Consideration of Simulation Scenarios for Safety Assessment of Heading, Speed and Track Control Function

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2024/10/29: MTEC/ICMASS 2024
Paper ID: 22

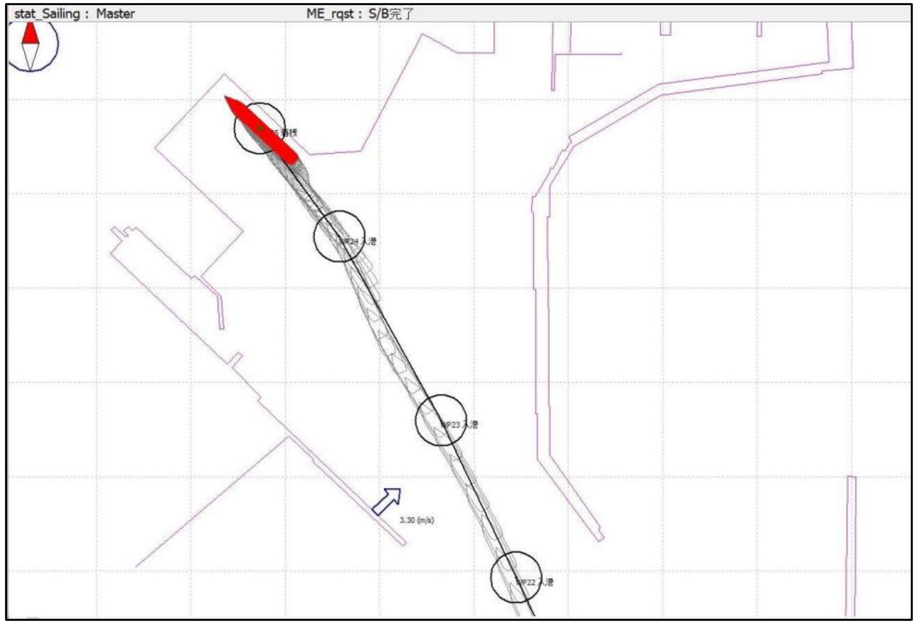
Automated manoeuvre including berthing/unberthing is being developed.

MEGURI2040 stage 1

They developed and demonstrated automated manoeuvring including automated berthing/unberthing.

- ✓ Demonstration ship: ***Sunflower Shiretoko (car ferry, 190 meters)***
- ✓ Berthing demonstration: ***Port of Oarai (Ibaraki pref., Japan)***

The Sunflower Shiretoko[1]



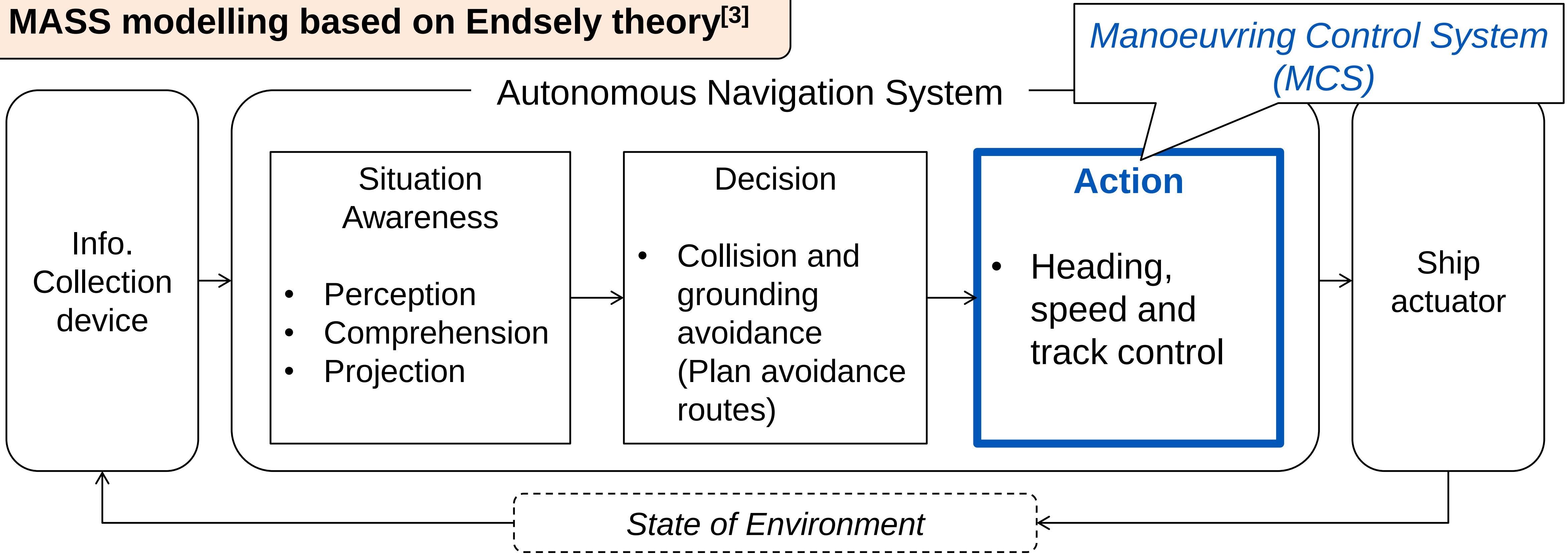
Result of demonstration of automated berthing[2]

