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TRANSPORTATION RESEARCH BOARD (TRB) Virtual Event
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NYK's Approach for Autonomous Ship
- Building a Conceptual Framework for Open Collaboration

15th March 2021

Hideyuki Ando

Director, MTI (NYK Group)

NYK GROUP

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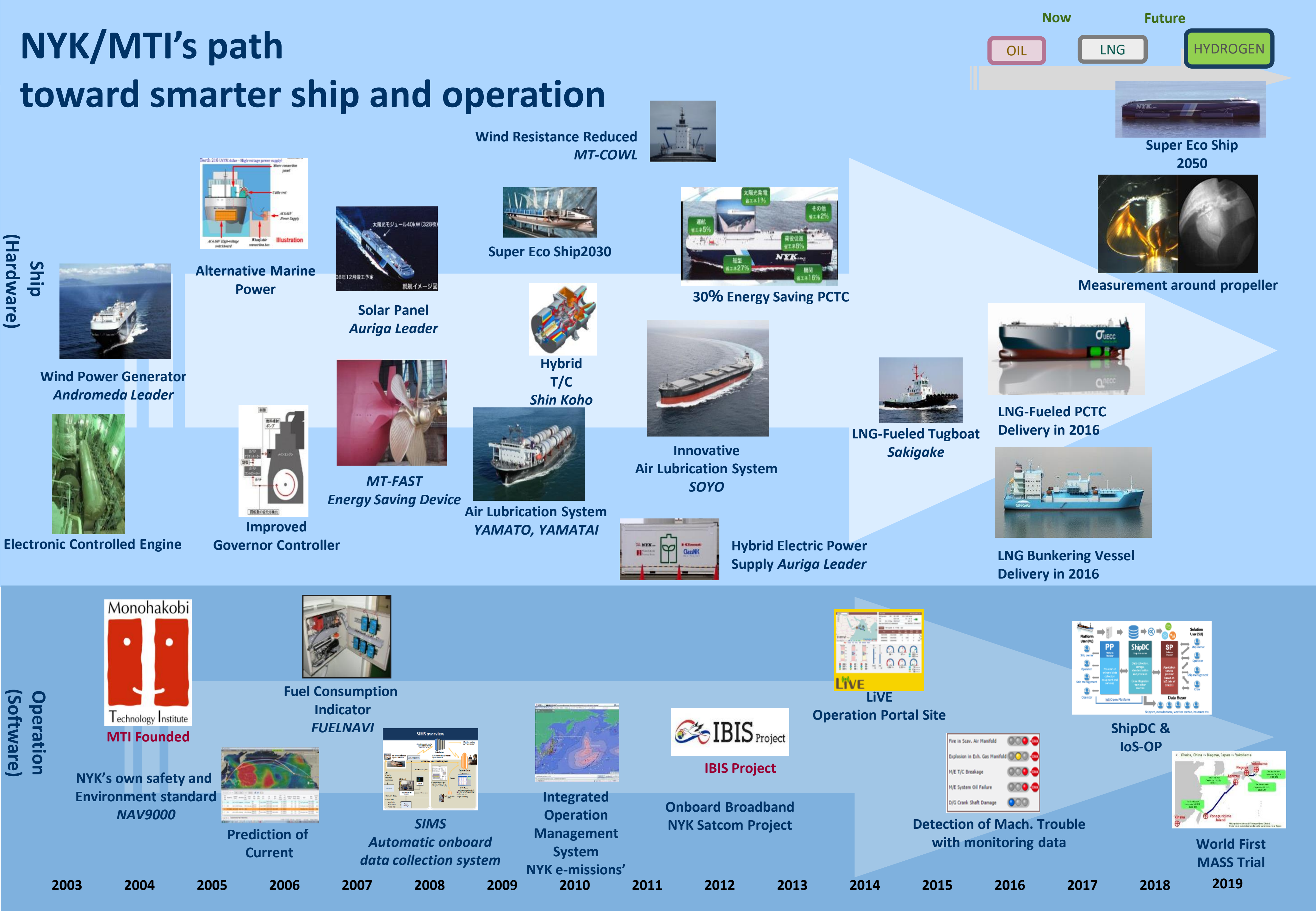
NYK LINE

- Head Office: Tokyo, Japan
- Founded: September 29, 1885
- Business Scope
  - Liner (Container) Service
  - Tramp and Specialized Carrier Services
  - Tankers and Gas Carrier Services
  - Logistics Service
  - Terminal and Harbor Transport Services
  - Air Cargo Transport Service
  - Cruise Ship Service
  - Offshore Service
- Employees: 34,857 (as of the end of March 2020)
- Revenues: 1,668,355 Million JPY (≒15.8 billion USD) (Fiscal 2019)

MTI (R&D Arm of NYK LINE)

- Established : April 1, 2004
- Equity capital : JPY 99 million
- Stockholder : NYK Line (100%)
- Number of employees : 69 (as of 1st April, 2020)

NYK/MTI's path toward smarter ship and operation



Contents

Value creating digitalization in shipping

1. Deep understanding of operating fleet and market
2. Optimized logistics and operations
3. Anticipation of failures

Better decisions

Continuous learning ↑

↓ Continuous Improvement

Pursuing total optimization of operation and ship

4. Incremental automation of ship functions

5. Monitoring fleet performance and improvement

Safer, more consistent operations

Reference) McKinsey Company, How digital innovation can improve mining productivity, 2015
https://www.mckinsey.com/industries/metals-and-mining/our-insights/how-digital-innovation-can-%20improve-mining-productivity

