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# NYK's Approach for Autonomous Navigation – Structure of Action Planning System and Demonstration Experiments -

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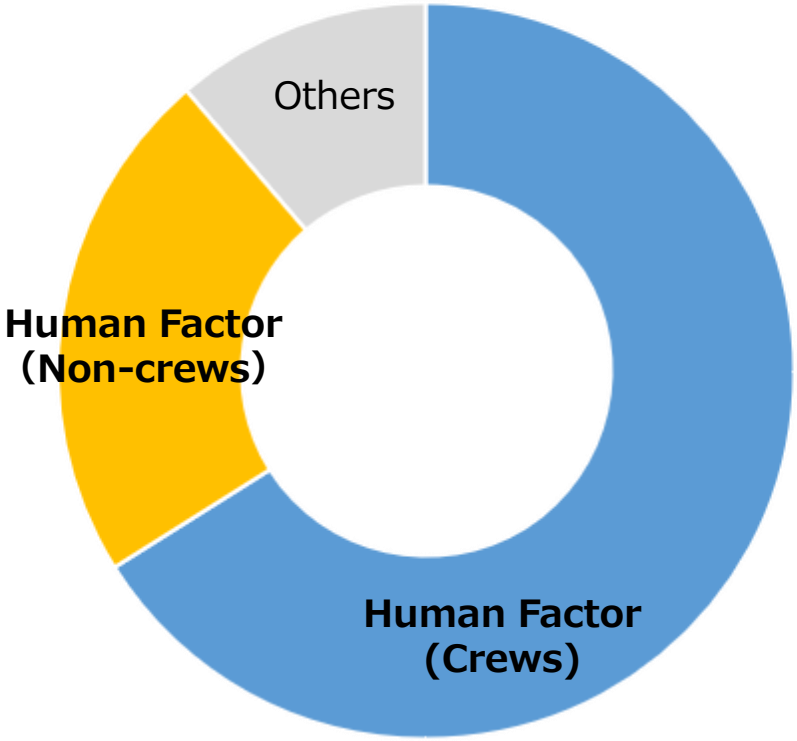
# Contribution of autonomous ship (short term)

