

# Developing the Autonomous Control for Navigation



November, 2022

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Back Ground

Approach to Autonomous System

Design the Autonomous System

Demonstration

Conclusion

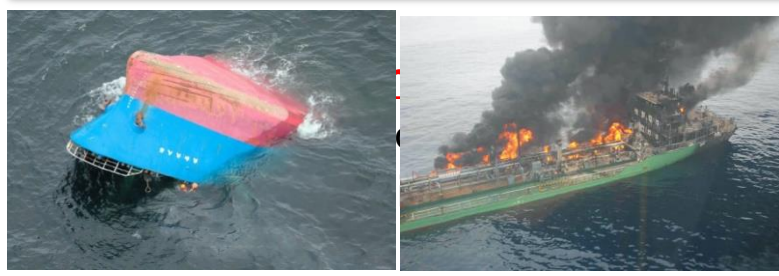
# 1. Back Ground

~ Why Autonomous System ? ~

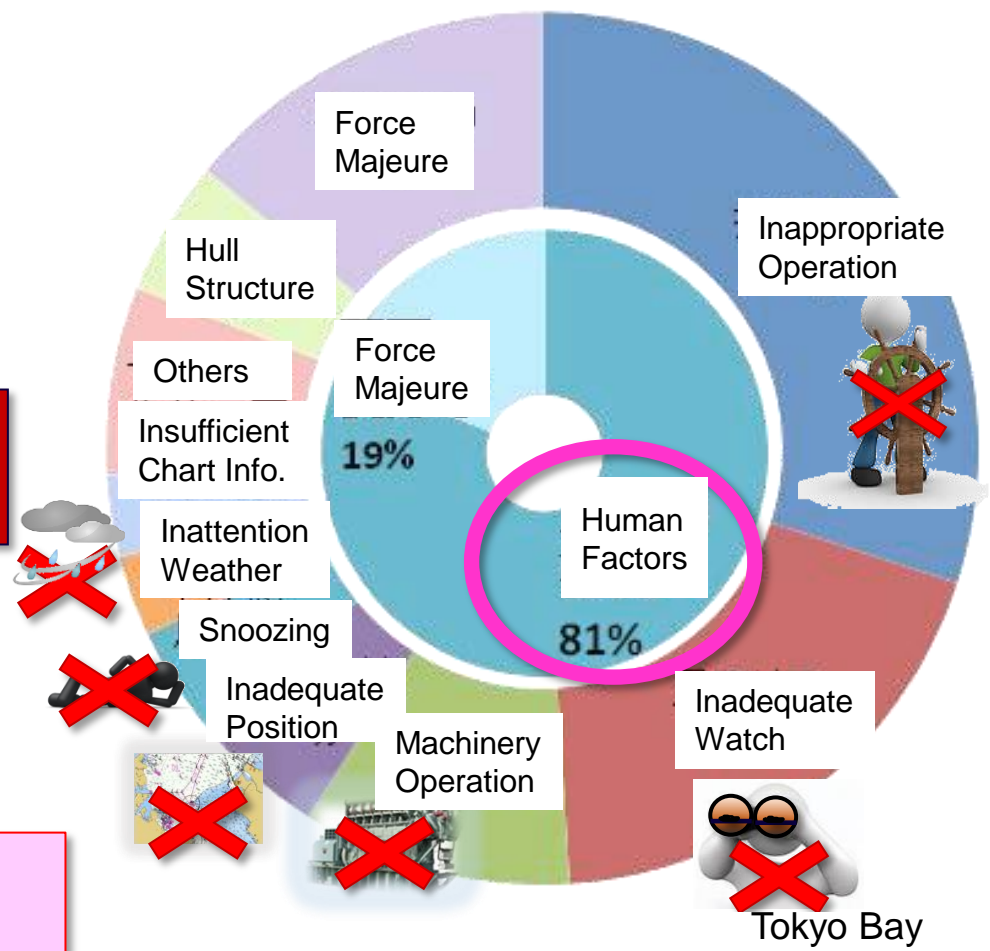
Marine Transportation supports Industry and Economy.  
Transportation of basic materials : Abt. 80%

Marine Transportation Capacity and Quality

Over 80% : Human Factors



Improve Labor Environment  
Safety of Ship's Operation



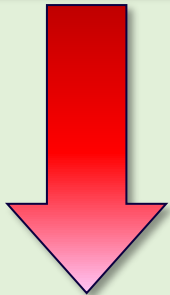
\*) Japan Coast Guard ( 2018 )

# 1. Back Ground

~ Why Autonomous System ? ~

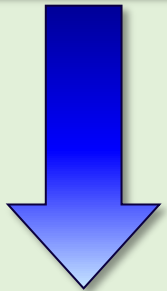
\* ) Ministry of Land, Infrastructure, Transport and Tourism

Aging, Decreasing number of Seafarers



Human Resources Urgent Issue

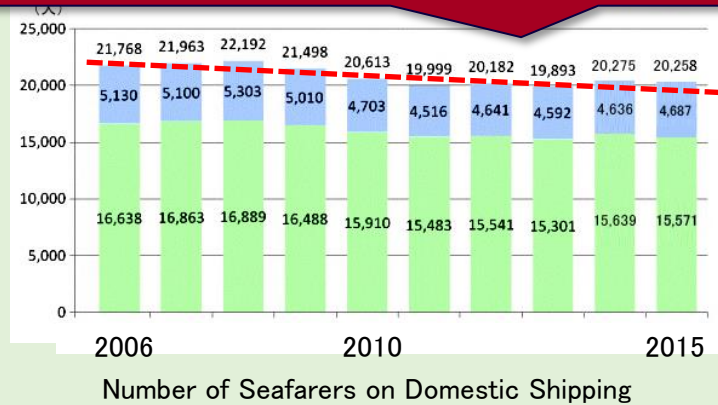
Increasing the Workload on board  
Concerns for Reducing Safety