R&D projects for safer operation
- open collaboration with industry partners -

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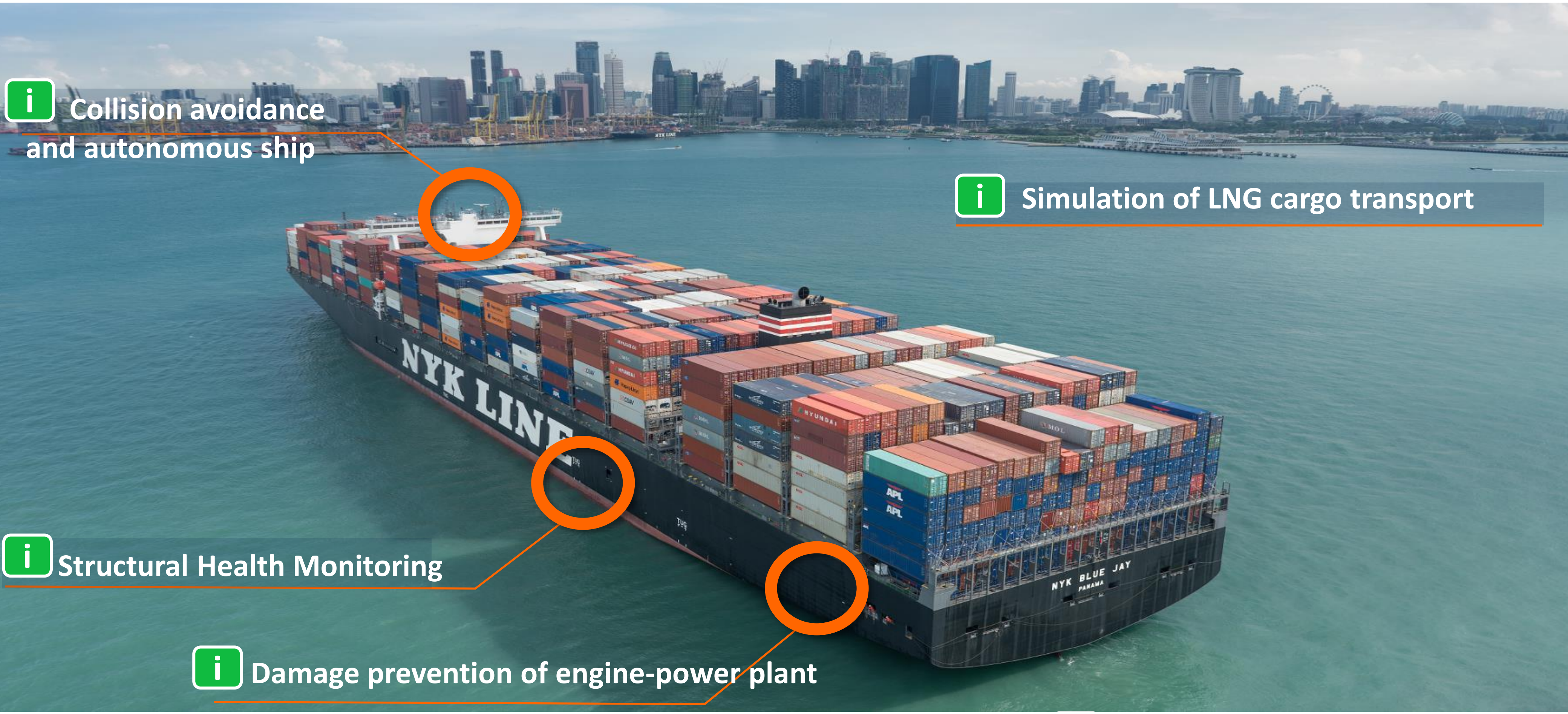

MLIT Ministry of Land, Infrastructure, Transport and Tourism

ClassNK

i-Shipping(Operation):
Japanese government funding R&D projects – IoT for safety (2016-2020)
Joint research with ClassNK

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Our activities toward Autonomous Ships

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Our objective

- Improve Safety (reduce the number of accident)
- Reduce workload (new approaches for future crew shortage)

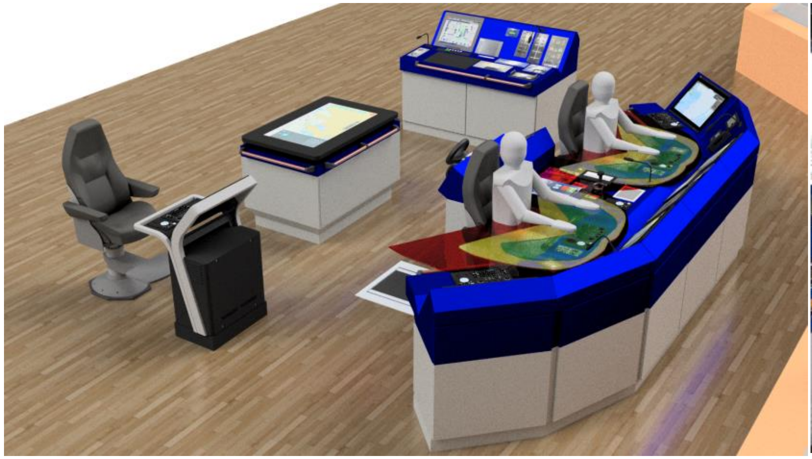
What do we need ?

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

How to approach ?

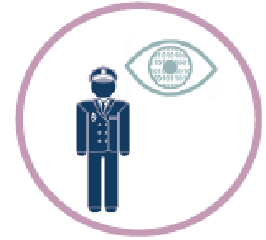
- User-centric … Involvement of experienced captains with know-how, skills & experiences to lead projects to the right direction
- Continuous improvement … identify the right issues to solve and improve step-by-step (bottom-up approach)
- Open collaboration with best partners

Manned-Autonomous Ship



Provided by Japan Radio Co. Ltd.