## Cause of navigation incidents

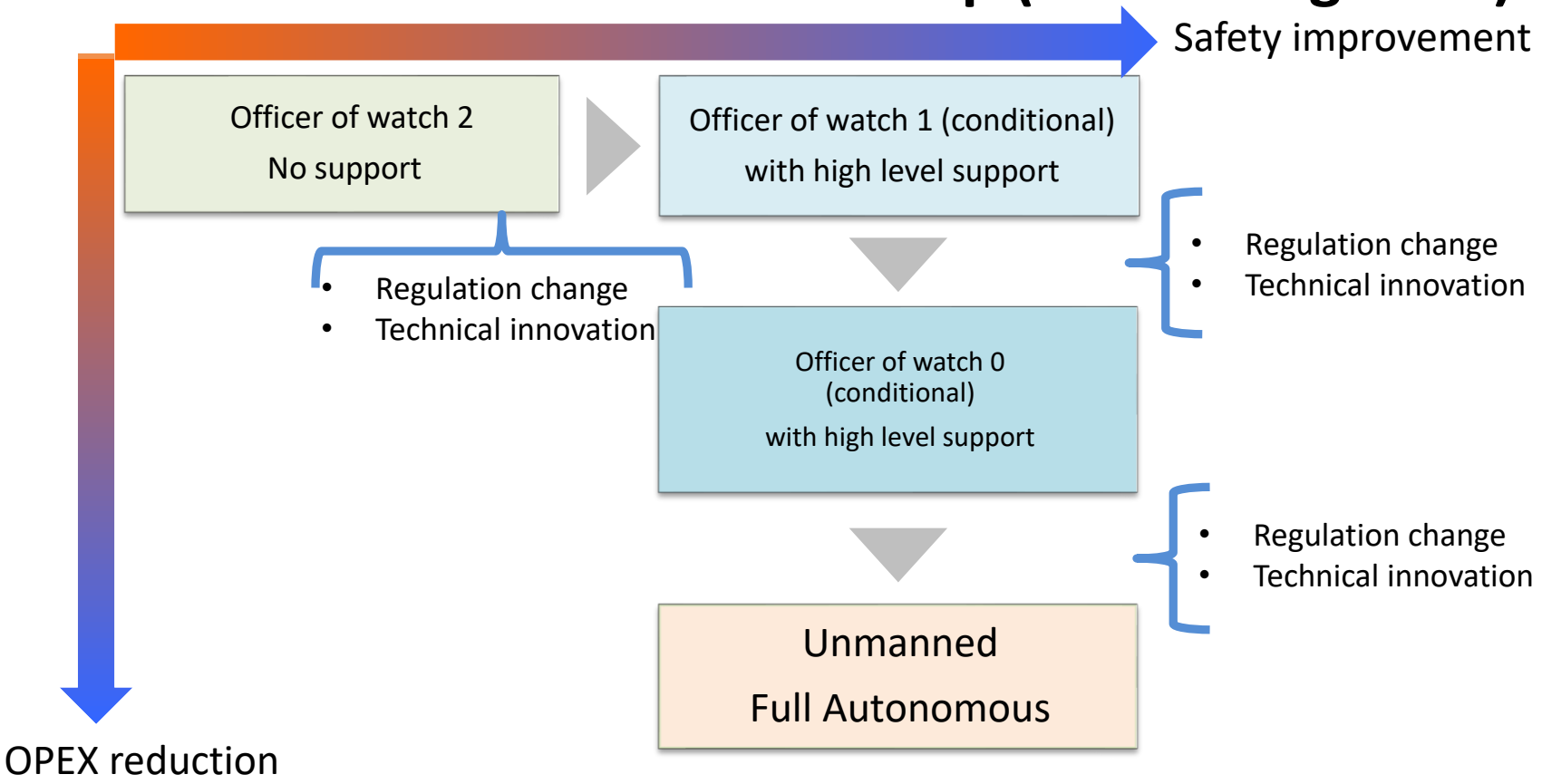



90% of incident causes relate to Human Factor