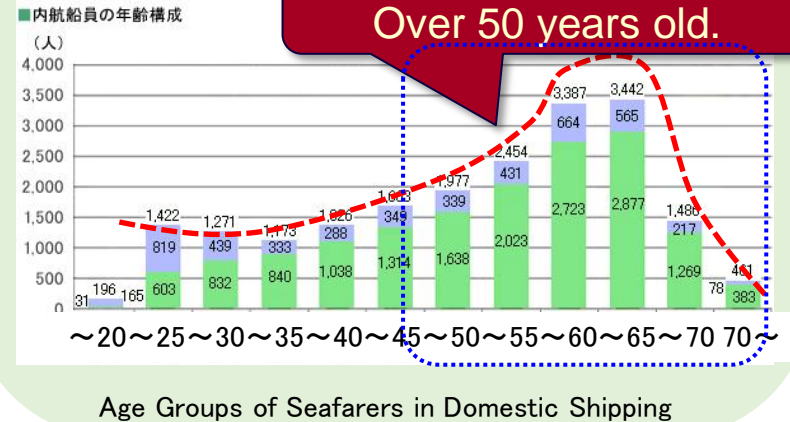
Automation & Autonomy Assist Seafarers

Improve Labor Environment and Safety of Ship's Operation

Shortage of thousands in near future.



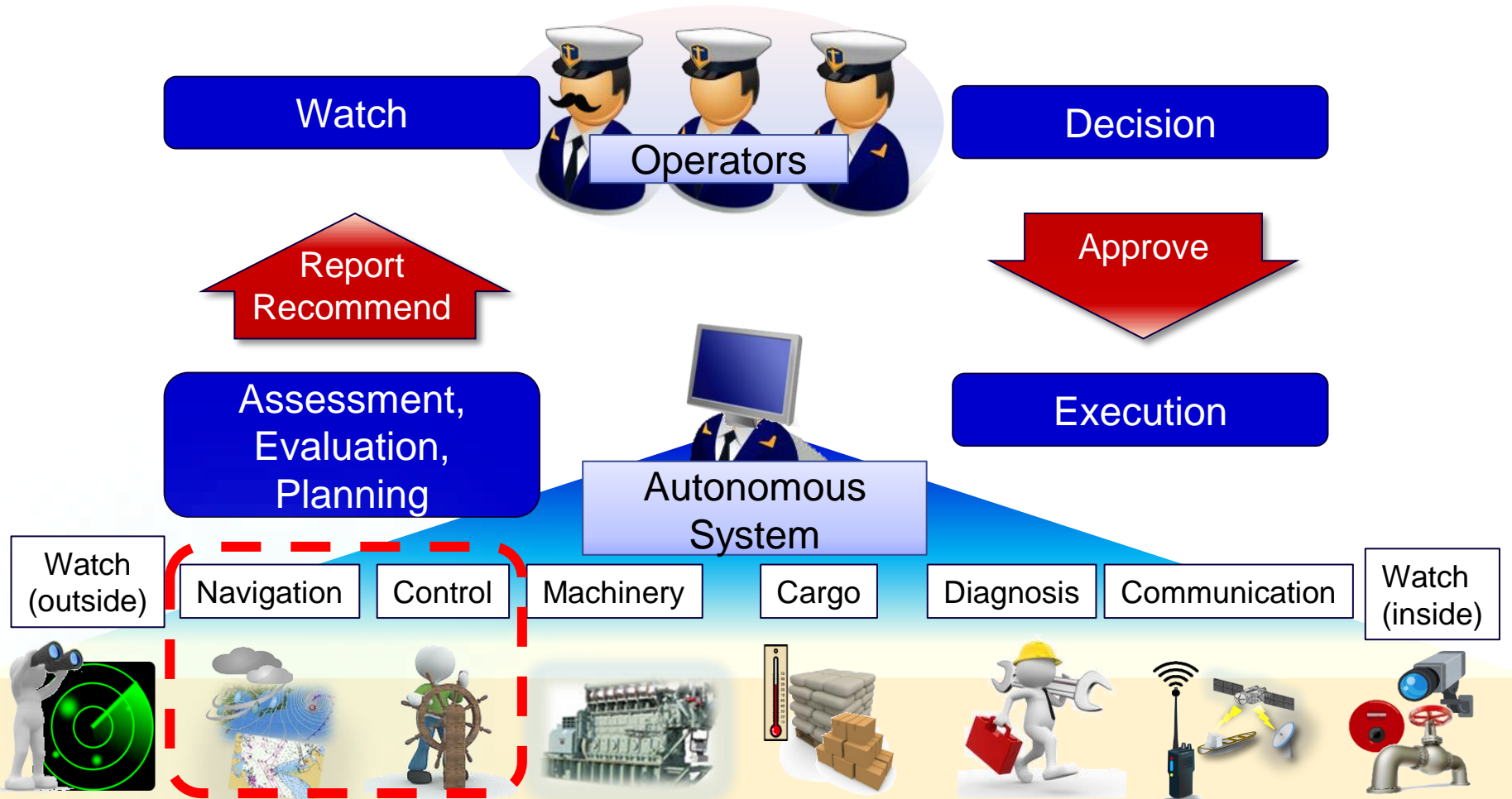
More than 50%, Over 50 years old.