- Advanced support system … additional functions to assist cognitive process of human operator based on existing navigation system
- Autonomous operation under approval of human operator



AL3

- Cyber access for autonomous/ remote monitoring and control
- onboard permission required
- onboard override possible

Information Acquisition → Analysis → Planning → Approval

Manned Autonomous	Onboard Equipment Seafarer	Onboard Equipment Seafarer	Onboard Equipment Seafarer	Seafarer

Reference：1) Lloyds Register, “Current and Emerging Cyber Risks facing Maritime Industries”, European Maritime Cyber Risk Management Conference, London, June 2017

Contribution of Autonomous Ship for Deep Sea

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Safety improvement

Officer and rating no support → **Officer and rating with high level support** → Conditional B-1 with high level support

- **Regulation change**
- **Technical innovation**

Conditional B-1 with high level support

- Regulation change
- Technical innovation

Conditional B-0

- Regulation change
- Technical innovation

Full Autonomous

OPEX reduction

Short-term target

Objective

✓ Improve safety
✓ Reduce crew workload

What do we need?

✓ Computer complement human factor
✓ Good balance of PPTO (People, Process, Technology & Organization)

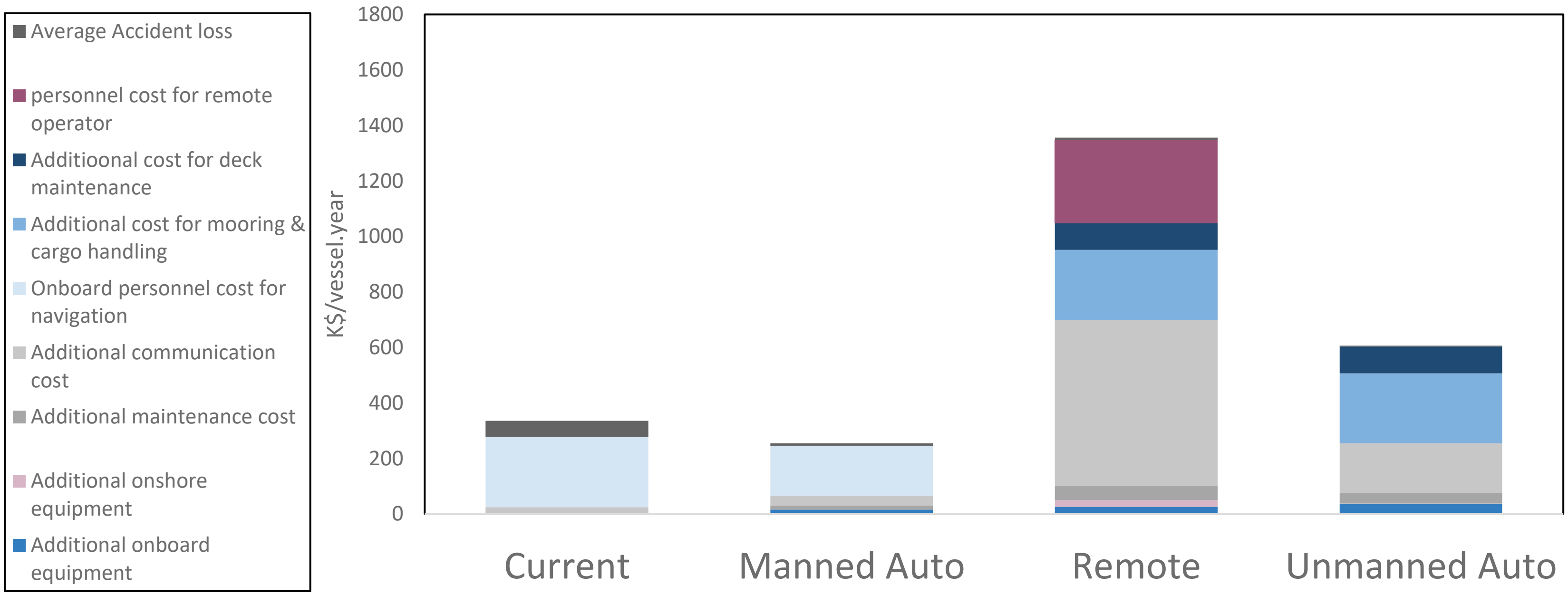
Mid&Long-term target

Objective

✓ + OPEX reduction

Economic evaluation (case: deep-sea going vessel)

Based on a feasibility study, at the current stage, manned-autonomous navigation has the highest economic performance with practicability.



Cost efficiency	Base	+	– –	–
Incident risk	Base	+	+	+ +
Workload	Base	+	+ +	+ +
Cyber risk	Base	Base	– –	–
Total reliability	Base	+	–	–

