fully autonomous operation of an operating container ship paves the way for future technological applications that will address the issues of crew shortages and heavy crew workloads, and also contribute to the reduction of operating costs.

4 For this demonstration test, the **MIKAGE** was equipped with a developed system for another ship detection based on AI learning with an automatic identification system (AIS) and radar, as well as visible light cameras and infrared cameras for use at night. The fully autonomous ship navigation system was also developed to avoid collisions based on the movements of other ships, and this was successfully demonstrated as well. In addition, an unmanned system using drones was developed to bring the heaving lines that secure the ship to the wharf, reducing the workloads of crew during mooring. The fully autonomous ship navigation system required monitoring from land, and this was done with a system that used AR technology to superimpose information sent from the ship onto a screen.

Figure 1: Container ship "Mikage"

Figure 2: Mooring operations using a drone

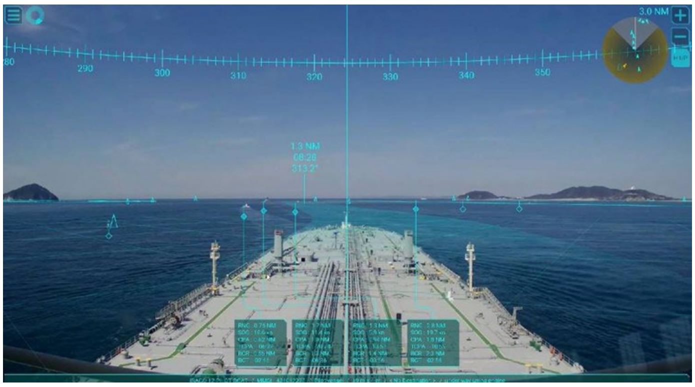


Figure 3: AR navigation system displayed on monitoring screens in the ship's control room and on land monitoring centre

Results of Demonstration on a large car ferry

5 The demonstration test, carried out on 6 and 7 February on the large car ferry "Sunflower Shiretoko" (190 meters, 11.410 gross tonnage) travelled a distance of 750 km over roughly 18 hours, from Tomakomai, Hokkaido, to Oarai, Ibaraki Prefecture, marking the world's longest successful demonstration of fully autonomous navigation in terms of both distance and time. Technologies developed for this project included an automated berthing and unberthing system and an AR navigation system for monitoring from land, which will contribute to improved safety and reduction of workloads for ships' crew.

6 Large car ferries transport both cargo and people simultaneously and play an important role in domestic logistics in Japan, with marine transport handling more than 80% of logistics between Hokkaido and the Kanto region in particular. At the same time, the number

of domestic passenger ferry crew members has declined by 30% since 2000, to roughly 7.000 from roughly 10.000,* and the length of car ferry voyages creates workload issues for the crew. The success of this demonstration test over a long distance and long time is expected to help reduce both crew workloads and operating costs.

7 For this test, the **Sunflower Shiretoko**, a large car ferry operated by MOL Ferry Co., Ltd., was equipped with a fully autonomous navigation system. The vessel was equipped with a developed fully autonomous ship navigation system for another ship detection based on AI learning, using information from an automatic identification system and radar, as well as visible light cameras and infrared cameras for use at night. Algorithms were also developed to avoid collisions with other ships. As these vessels will need to be monitored from land, an AR navigation system was developed using AR technology to superimpose various information onto images sent from the vessel.

Ensuring the safety of demonstration test

8 Prior to demonstration test demonstration, ClassNK Consulting Services Co., Ltd. conducted a risk assessment of the test ships using the HAZID method, and MOL Marine & Engineering conducted a ship manoeuvring simulation of the test ships using a 3D simulator to ensure the safety of the demonstration test.

Figure 4: large car ferry **Sunflower Shiretoko**

* According to Ministry of Land, Infrastructure Transport and Tourism, Maritime Bureau data.