~ What's Autonomous System ? ~

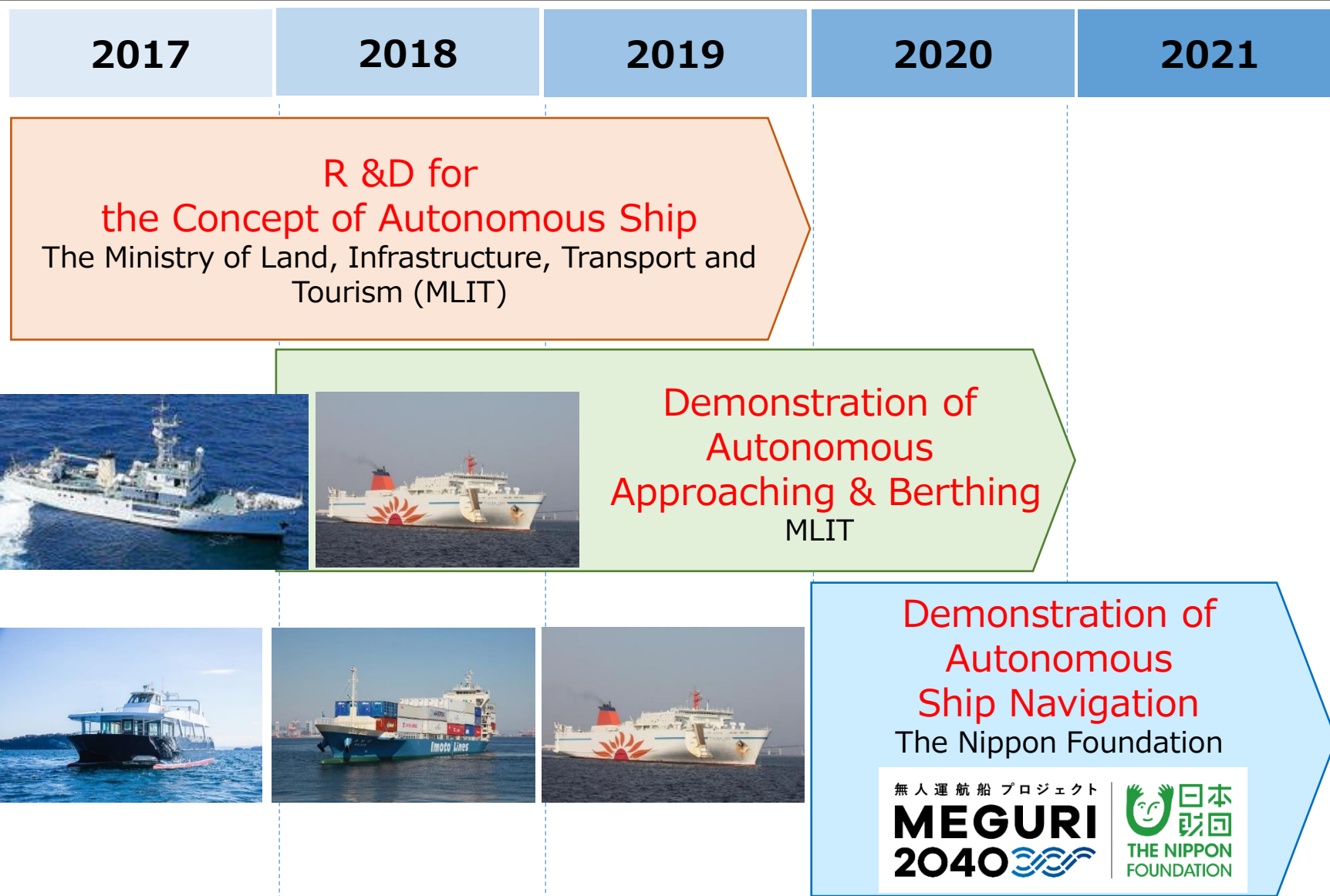
Image of the System : Support the Operation “Tireless, Competent Crew”

Assessment, Evaluation, Planning and Recommend to Operator.



## 2. Approach to Autonomous System

### ~ Projects of R&D for Autonomous System ~



## 2. Approach to Autonomous System

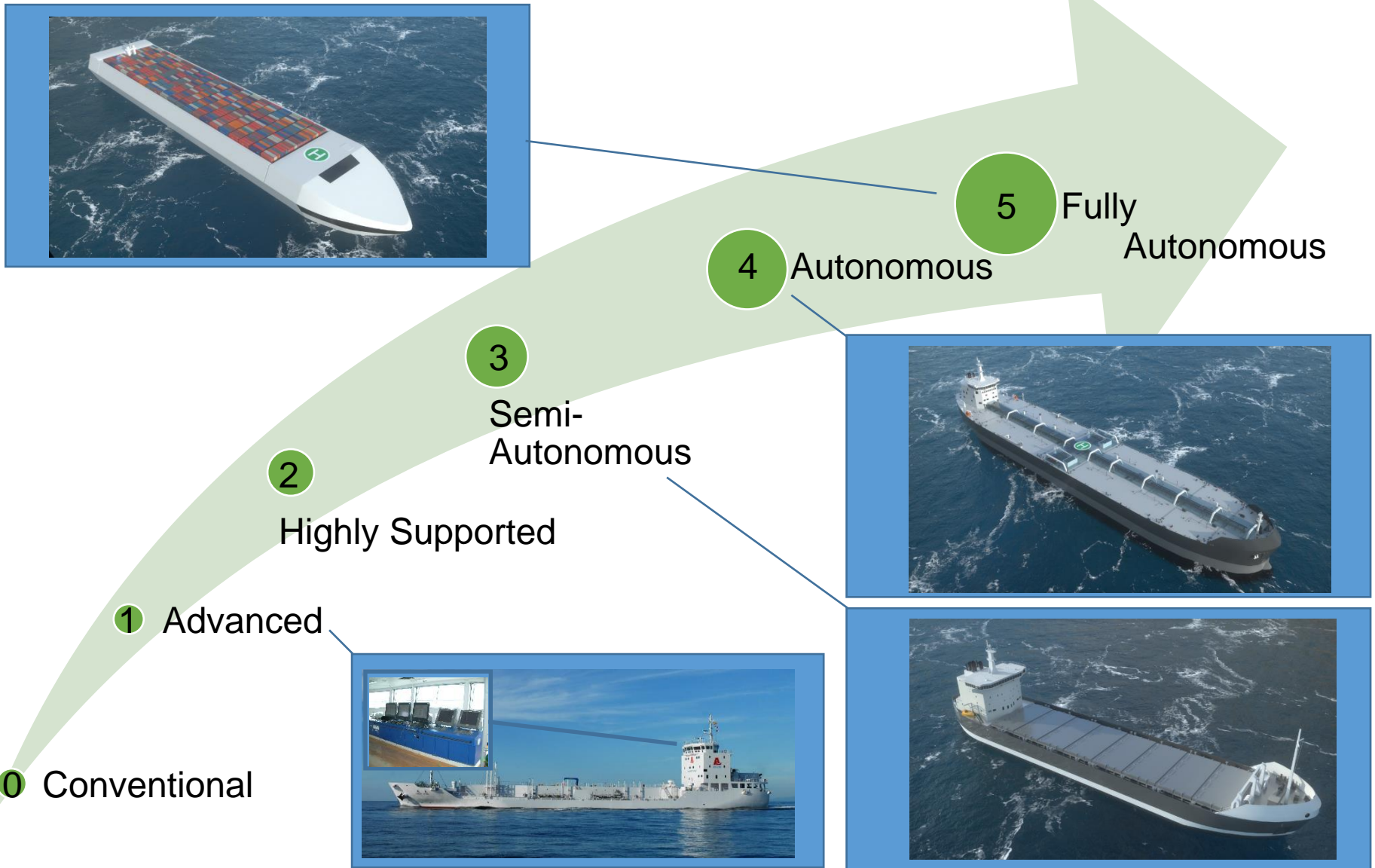
### ~ Proposal about the Ship Category of Autonomous Level ~