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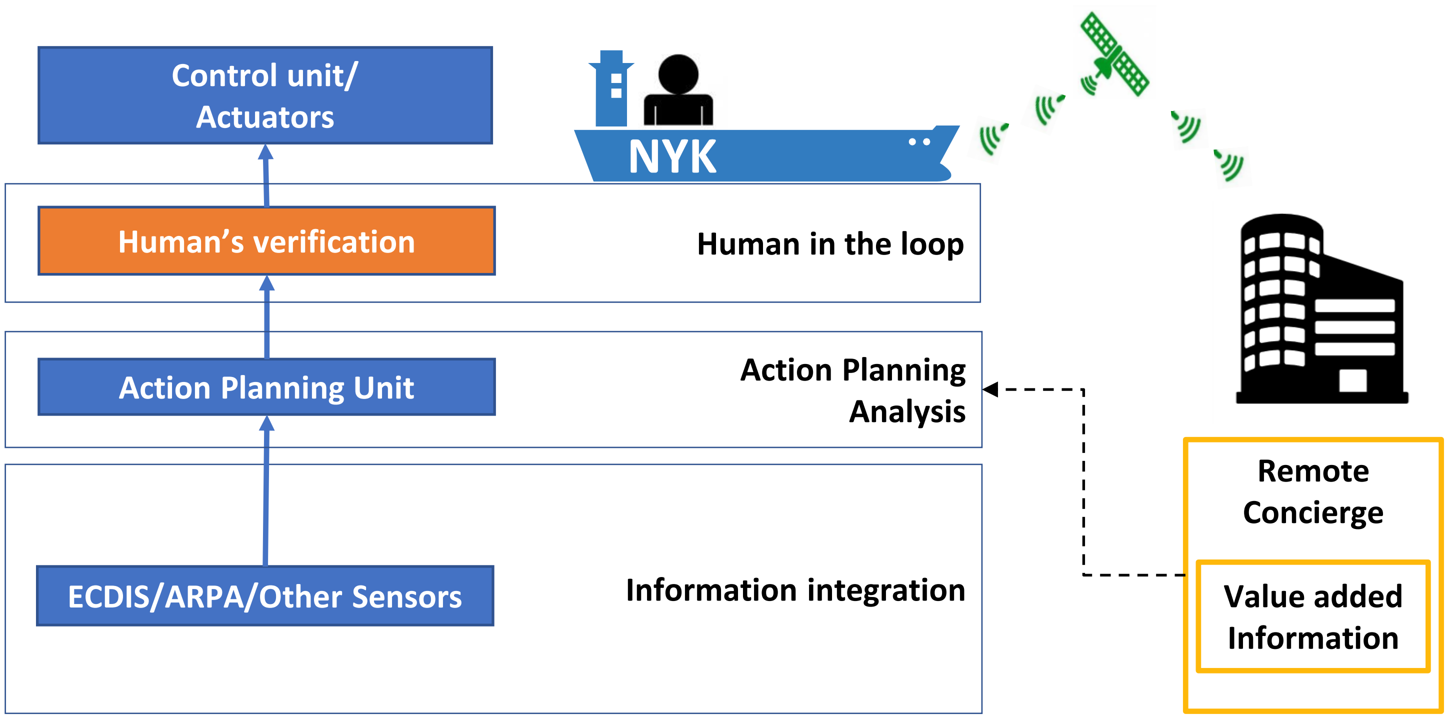
A Conceptual framework - Action Planning and Execution System (APExS)

- NYK group defines a manned-autonomous system framework as ***Action Planning and Execution System (APExS).*** The concept of APExS receives AiP (Approval in Principle) approval by ClassNK in 2020.



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.

Division of roles
– machine and human operator -

Table 1. Division of roles between machine and human operator.

Task No.	Task	Main	Sub
1	Information acquisition	Machine	Human
2	Information integration	Machine	Human
3	Risk analysis and action planning	Machine	NA
4	Verification and approval	Human	NA
5	Execution and control	Machine	Human

ODD (Operational Design Domain)

The ODD for APExS is roughly defined as follows. Since onboard seafarers validate the action plan from the system, those who handle APExS should be required to have appropriate competences.

1. **The geographic and weather condition are acceptable enough** that ships can be controlled by the system, which refers to the standards for other navigation instruments, such as the Dynamic Positioning System, etc.

2. **The system behaves correctly**, i.e., information is correctly displayed on the monitor, and the results are validated by human judgment.

3. **Integral and reliable information including human manual function can be obtained** for situation assessment and action planning.

Integrity and reliability of equipment for subtask

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No.	Task/Sub Task	Human Backup	Equipment	Integrity	Reliability	Main	Num
1	Information Acquisition/ Position Detection	Available	GNSS	A	B	Main	2
			GPS Compass	A	B		1
2	Information Acquisition/ Azimuth Measurement	Unavailable	Gyro Compass	A	A	Main	2
			GPS Compass	A	B		(1)
3	Information Acquisition/ Speed Measurement	Available	Speed Log	A	B	Main	2
			GNSS	A	B		2
			GPS Compass	A	B		(1)
4	Information Acquisition/ Target Detection and Tracking	Available (only for confirmation of existence)	Radar	A	B	Main	2
			AIS	B	B		1
5	Information Acquisition/ Geographic Information	Unavailable	ECDIS	A	A	Main	2
			User Chart	C	A		1
			Echo Sounder	C	B		1
6	Information Integration	Unavailable	APU	A	B	Main	1
7	Risk Analysis & Action Planning	Unavailable		A	B	Main	1

Integrity: Functional integrity for each Task
A: Full
B: Partial
C: Low(Only supplemental information)