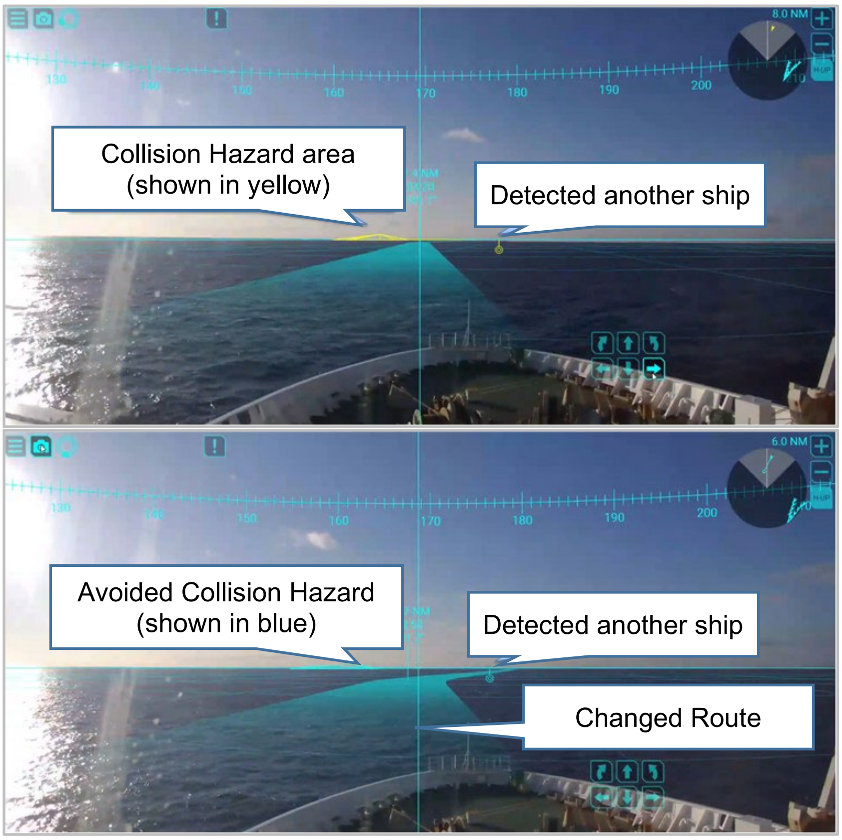


Figure 5: Image of an evasion plan after another ship has been detected ahead

***

ANNEX 3

**Results of Demonstration Test of Fully Autonomous Ship Navigation
".3 Fully autonomous navigation at Sarushima, Yokosuka"**

Consortium members of Demonstration Test

1 The demonstration test was conducted by a consortium consisting of the following members:

- .1 Marubeni Corporation (leader)
- .2 Mitsui E&S Shipbuilding Co., Ltd.
- .3 Tryangle Inc.
- .4 Yokosuka City (Kanagawa Prefecture)

Results of Demonstration on a small passenger ship

2 The demonstration test, carried out on 11 January 2022, an autonomous small passenger ship **SEA FRIEND ZERO** navigated the waters around Sarushima, an island off the coast of Yokusuka City in Kanagawa Prefecture. This was the world's first successful demonstration of fully autonomous navigation (automated navigation from departure to docking) of a small tourism boat, and the application of this technology is expected to allow small boats to be used to support the daily lives of residents of offshore islands and alleviate Japan's shortage of ship operators, more than half of whom are over the age of 50.

3 The vessel navigated a roughly 1.7 km route from Shin-Mikasa Pier to Sarushima, including departure and docking. The vessel was equipped with various sensors including three cameras, which were used for image analysis to detect small boats, a global navigation satellite system, and an automatic identification system (AIS). The system, which used sensor data to detect other ships or obstacles, processed that information and sent it to the fully autonomous navigation system, which automatically navigated around the obstacle. The fully autonomous navigation system also handled docking and departure, which are difficult even for manned crews, with a throttle lever in the control room automatically making repeated, incremental movements.

Figure 1: Small passenger ship "Sea Friend Zero"

Figure 2: Automated throttle lever

Figure 3: Cameras mounted on the vessel to detect obstacles

***

ANNEX 4

Results of Demonstration Test of Fully Autonomous Ship Navigation ".4 Smart ferry development"

Consortium members of Demonstration Test

1 The demonstration test was conducted by a consortium consisting of the following members:

.1 Mitsubishi Shipbuilding Co., Ltd. (leader)
.2 Shin Nihonkai Ferry Co., Ltd.

Demonstration test and development highlights

2 The demonstration test of the world's first fully autonomous ship navigation systems of a large car ferry **SOLEIL** was conducted on a 240 km route from Shinmoji in Northern Kyushu to Iyonada along the Japanese coast, which takes approximately 7 hours, at a maximum speed of 26 knots, and successfully completed on 17 January 2022. The newly built coastal ferry (222 meters, 15.515 gross tons) began navigating with onboard crew on 1 July 2021, compiling data for the development of a fully autonomous ship navigation system.

Figure 1: Coastal car ferry **SOLEIL**

3 The test vessel was equipped with:

.1 a high-precision sensor image analysis system with infrared cameras that can detect and locate other ships and obstacles even in darkness;
.2 a SUPER BRIDGE-X automated ship navigation system that, combined with autopilot system, provides track control and automated avoidance function; and
.3 an advanced automated port berthing/unberthing operation system that can perform turning and reversing movements, which are even difficult for manned vessels.

4 One of the biggest issues for a fully automated vessel is that onboard maintenance or repair of systems and equipment is not possible in case of failure or malfunction of them while underway. Therefore, enhanced engine monitoring technologies that monitor engine conditions are being developed and tested as well with a view to predicting and preventing faults. In this project, various other technologies essential to the practical application of fully autonomous navigation were also developed, which includes platforms for advanced data security to protect the navigation data used for onshore monitoring and support.