Level / Title		Functions
5	Fully Autonomous	System performs all functions <b>anytime</b> . Operator <b>monitors remotely</b> .
4	Autonomous	System performs all functions <b>except for emergencies</b> . Operator takes control in emergency.
3	Semi-Autonomous	System <b>makes plan and recommend</b> it <b>under certain conditions</b> . Operator watches and makes decision.
2	Highly Supported	System integrates / processes information. Operator makes plan / decision. Almost operations are automated.
1	Advanced	System integrates / processes information. Operator makes plan / decision, and operates equipment. Major operations are automated.
0	Conventional	Operator performs almost functions. Some operations are automated.

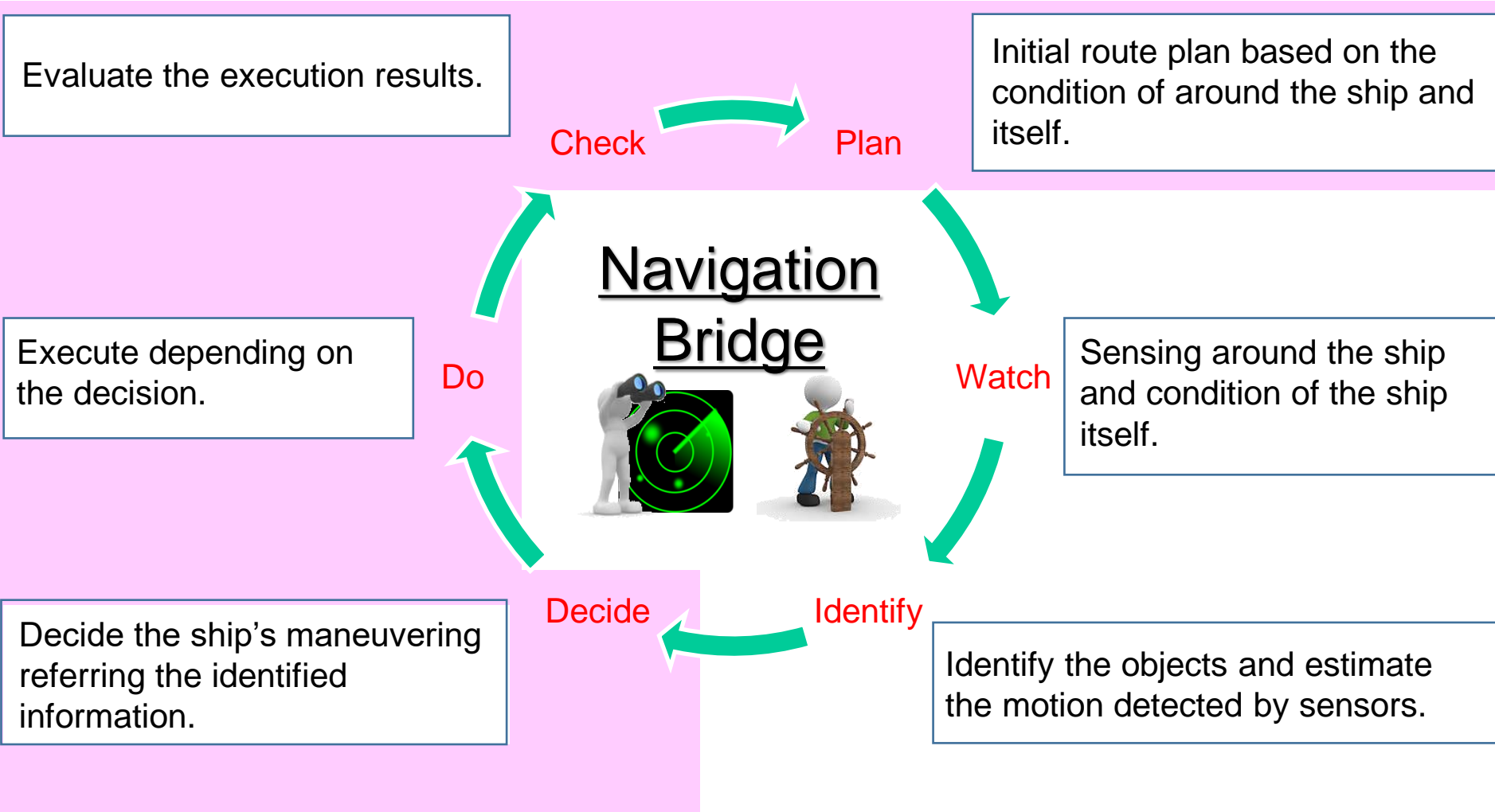
Proposed in “R&D for the Concept of Autonomous Ship” (MLIT), 2019.