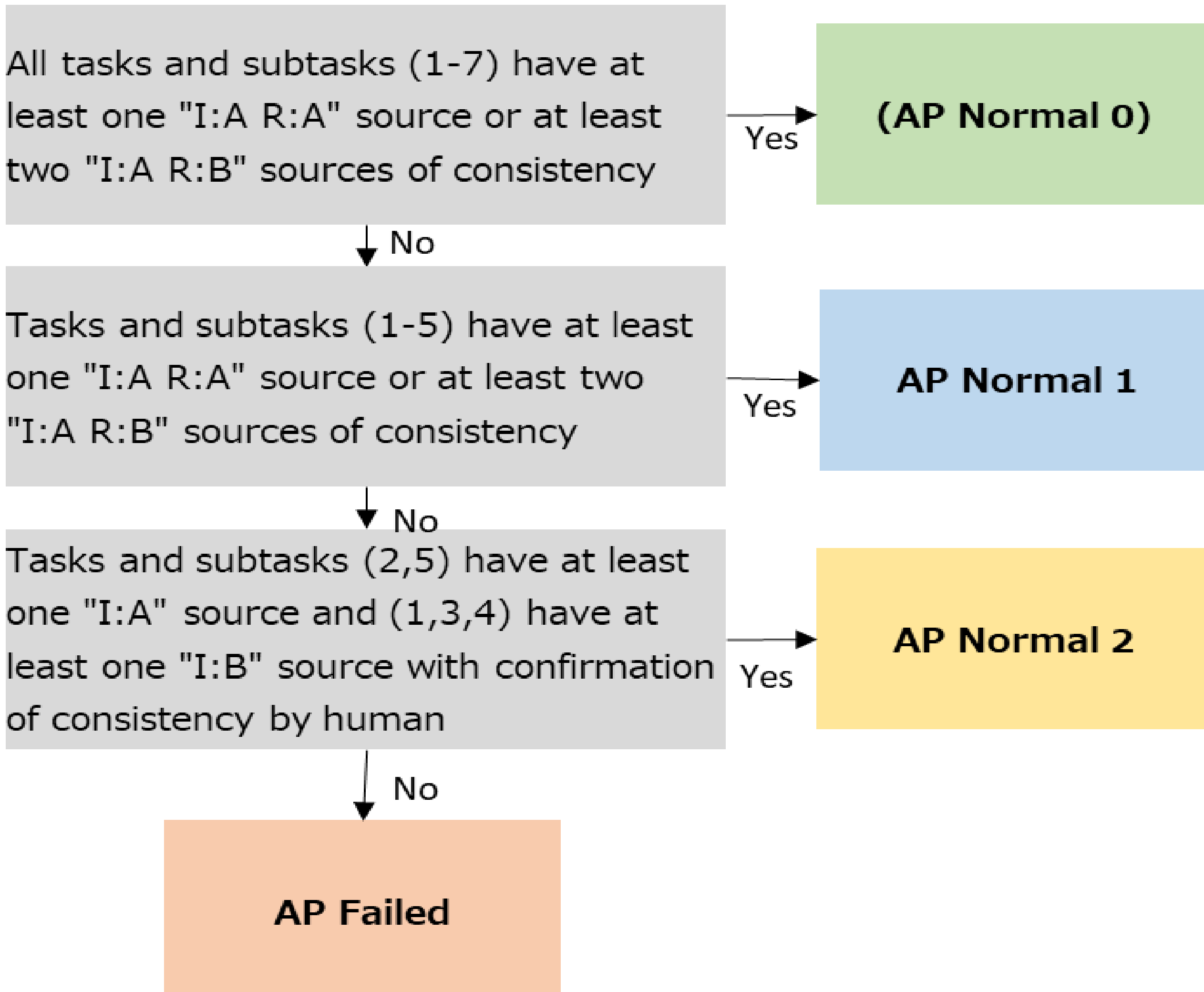
Reliability: Information Reliability
A: High
B: Intermediate (available for action planning)
C :Low (Unavailable for action planning)