[1] 3rd and 4th Demonstration Tests of Fully Autonomous Ship Navigation Successfully Completed | The Nippon Foundation (nippon-foundation.or.jp)
[2] 大型フェリー「さんふらわあ しれとこ」の自動航海実証実験の成功 | ニュースリリース | 三井E&Sグループ (mes.co.jp) (in Japanese)

Scope of this study

Safety assessment of the system responsible for "Action" task.

MASS modelling based on Endsely theory[3]

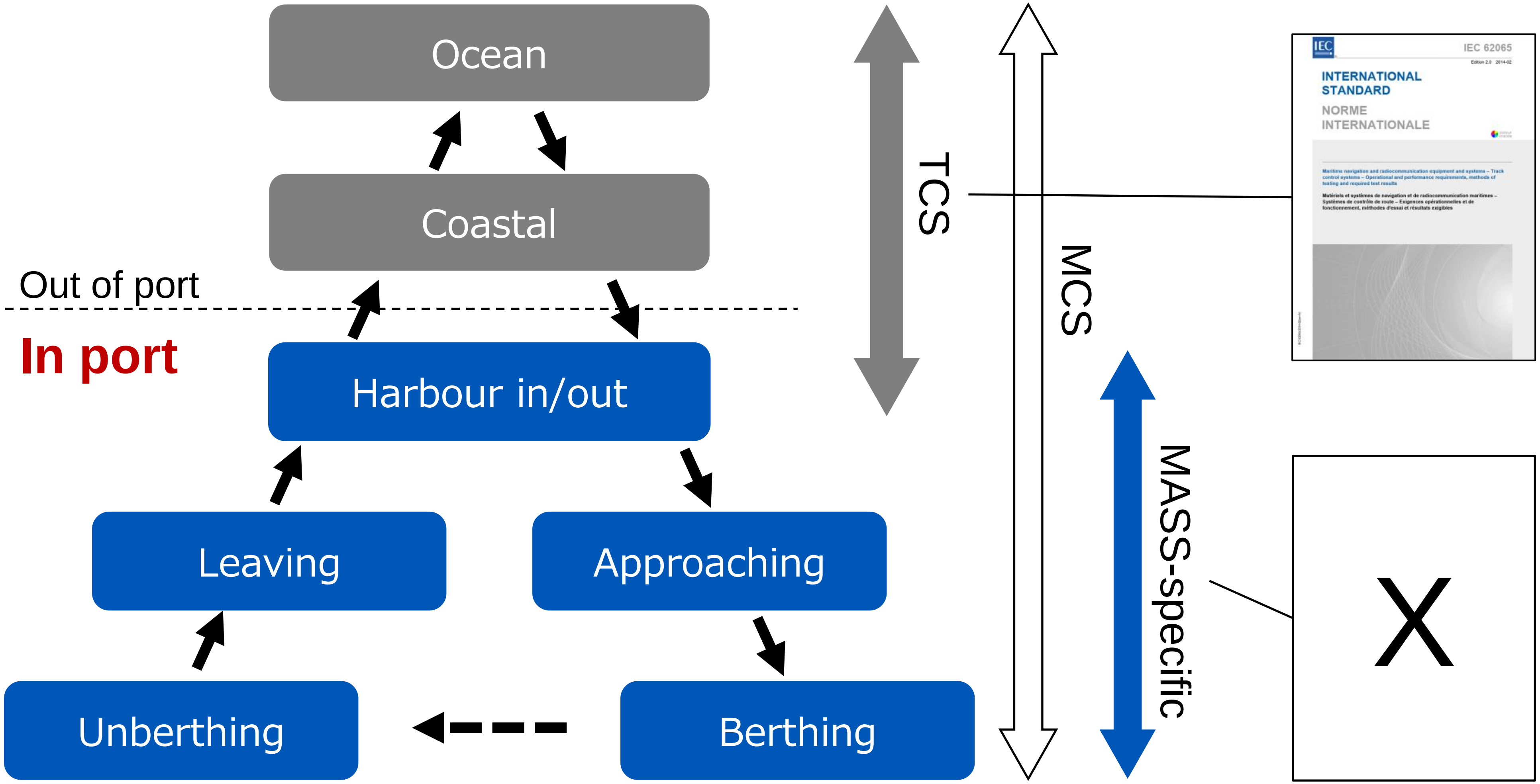


Key issue is how to verify the safety of control algorithm in Manoeuvring Control System (MCS)

[3] M. R. Endsely, Toward a Theory of Situation Awareness in Dynamic Systems, The Journal of the Human Factors & Ergonomics Society, Vol. 37(1995), No. 1, pp. 32-64