## 2. Approach to Autonomous System

~ Images of Ship in Future depend on the Autonomous Level ~



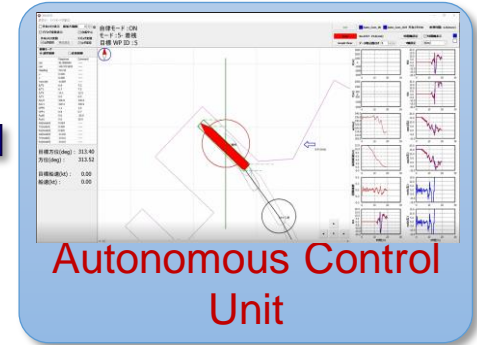
## 2. Approach to Autonomous System ~ Tasks for Navigation in Bridge ~



### 3. Design the Autonomous System

~ How to Automimize ? ~

- Install the existing Advanced Control System "MMS※" as **Autonomous Ready**.
- **Autonomous Control Unit** is added to upgrade the ship to Autonomous Ship.



Install **MMS** (Autonomous Ready)

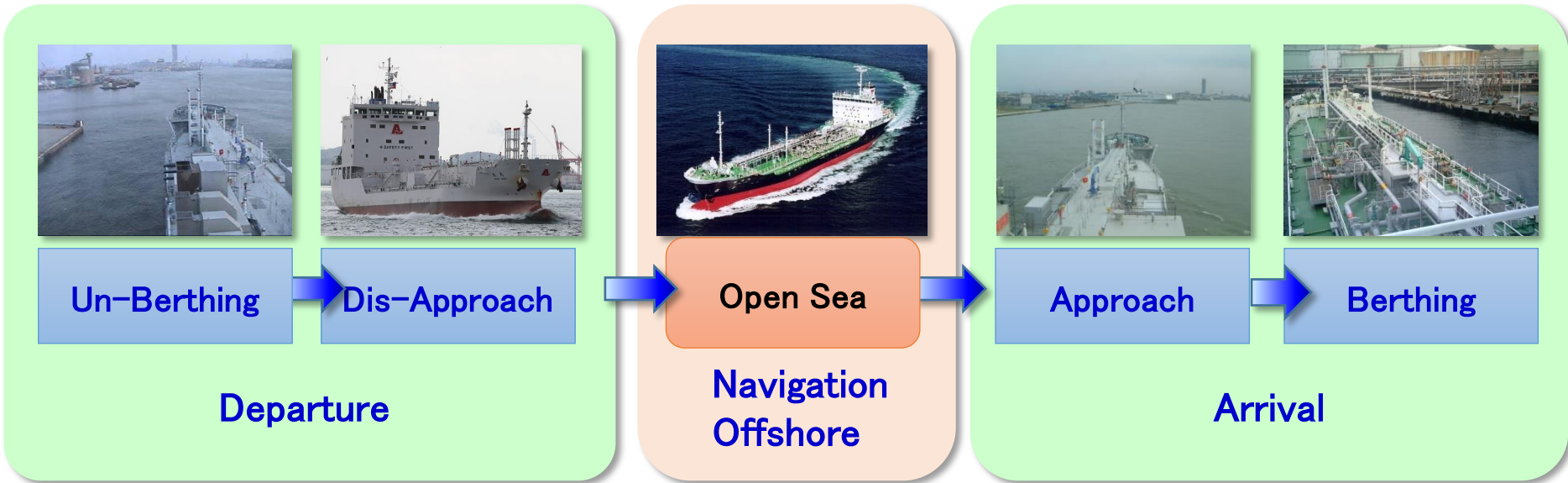
**Autonomous Control System**

**Autonomous Ship**

※ MMS (Mitsui ship Maneuvering Control System)

Dynamic Positioning System (MDPS series) and Joystick System, which has been Installed over 110 ships since 1985.

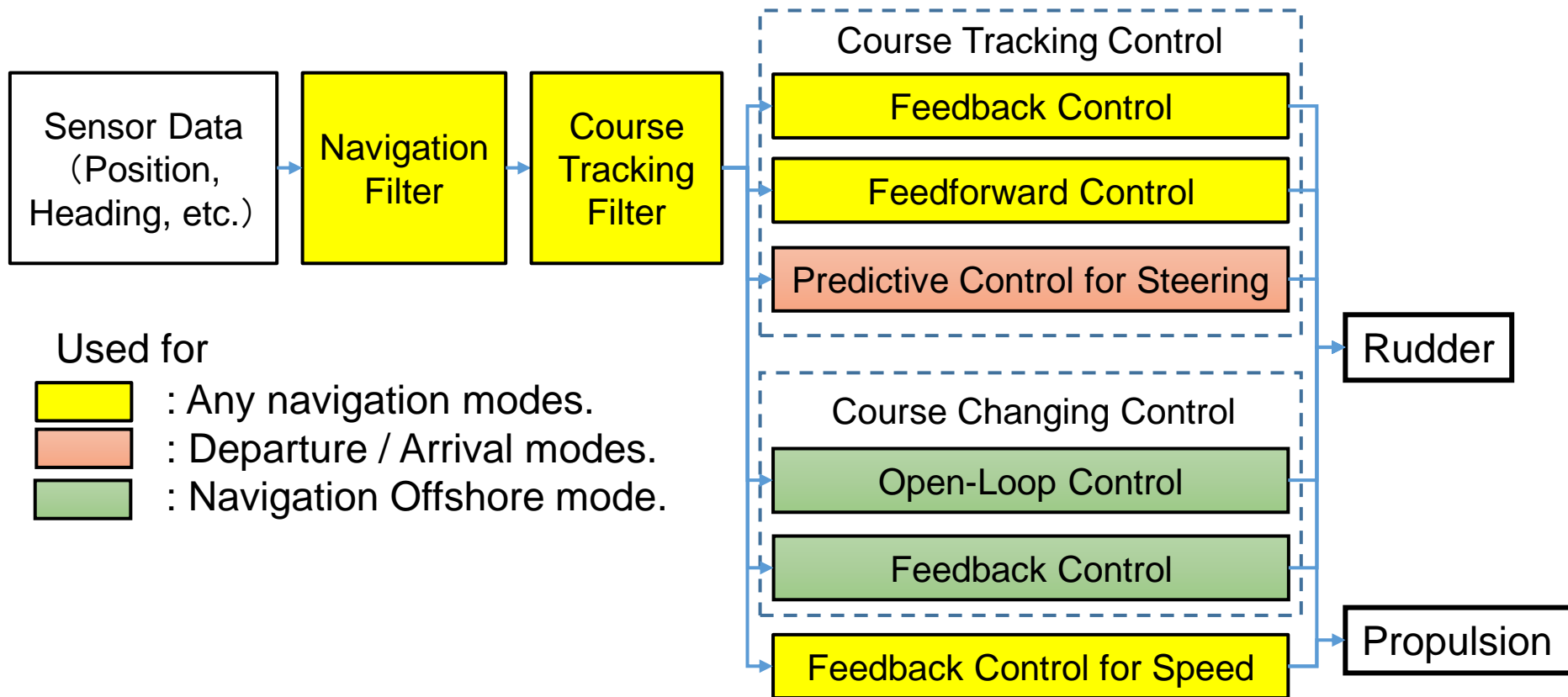
### 3. Design the Autonomous System ~ Navigation Mode Configuration ~