## Gains by automation and high level support


## Customer reliability

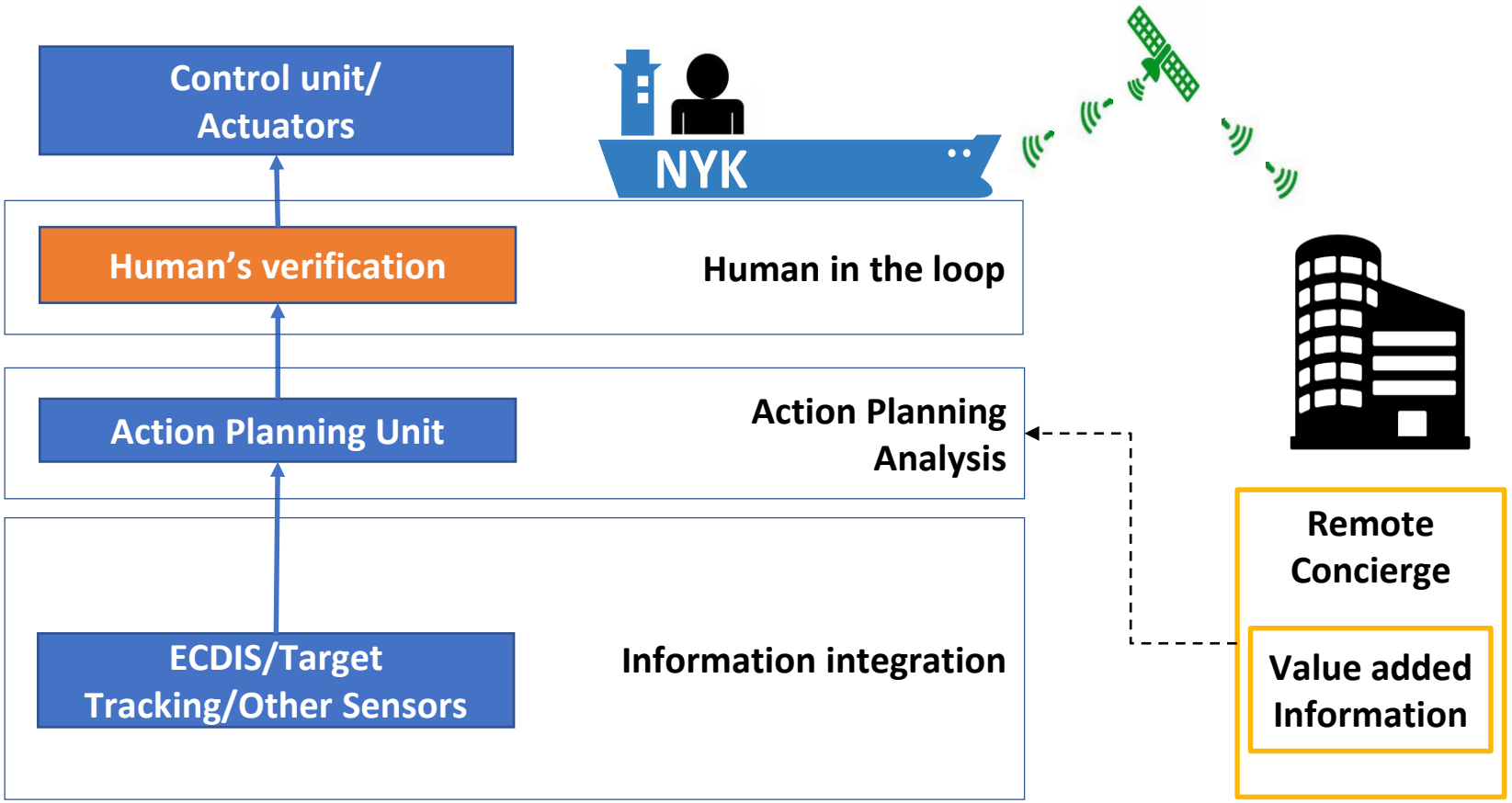
# Contribution of autonomous ship (mid & long term)