MCS vs. TCS (Track Control System)

MCS covers all phases of navigation including berthing/unberthing.



IEC 62065[4]
Verification methods using **simulation** has already defined.

Verification methods for "in-port MCS" using simulation should be developed.

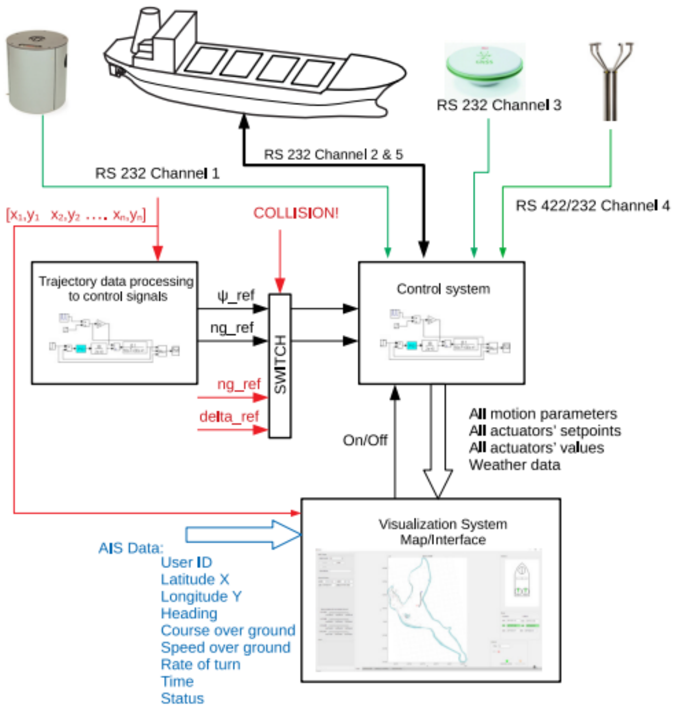
[4] International Electrotechnical Commission, Maritime Navigation and Radiocommunication Equipment and Systems – Track Control Systems – Operational and Performance Requirements, Methods of Testing and Required Test Results, 62065, 2014.

Related study of MCS (Manoeuvring Control System)

Research from the viewpoint of the verification method is limited.