- Departure : Leave the pier, increase speed to “**Harbor Full**”, exit the harbor.
- Navigation Offshore : Order “Ring Up Engine”, navigate with the speed “**Navigation Full**”. Before approaching destination port, order “**Stand-by Engine**”.
- Arrival : Enter the harbor, decrease speed to “**Harbor Full**”, Berthing the pier.

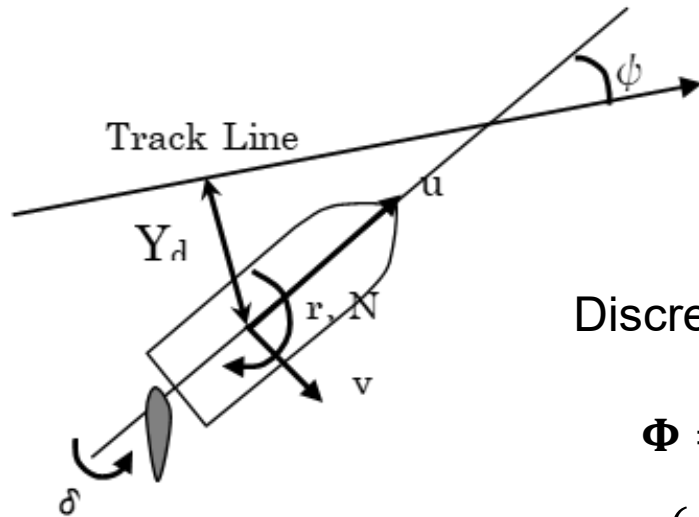
### 3. Design the Autonomous System

#### ~ Configuration of Autonomous Control ~



- Navigation Filter : Minimize the noise in sensor's data.
- Course Tracking Filter : Estimate the ship's motion and the effect of external forces.

## Coordinate Systems



- $u, v, r$ : Speed and Rate of Turn
- $\psi$  : Heading Deviation from Course
- $Y_d$  : Deviation from Track Line
- $\delta$  : Rudder Angle

## Discretized Equations of Ship's Motion

$$\Phi = e^{A\Delta t}, \quad \Gamma = B \int_t^{t+\Delta t} e^{A\Delta t} dt$$

$$x(n+1) = \Phi x(n) + \Gamma u(n)$$

$$x(n) = [v(n) \quad r(n) \quad \varphi(n) \quad Y_d(n)]^T, \quad u(n) = \delta(n)$$

## Course Tracking Filter

- Estimate the ship's motion including drifting by using Kalman Filtering Technique.

➡ Drifting speed  $d_Y(n)$  in  $Y_d$  direction is add in  $x(n)$ .

$$x(n) = [v(n) \quad r(n) \quad \varphi(n) \quad Y_d(n) \quad d_Y(n)]^T$$

### 3. Design the Autonomous System

#### ~ Configuration of Autonomous Control ~

#### Course Tracking Control

##### Feedback Control

Suitable rudder angle  $u(n)$  → Minimize the  $J_N$ , evaluation function.

Decide the weight matrix  $Q, R$  to minimize the course deviation and rudder angle.

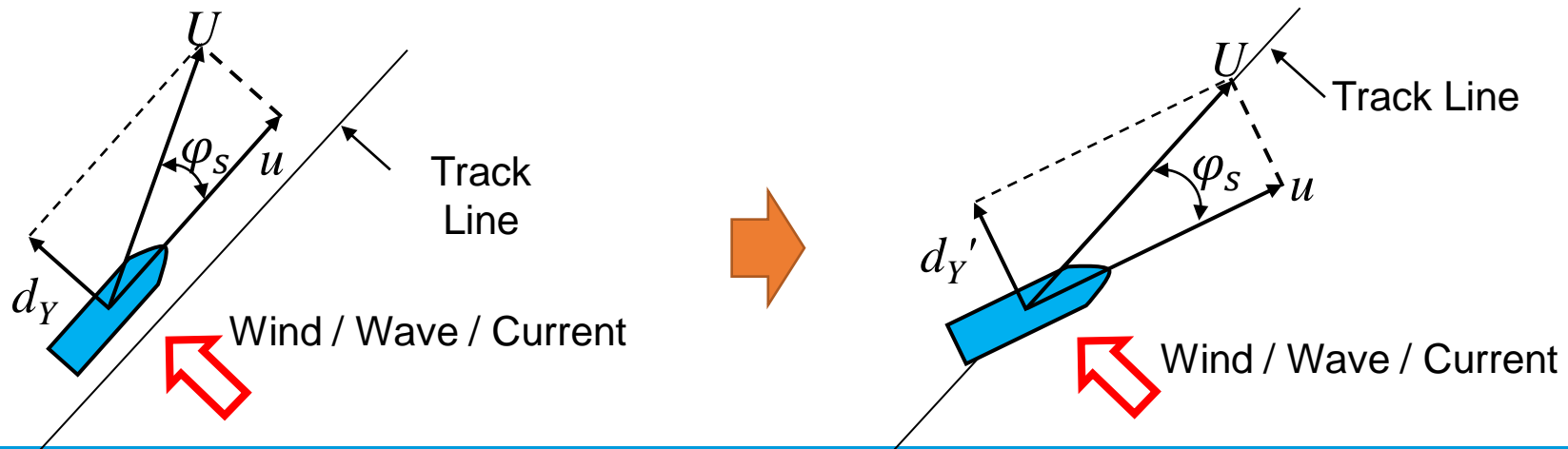
$$J_N = \sum_{n=1}^N [x^T(n) \mathbf{Q} x(n) + u^T(n-1) \mathbf{R} u(n-1)]$$