Automated navigation

5 To realize the fully automated navigation between ports, the automation systems were developed for navigation outside and within ports, respectively. Each system was provided with input from object detection and ranging systems to detect and locate surrounding ships and other obstacles.

Automated ship navigation system

6 Outside ports, route tracking was performed using the track control function of the autopilot system of the ship combined with a SUPER BRIDGE-X navigation support system provided by MHI Marine engineering, LTD. Automated navigation was achieved by tracking a planned route with heading and speed control and collision avoidance functions. In the trial, the system performed those functions several times even in high traffic density areas, and accumulated experience and data were used to sophisticate the system to be acceptable to crew.

Figure 2: Automatic ship collision avoidance carried out during the trial

Automated berthing/unberthing operation system

7 In port and during berthing operation, a ship had to follow a planned route with high accuracy and thus this system was developed to perform advanced manoeuvring using thrusters as well as a rudder and a propeller. In this system, AI is used to determine the optimal output of the rudder, propeller, and thrusters, achieving highly accurate route tracking.

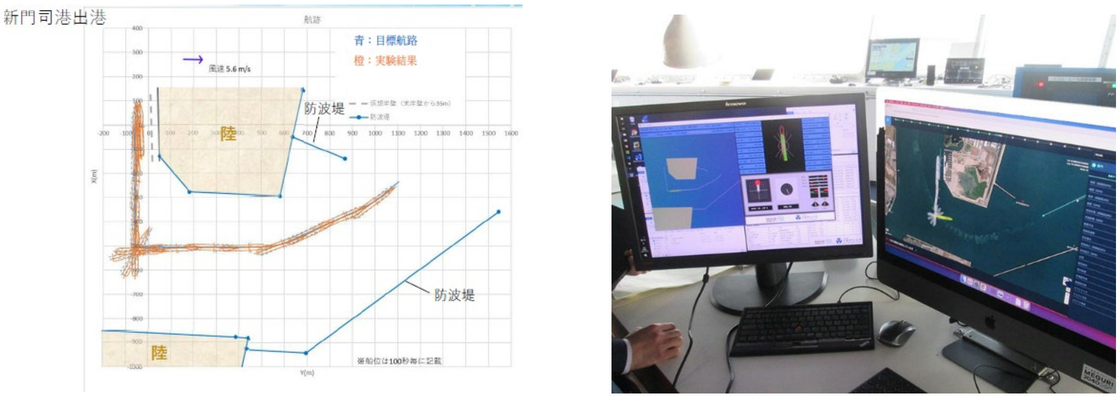


Figure 3: Automatic ship unberthing(left) and automated berthing/unberthing system monitor and navigation monitor (right)

Object detection and sensor image analysis system

8 To provide automated navigation system with position and speed with direction (velocity vector) of obstacles to navigation, such as other ships and buoys, as radar and/or AIS do, object detection and image analysis system was developed. For this purpose, the ship was equipped with infrared cameras (telephoto cameras to detect objects within approx. 2 km and wide-angle cameras for short-range detection), enabling high-precision detection, positioning, and ranging of objects even at night. The result of the test demonstrated that the system was capable of recognizing and locating other ships and buoys and of detecting objects up to approx.2 km away from the ship. Position of objects calculated by the system was close to the AIS data, while there was still room for improvement in accuracy and stability of calculating a velocity vector (path and direction) of an object.

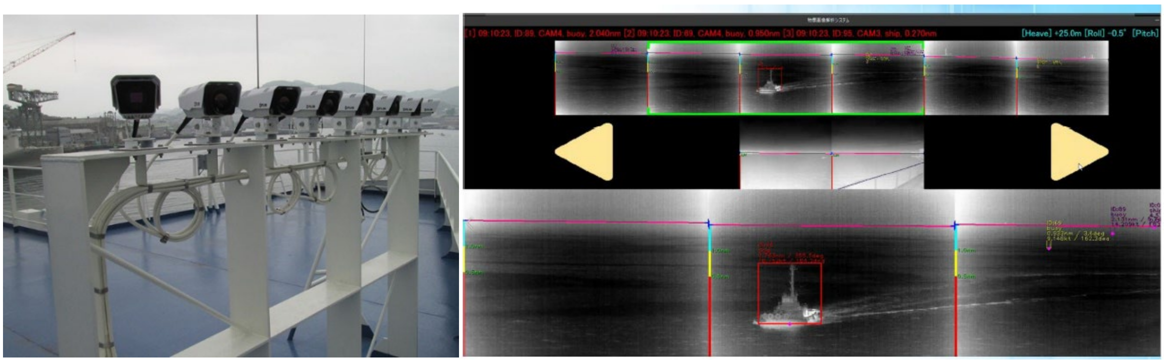


Figure 4: Infrared cameras (left) and recognized other ship (right)

____