Definition of system status

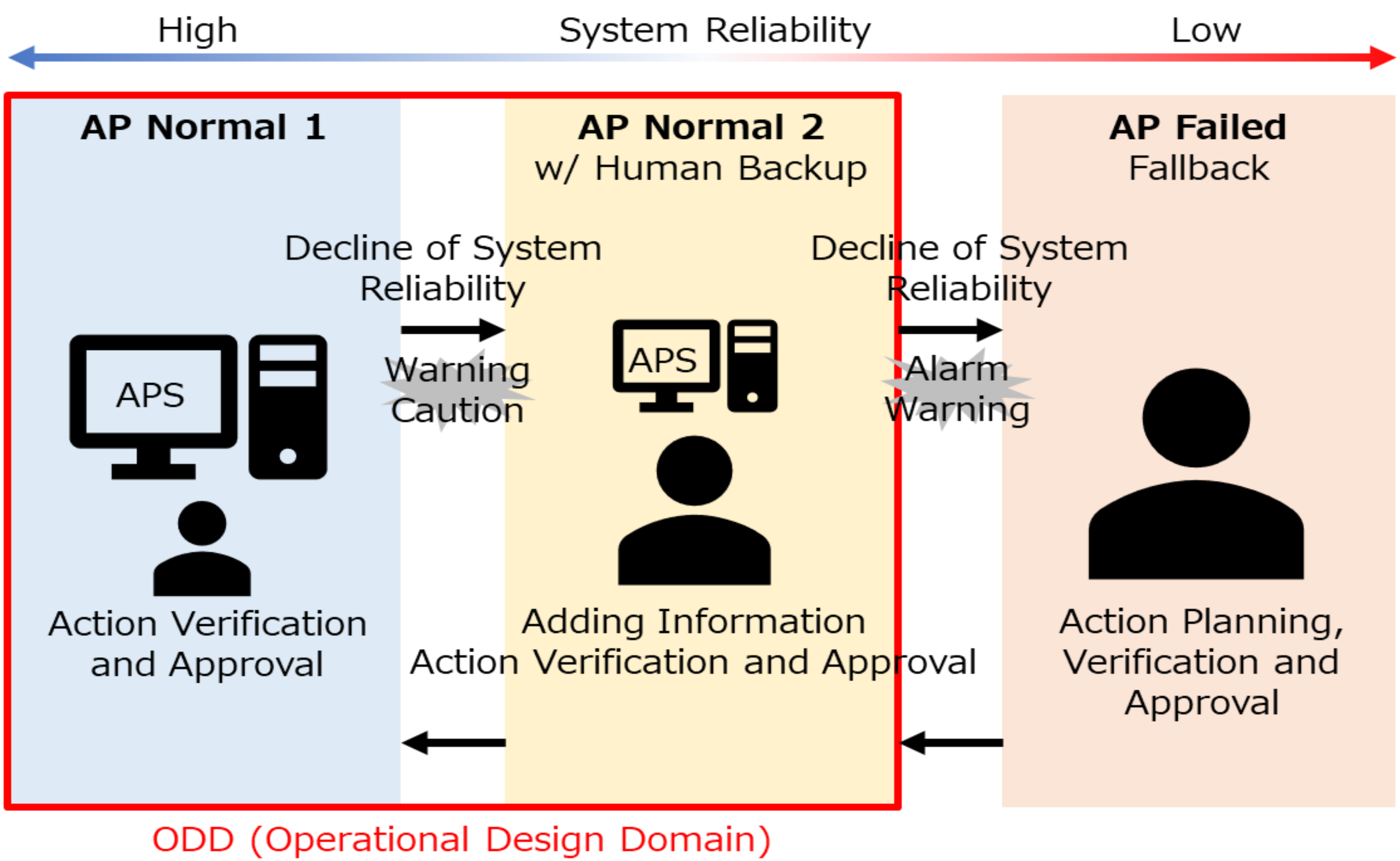
Definition of APExS system status

	Status	Target	Definition
ODD	AP Normal 0	Fully autonomous navigation	It has highly reliable information and planning algorithms to carry out all tasks. Human approval can be skipped in usual situations. It does not apply to the current APS, but it is assumed to be available for achieving automation only with machines in the future.
ODD	AP Normal 1	Manned autonomous navigation	It has reliable information to carry out tasks till action planning. Human intervention and additional actions other than verification and approval of navigation plans are unnecessary.
ODD	AP Normal 2	Manned autonomous navigation	To maintain all tasks to be executed with high accuracy, part of the input information is missing, or some tasks depend on the manual inputs by human only.
Fallback	AP Failed	NA	A state in which some or all the information sources of tasks are missing, and it is impossible to present an appropriate analysis and action plan even if a human adds and/or modifies information.

Criteria for determining status



Status Transition



Risk assessment to check relative safeness (HAZID)

- As part of a demonstration project in Japan under MLIT program -

HAZID (Hazard Identification)

Node	Function	Design intention concept		Hazard	Causal Factor	Local Impact	Consequence	Conventional Ship								Ship with APS						
								Apply	Risk Mitigation			Counter measure	Risk			Apply	Risk Mitigation				Risk	
									Training	Procedure	Design		F	S	R		Training	Procedure	Design	Counter measure	F	S	R
System-Manual Task	Verification	B2.2	Proper consideration on human factor is required for avoiding man-machine miscommunication.	Failure in verification of alert by human	A. No response by human on plan verification within specified time due to inadequate warning system B. Improper man-machine I/F to understand background/or intention of action plan C. Improper man-machine	Slow reaction time. Increasing risk of collision.	Collision	Y	Y	Y	Y	Alert standard.	1	4	5	Y	Y	Y	Y	A.Set proper I/F. A.Conduct familiarization type of alarms. B.Discuss the procedure of APS when human does not notice an alert escalation. C.Design Human Machine Interface enable to notice for AP-Status changing with clearly reason.	1	4	5
System-Manual Task	Verification	B2.3	Proper consideration on human factor is required for avoiding man-machine miscommunication.	Failure in verification of working condition of system by human	A. Improper man-machine I/F to confirm working status of equipment	Incorrect operation due to miscommunication of Human machine interface.	Collision Grounding	N								Y			Y	A. Designed to determine detect APU failed(Freeze).	1	4	5
System-Manual Task	Action and control	B3.1	Proper consideration on human factor is required for avoiding man-machine miscommunication.	Failure in manual operation to execute action plan.	A. Insufficient output content which could human engage manual maneuvering to follow plans	Possibility of improper ship's maneuvering.	Collision Grounding	N								Y			Y	･Indicate the usage of proper simplifications ship's maneuvering. ・ enable monitoring or FB of control result. IF design. ･Execution Action planning detect the difference of o plan. ･Alert properly about speed and track.	1	4	5
System-Manual Task	Action and control	B3.2	Proper consideration on human factor is required for avoiding man-machine miscommunication.	Failure in reviewing execution of action plan	Inadequate warning systems	Execution of improper action planning.	Collision Grounding	Y			Y	Display the mode recognizable indicator of TCS and Autopilot.	2	4	6	Y		Y	Y		2	4	6

1. **Hazard identification**
2. **Risk evaluation and consideration of risk mitigation measures**

Risk assessment to check safety equivalence (FMEA)

- As part of a demonstration project in Japan under MLIT program -

FMEA（Failure Mode Effect Analysis）

					Effect of failure1		Effect of failure2			Evaluation after applying alternative provision		
Failure category	Failure task1	Failure status1	Failure task2	Failure status2	Local effect	End effect	Local effect	End effect	Truth Tabl	Alternative Provision	System end effect	Failure detection
Single line failure	APU-DTC	disconnect APU1-DTC1	NA	NA	System lost redundancy of communication	System may not be affected reliablity of information	NA	NA	1.APU:o 2.APU:o 1.Line:x 2.Line:o 1.DTC:o 2.DTC:o	Switch to the other system.	AP Normal1	APU DTC
Single line failure	APU-DTC	Mulfunction APU1	NA	NA	System lost redundancy of communication	System may not be affected reliablity of information	NA	NA	1.APU:x 2.APU:o 1.Line:o 2.Line:o 1.DTC:o 2.DTC:o	Switch to the other system.	AP Normal1	DTC
Single line failure	DTC-Contorller	disconnect DTC1-Controller	NA	NA	System lost redundancy of communication	System may not be affected reliablity of information	NA	NA	1.DTC:o 2.DTC:o 1.Line:x 2.Line:o Cont.:o	Switch to the other system.	AP Normal1	DTC Controller
Single line failure	DTC-Contorller	Mulfunction DTC1	NA	NA	System lost redundancy of communication	System may not be affected reliablity of information	NA	NA	1.DTC:x 2.DTC:o 1.Line:o 2.Line:o Cont.:o	Switch to the other system.	AP Normal1	APU Controller
Single line failure	DTC-Contorller	Mulfunction Controller	NA	NA	System unable to allocate order to actuator	System lost auto control system	NA	NA	1.DTC:o 2.DTC:o 1.Line:o 2.Line:o Cont.:x	NA	AP Fail	DTC