$Q$  : Weight matrix for State Variables  $x(n)$ .

$R$  : Weight matrix for Output (Rudder Angle)  $u(n)$ .

##### Feedforward Control

Heading is controlled to adjust the direction of  $U$  on the Track Line.



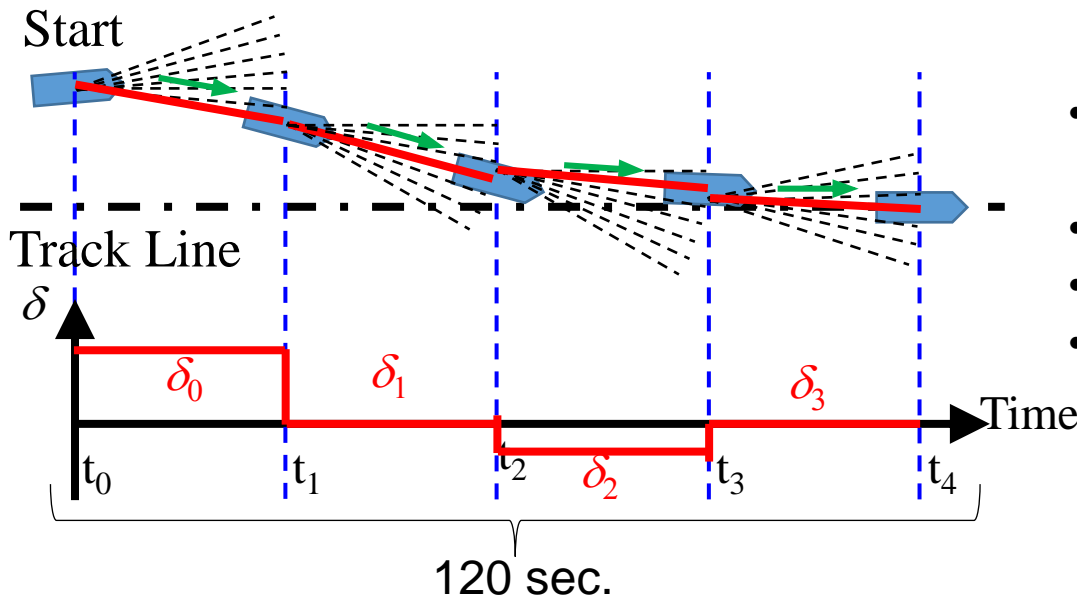
## Predictive Control for Steering

### Shooting Method ( Search for Optimum Rudder Angle )

Simulations with various rudder angle for predicting the ship's motion in future.  
 Suitable rudder angle  $\delta_i$  → Minimize the  $J$ , evaluation function.

$$J = \sum_{i=0}^n (q^{n-i} (W_y Y_{d,i}^2 + W_\psi \Delta\psi_i^2 + W_r r_i^2) + W_\delta \delta_i^2)$$

Course Deviation	Heading Deviation	Turning Speed	Rudder Angle
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- Simulations start from present position.
- Periodically ( Every 20 sec. )
- Simulation time length : 120 sec.
- Change rudder angle some times.

## Course Changing Control

### Open-Loop Control

Initial rudder angle to turn with R is decided based on the database.

- Ship speed
- Degree of course changing
- Rudder angle

### Feedback Control

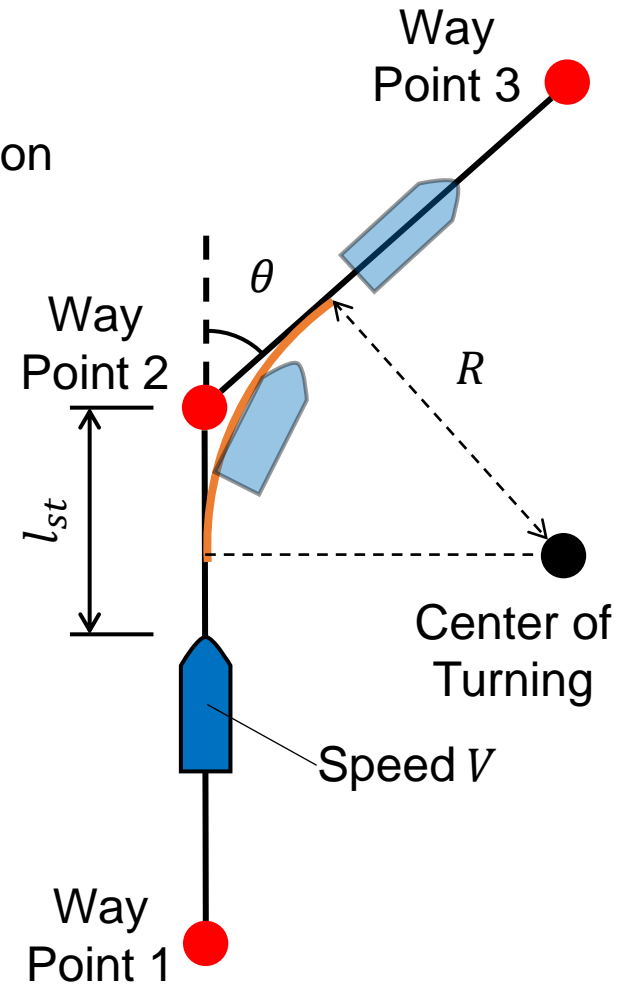
Adjust rudder angle to compensate the deviation between assumed circle and heading.