Miller et al. (2021)[5]

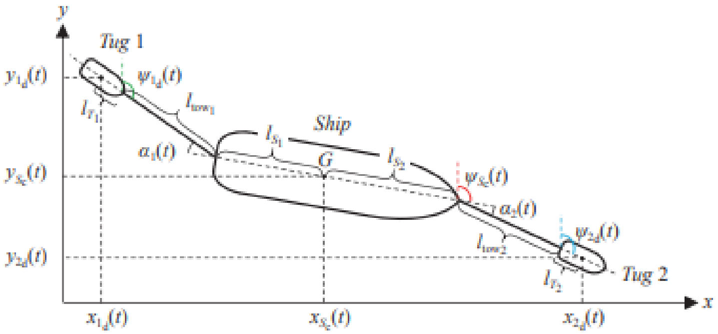
Control experiments using a scale model ship are demonstrated.



[5] A. Miller, M. Rybczak and A. Rak, Towards the Autonomy: Control Systems for the Ship in Confined and Open Waters, Sensors, Vol. 21(2021), No. 7, 2286.

Du et al. (2021) [6]

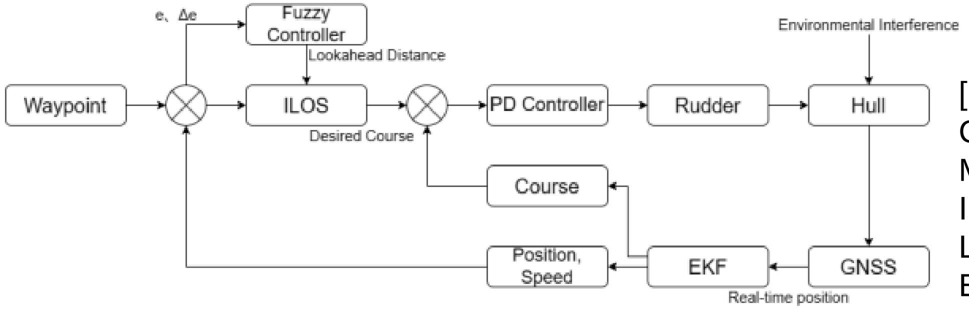
Control algorithm for towing a ship is proposed.



[6] Z. Du, R. R. Negenborn and V. Reppa, Cooperative Multi-Agent Control for Autonomous Ship Towing Under Environmental Disturbances, Journal of Automatica Sinica, Vol. 8(2021), No. 8, pp. 1365-1379.

Han et al. (2024) [7]

A Fuzzy control improvement method is proposed.



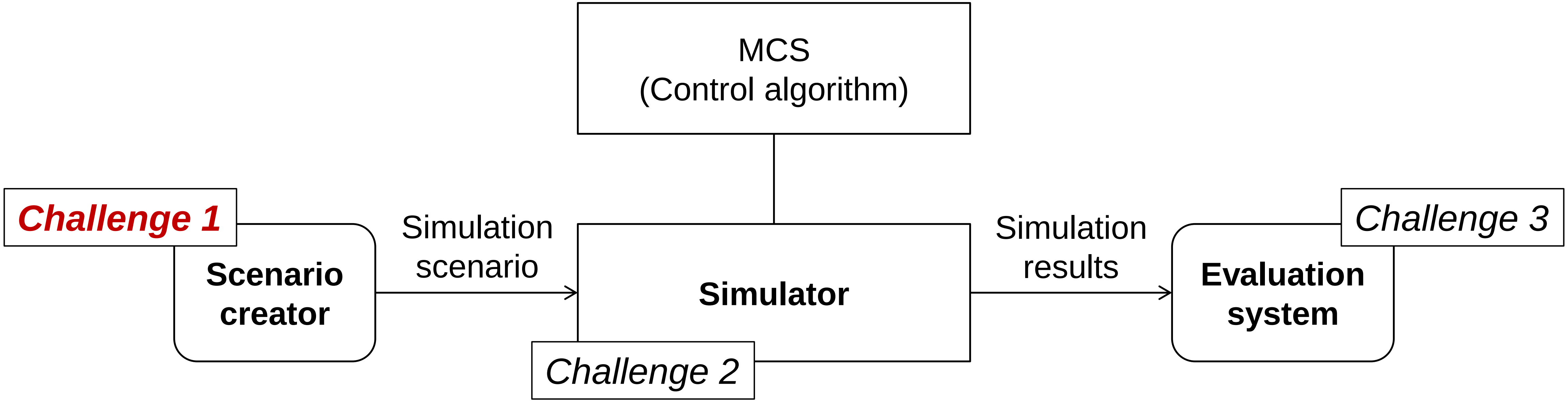
[7] B. Han, Z. Duan, Z. Peng and Y. Chen, A Ship Path Tracking Control Method Using a Fuzzy Control Integrated Line-of-Sight Guidance Law, Journal of Marine Science and Engineering, Vol. 12(2024) No. 4, 586.