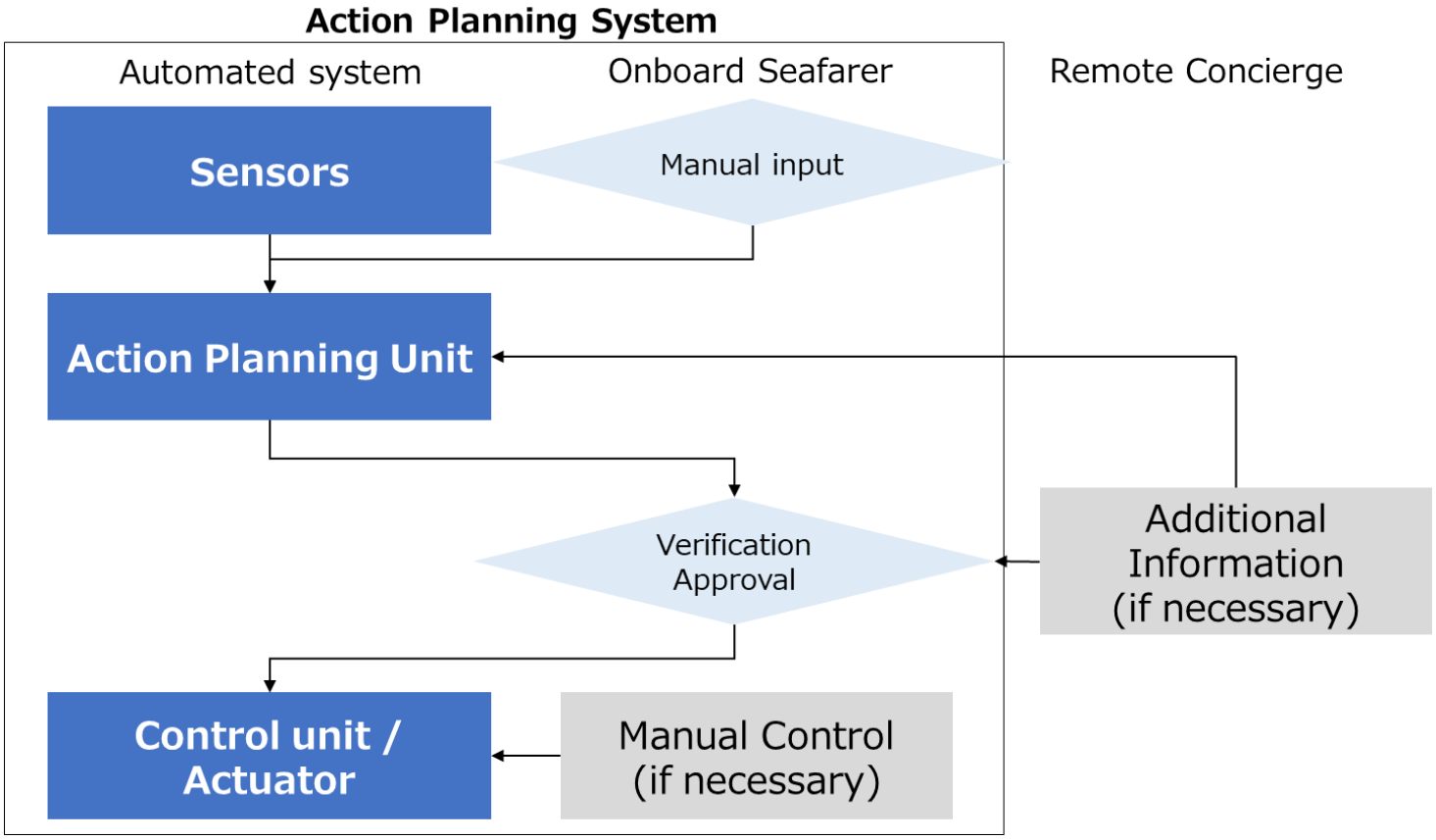

- In the meantime, loss reduction and customer reliability are targets
- In long run, OPEX reduction can be expected

# Concept of Action Planning System (APS)

- NYK group aims to define a manned-autonomous system framework as ***Action Planning System (APS)*** and to clarify requirements for APS through open collaboration.



# Conceptual diagram of Action Planning System



# Function of APS

The APS 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) of APS

The ODD for APS is roughly defined as follows. Since onboard seafarers validate the action plan from the system, those who handle APS 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 related equipment by subtask