Necessary redundancy of the system is confirmed

Risk assessment to check safety equivalence (HAZID, FMEA)

- As part of a demonstration project in Japan under MLIT program -

		Criticality / Freq scale	Extremely remote Once per 20 years per 5000 vessels 1	Very remote Once per 10 years per 1000 vessels 2	Remote Once per year per 1000 vessels 3	Seldom Once per year per 100 vessels 4	Resonably probable Once per year per 10 vessels 5	Probable Once per year per vessel 6	Frequent Once per month per vessel 7
Conventional Ship	Minor	1							
	Moderately serious	2							
	Serious	3							
	Major	4	F1-common A1.1, B2.3	F2-common A3.1, A4.3, A3.3, B2.2, B3.2 D1.1, D2.1, F1.2, F1.4, F1.5	F3-mitigation A4.1, A4.2, B1.2, E1.1, E2.1, E2.2, E3.1, E3.2 F3-common A3.2, C1.5, E4.2, F1.3	F4-mitigation C1.2, C1.3, C1.4, C2.1, C3.1, C3.2, D1.2, D1.3, D3.1, D4.1			
	Exceptional	5							
Ship with APS	Minor	1		F2-new risk A2.1	F3-new risk F1.6				
	Moderately serious	2							
	Serious	3							
	Major	4	F1-mitigation C3.2 F1-common A1.1, B2.2 F1-new risk A1.2, A2.2, B1.1 B2.3, B3.1	F2-mitigation A4.1, A4.2, B1.2, E1.1, E2.1, E2.2, E3.1, E3.2 F2-common A3.1, A4.3, A3.3, B2.1, B3.2 D1.1, D2.1, F1.2, F1.4, F1.5 F2-new risk E4.1, F1.1	F3-mitigation C1.2, C1.3, C1.4, C2.1, D1.2, D1.3, D3.1, D4.1 F3-common A3.2, C1.5, E4.2, F1.3				
	Exceptional	5							

Blue : risk mitigated

Red: new risk

Contents

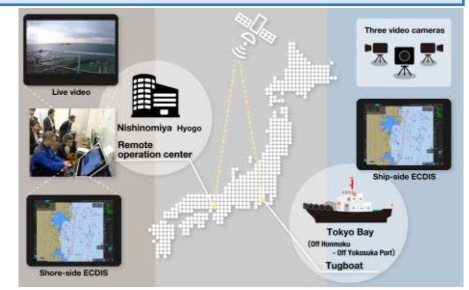
Remote Operation Demonstration in Japan t/w MLIT

- Objective: Demonstrate Remote Operation Concept
- Target ship: Tug boat “Yoshino Maru” (Shin-Nippon Kaiyosha)
- Project 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)

Open Innovation by
Diverse Expertise + Shared Concept + Project Management

Objective: Demonstration of the developed technology in i-Shipping (operation) project (2016-2020) and feedback to MLIT for their guideline & rule making

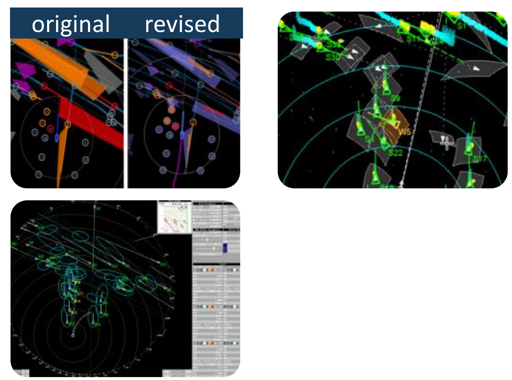
1st demonstration was conducted on 22nd January 2020.
2nd demonstration will be conducted on 3rd December 2020.



Remotely operate tug-boat in Tokyo bay from ROC in Nishinomiya (500km away)

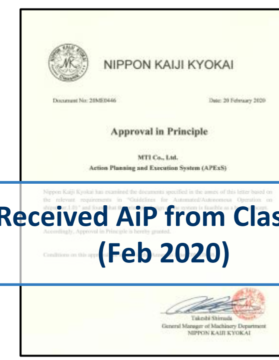
Enhanced situation awareness

- Visualize collision risk



Autonomous Ship Framework

- APExS (Action Planning and Execution System)



Received AiP from ClassNK (Feb 2020)