Objective of this study

Establishing a safety assessment method using simulation for the control algorithm.

Challenges

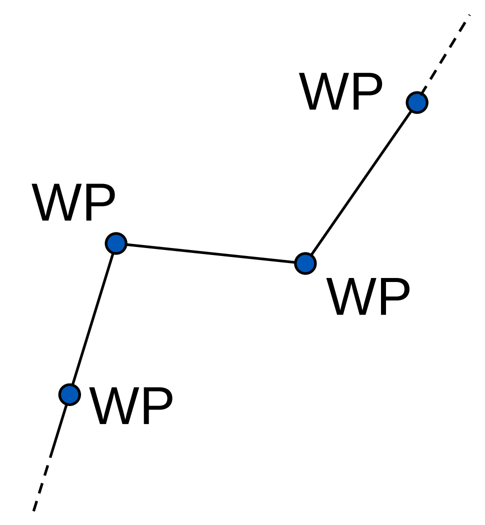
1. **How to create simulation scenarios? (Today's presentation)**
2. What is the functionality of the simulator (especially mathematical manoeuvring model)?
3. How to evaluate the simulation results for the safety assessment?



Concept of creating simulation scenarios

Simulation scenario is defined as a combination of the passage plan and environment conditions.

Passage plan
- ✓ Hypothetical route for simulation
- ✓ Each WP (Way Point) has designated speed.



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Environment condition
- ✓ Wind & tidal currents
- ✓ Magnitude and direction are considered for a comprehensive verification
- ✓ Details are shown in our paper.

= Simulation scenario

How to create a passage plan?

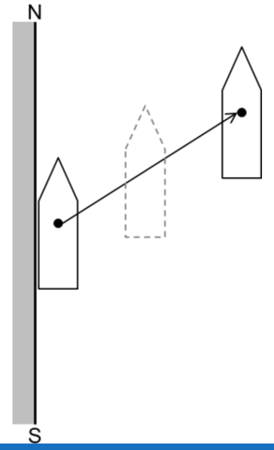
Passage plan is created by combining manoeuvring patterns developed by general manoeuvres for each navigational mode.

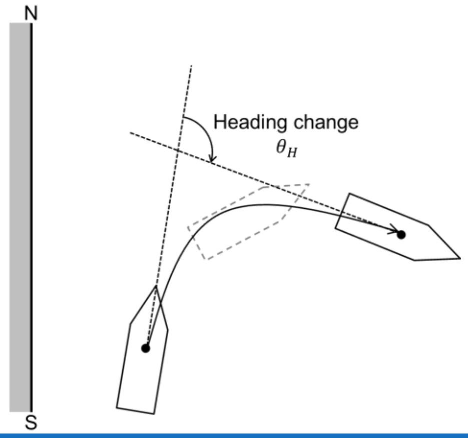
Passage plan (All voyages take place in a port)

Unberthing	Leaving	Harbour in/out	Approaching	Berthing
Manoeuvring pattern (a)~(f)	Manoeuvring pattern (a)~(c)	Manoeuvring pattern (a)	Manoeuvring pattern (a)~(c)	Manoeuvring pattern (a)~(f)

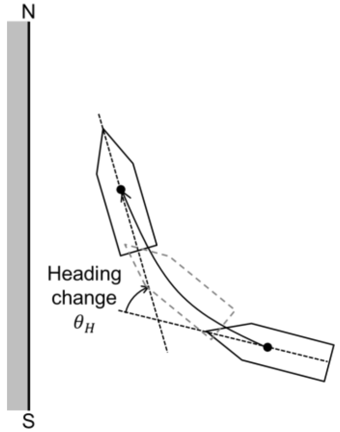
Example

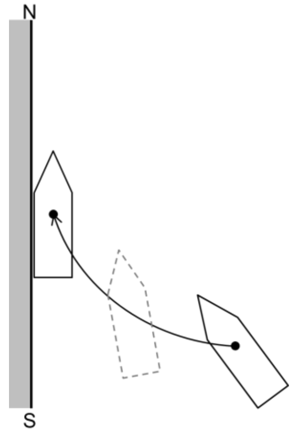
(b) — (c) — (a) — (b) — (e)