### Start Point ( $l_{st}$ )

$$l_{st} = R \tan\left(\frac{\theta}{2}\right) + V \left(T + \frac{\tau}{2}\right) + l_c$$

$\tau$  : Time for Steering

$l_c$  : Correction distance

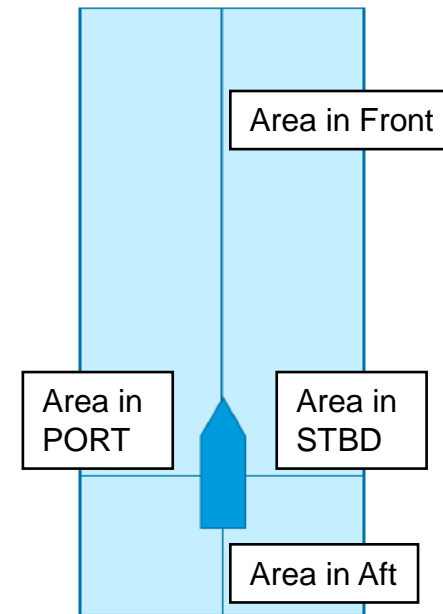
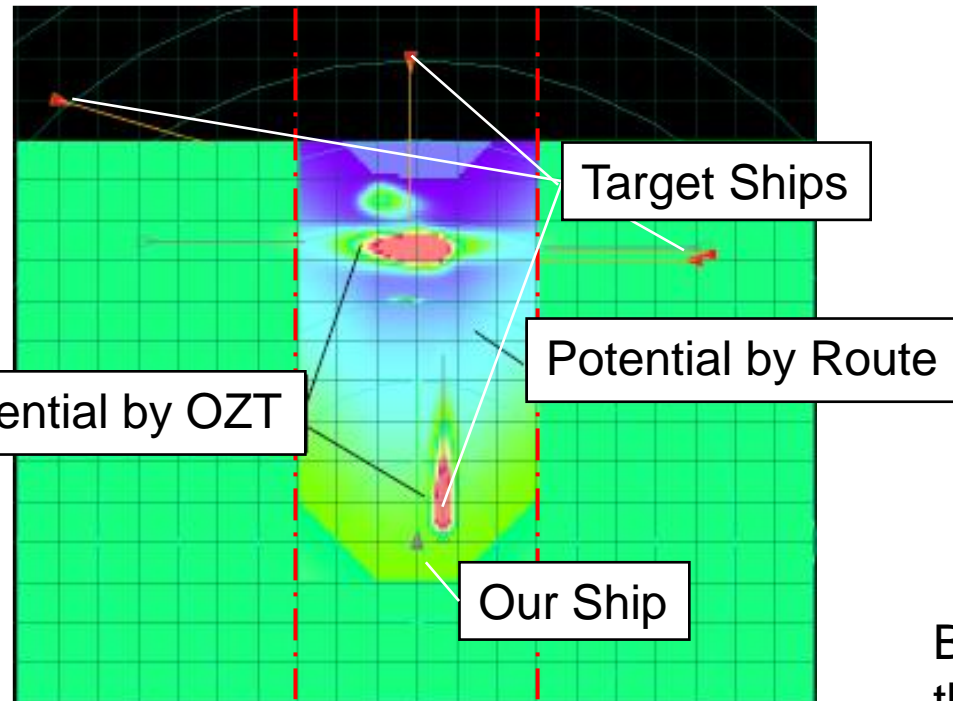


#### Collision Risk Assessment

The route to avoid collision is recommended based on the Risk Potential.

##### Constraints

- Width of the Route ( Parallel Line )
- Obstacle Zone by Target ( OZT )
- Prescribed Bumper Area
- Maneuverability



Bumper Area is prescribed based on the characteristics of the ship.

## 4. Demonstration

### ~ Ships for Autonomous Demonstration ~

#### Demonstration Ships (2020~2021)

Ship's Name	Sea Friend Zero	Mikage	Sunflower Shiretoko
Type	Small Passenger Ship	Coastal Container Ship	Large Car Ferry
Lpp	19.8 (m)	95.5 (m)	190 (m)
Breadth	7.1 (m)	13.5 (m)	26.4 (m)
G.T.	19 (ton)	749 (ton)	11,404 (ton)
Eng. Prop.	2 × Eng. + 2 × F.P.P.	1 × Eng. + 1 × C.P.P.	2 × Eng. + 2 × C.P.P.
Rudder	2 × Rudders	1 × Flap Rudder	2 × Rudders
Thruster	2 × B/T	1 × B/T	2 × B/T + 1 × S/T
Owner	TRYANGLE Inc.	Imoto Lines, Ltd.	MOL Ferry Co., Ltd.
Image			

## 5. Conclusion

We Studied, Developed and Demonstrated the Autonomous Navigation Control System.

- For Semi-Autonomous Ship

  - System makes plan and recommend it under certain conditions.
  - Operator watches and makes decision.

- At first, Autonomous Ready, then Upgrade to Autonomous

  - At first, Install well-experienced existing advanced control system (MMS).

    - ⇒ Autonomous Ready

  - Autonomous Control Unit is added to upgrade to Autonomous.

- Demonstrate the Autonomous navigation from Port to Port operation on 3 ships.

  - Confirmed the effective functionality and performance of the developed system under various weather conditions,  
on 3 ships of different Sizes, Types and Operation Areas.

We will continue to work on improving the Accuracy, Versatility and Reliability of the Autonomous System in order to bring its values to the market as soon as possible.



Thank you for your attention.



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