| 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 APS status

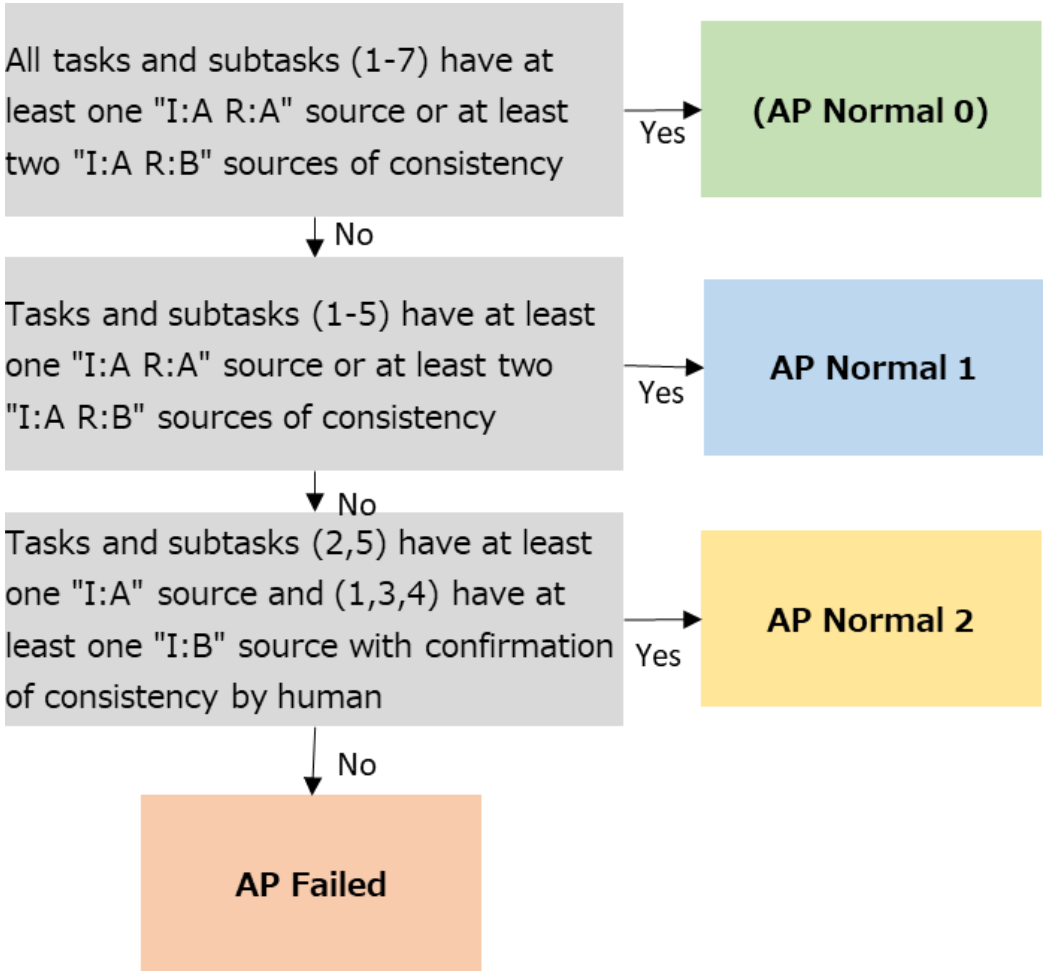
**Table 3.** Definition of APS status.

| Status | Target | Definition |
|---|---|---|
| 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. |
| 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. |
| 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. |
| 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. |