Manoeuvre with turning





[Reference] Manoeuvring patterns of the unberthing

(a) Crabbing
Moving laterally at zero forward speed without altering heading

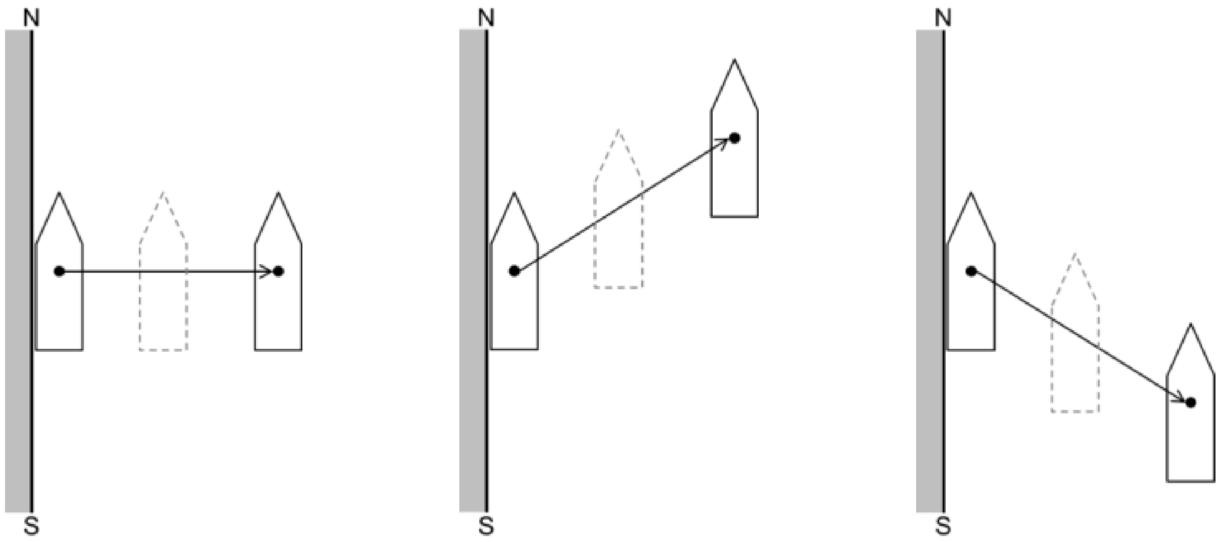
(b) Forward crabbing
Moving laterally at slow forward speed without altering heading

(c) Aftward crabbing
Moving laterally at slow aftward speed without altering heading

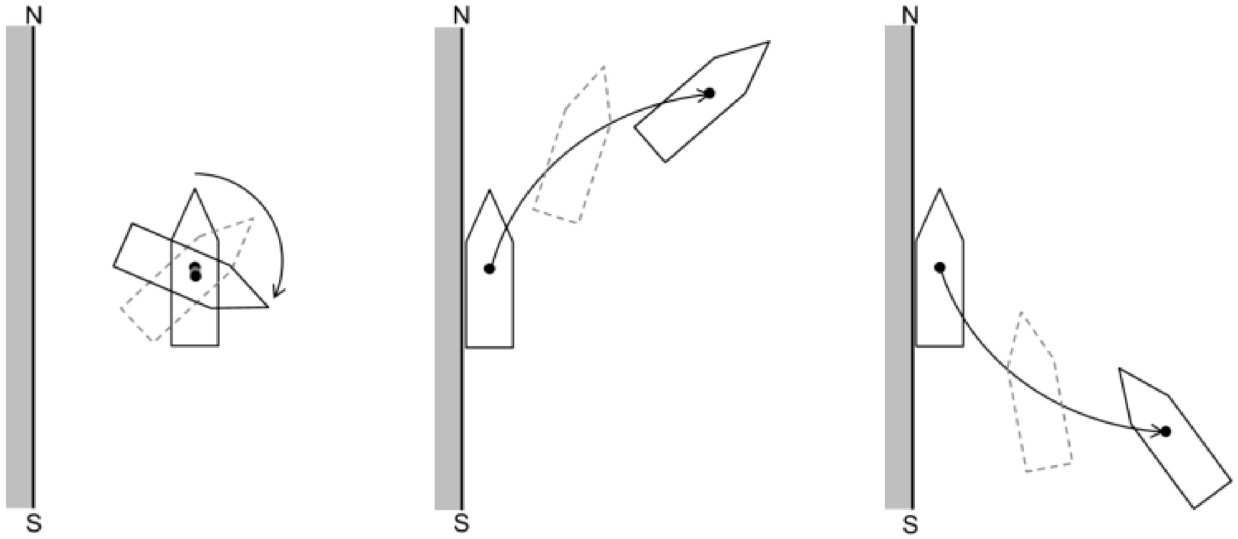
(d) Pivot turn
Turning at zero forward speed