DFFAS (Designing the Future of Full Autonomous Ship) Project

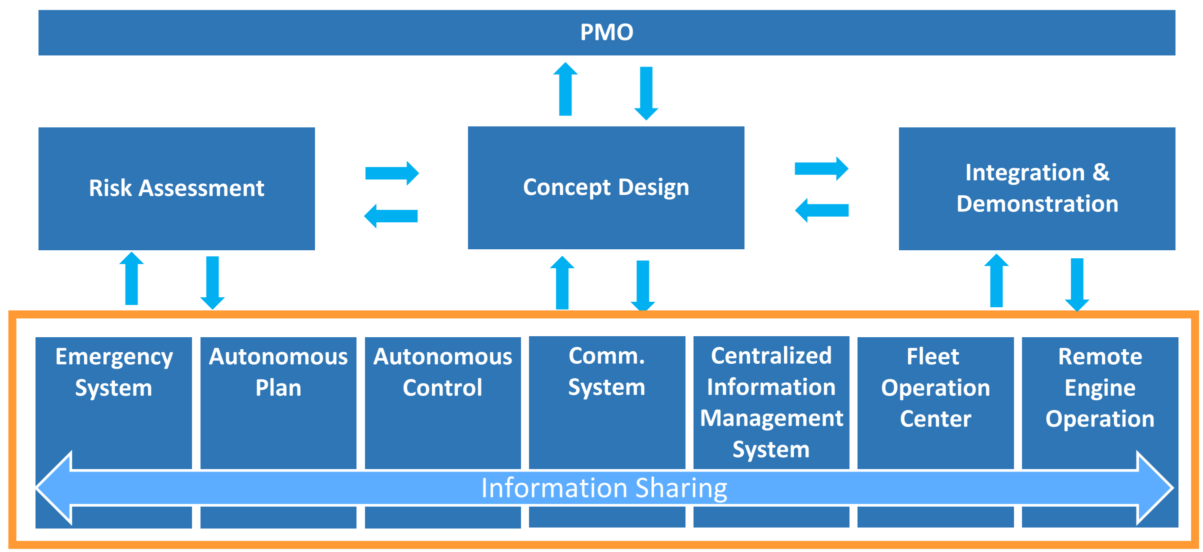
Objective
- Demonstrate functions for full autonomous ship

Project consortium & partners
- Consortium: 27 organizations (domestic)
- Partners: 20 organizations (global)

Target schedule
- **Demonstration in Feb 2022 (plan)**

Target ship and route	Container ship “Suzaku”

Organization chart of DFFAS PJ



Operation Concept (ConOps), Risk Assessment, Model-based Systems Engineering (MBSE), System Reliability Test by using Simulation and Project Management → Development of Open Architecture & Open Process for Open Innovation for future complex system development & operation

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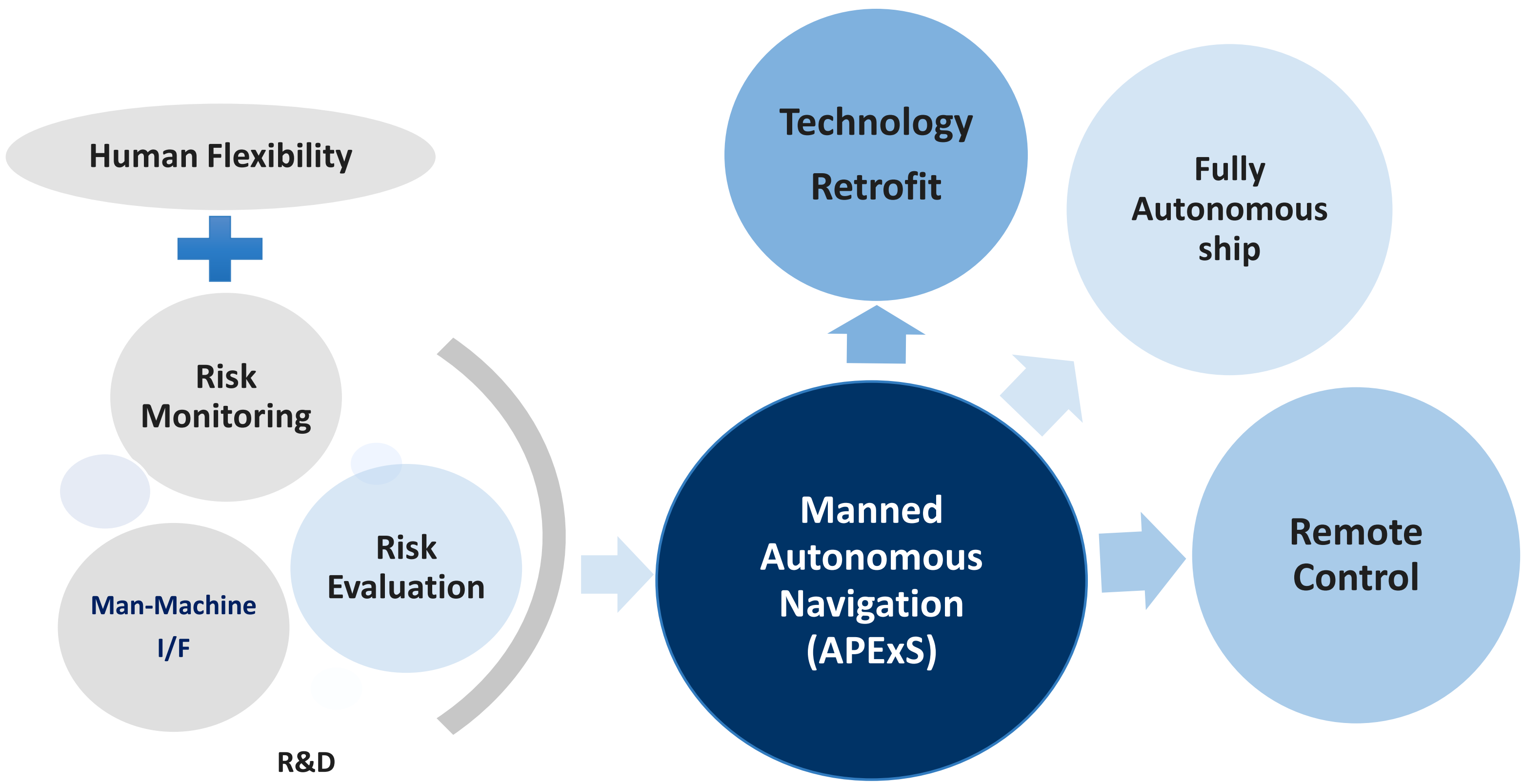
Manned-Autonomous Navigation as a waypoint

- A conceptual framework for manned autonomous ship, “APExS”, was introduced.
- Manned autonomous navigation can be positioned as a “technological waypoint” towards fully autonomous and remotely controlled navigation



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