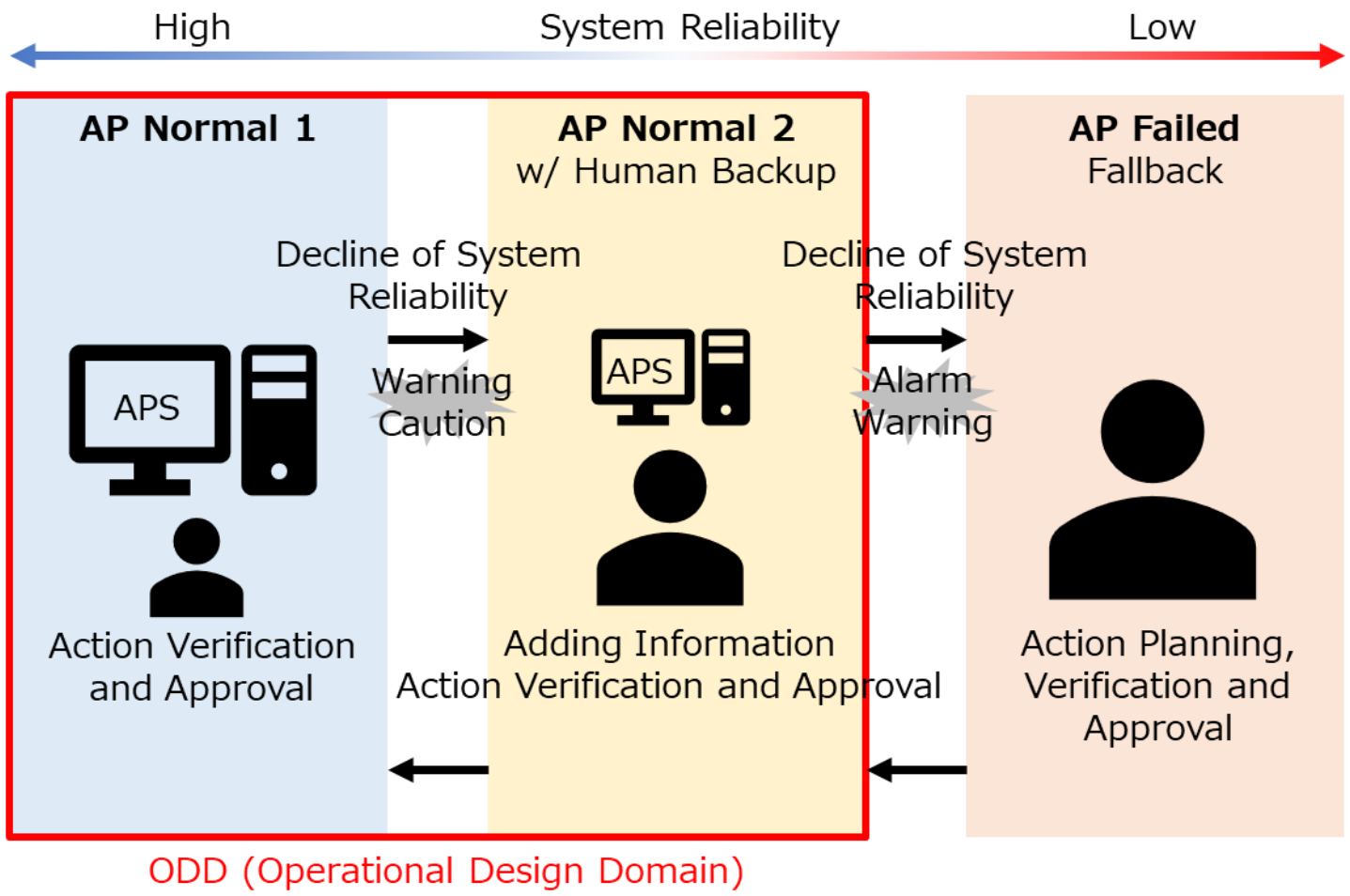
ODD

Fallback

# Criteria for determining APS status



# APS Status Transition



# Risk assessment to check relative safeness (HAZID)

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

## HAZID (Hazard Identification)

| | | | | | | | | Conventional Ship | | | | | | | | Ship with APS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Node | Function | Design intention concept | | Hazard | Causal Factor | Local Impact | Consequence | 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<br>B. Improper man-machine I/F to understand background/or intention of action plan<br>C. Improper man-machine | Slow reaction time.<br><br>Increasing risk of collision. | Collision | Y | Y | Y | Y | Alert standard. | 1 | 4 | 5 | Y | Y | Y | Y | A.Set proper I/F.<br>A.Conduct familiarization type of alarms.<br>B.Discuss the procedure of APS when human does not notice an alert escalation.<br>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.<br>･ enable monitoring or FB of control result. IF design.<br>･Execution Action planning detect the difference of o plan.<br>･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 measure**

# Risk assessment to check relative safeness (FMEA)

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

## FMEA（Failure Mode Effect Analysis）

| | | | | | Effect of failure1 | | Effect of failure2 | | | Alternative Provisionを反映したシステムの結果 | | Failure detection |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | |
| 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<br>2.APU:o<br>1.Line:x<br>2.Line:o<br>1.DTC:o<br>2.DTC:o | Switch to the other system. | AP Normal1 | APU<br>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<br>2.APU:o<br>1.Line:o<br>2.Line:o<br>1.DTC:o<br>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<br>2.DTC:o<br>1.Line:x<br>2.Line:o<br>Cont.:o | Switch to the other system. | AP Normal1 | DTC<br>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<br>2.DTC:o<br>1.Line:o<br>2.Line:o<br>Cont.:o | Switch to the other system. | AP Normal1 | APU<br>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<br>2.DTC:o<br>1.Line:o<br>2.Line:o<br>Cont.:x | NA | AP Fail | DTC |

**Redundancy of the system is confirmed.**

# Risk assessment to check relative safeness (HAZID, FMEA)

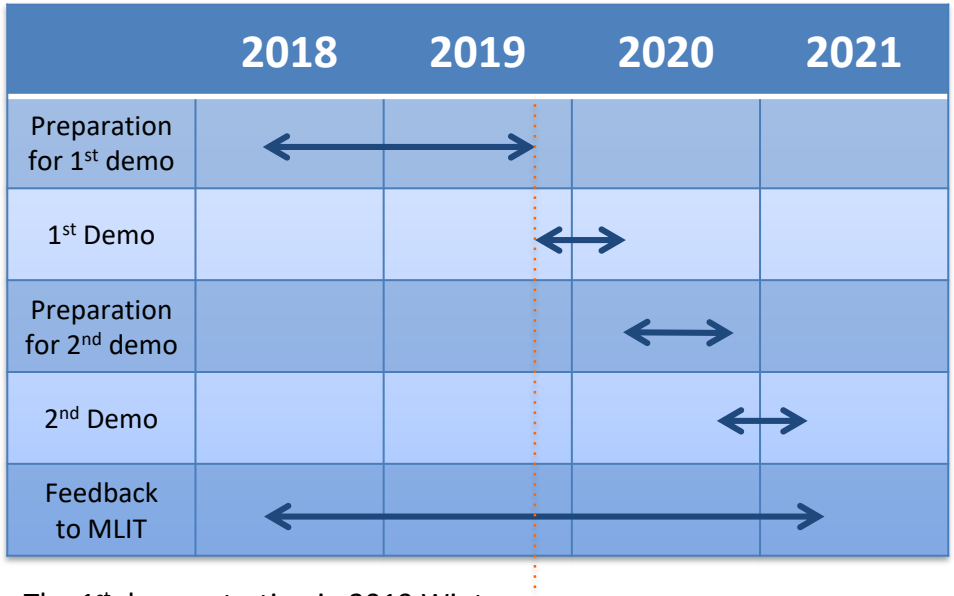
- As part of the demonstration project in Japan under MLIT program -

| | | Criticality / Freq scale | Extremely remote | Very remote | Remote | Seldom | Resonably probable | Probable | Frequent |
|---|---|---|---|---|---|---|---|---|---|
| | | | 5000隻で20年に1回の頻度 | Once per 10 years per 1000 vessels | Once per year per 1000 vessels | Once per year per 100 vessels | Once per year per 10 vessels | Once per year per vessel | Once per month per vessel |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 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<br>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<br>F1-common A1.1, B2.2<br>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<br>F2-common A3.1, A4.3, A3.3, B2.1, B3.2 D1.1, D2.1, F1.2, F1.4, F1.5<br>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<br>F3-common A3.2, C1.5, E4.2, F1.3 | | | | |
| | Exceptional | 5 | | | | | | | |

Blue : risk mitigated
Red: new risk

# Demonstration Project in Japan under MLIT program

- Objective: Demonstrate APS concept
- Target ship: Tug boat of Shin-Nippon Kaiyosha
- Period: 2018 – 2020
- 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)


The 1st demonstration in 2019 Winter
The 2nd demonstration in 2020 Winter

# Demonstration Project in Japan under MLIT program

“Existing” communication

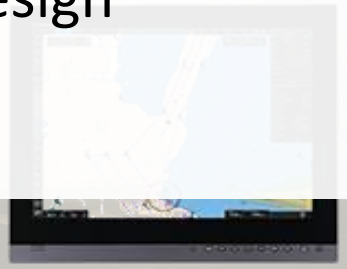


“Existing” sensor

## 2019 Target

1. Phase 2 Level* Autonomous - system design
2. Risk assessment (HAZID, FMEA)
3. Receive AiP approval from ClassNK

Autonomous



Azimuth Thruster (optional)

“Existing” control system


∗ : Phase 2 Level Autonomous … Highly integrated system. System propose plan. Final decision make is done by Human.

# Conclusions

- This paper introduced the concept of Action Planning System (APS), which is being developed and demonstrated as a core technology of manned autonomous navigation by the NYK Group.

- According to the risk assessment we conducted with reference to class guidelines for autonomous ship, APS with risk-mitigation measures has a much higher safety level than current navigation systems.

- This system will be verified by the demonstration in actual sea conditions in FY2019.

# Thank you very much for your attention