(e) Forward turn
Turning at slow forward speed

(f) Aftward turn
Turning at slow aftward speed



(a) Crabbing (b) Forward crabbing (c) Aftward crabbing



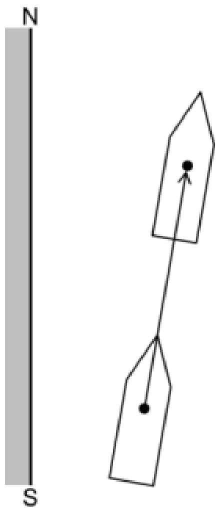
(d) Pivot turn (e) Forward turn (f) Aftward turn

[Reference] Manoeuvring patterns of the leaving

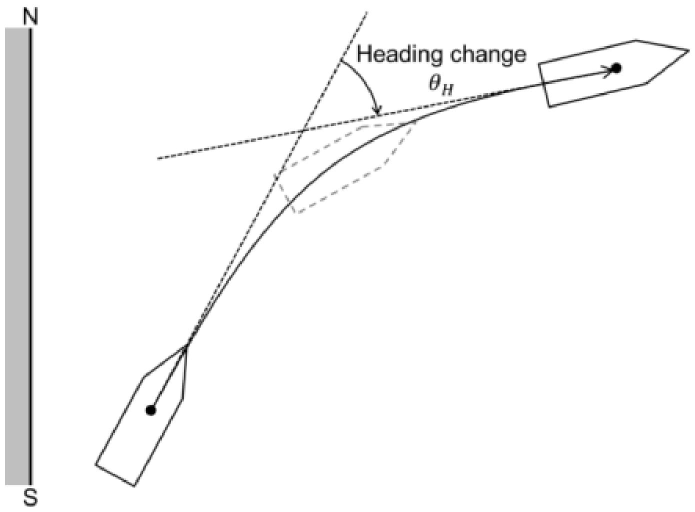
(a) Straight acceleration
Accelerating without turning

(b) Turning acceleration
Accelerating while turning

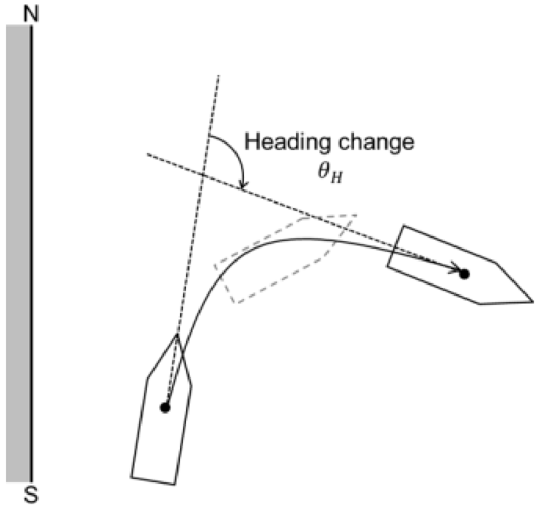
(c) U-turning acceleration
Accelerating while turning with large heading change



(a) Straight acceleration



(b) Turning acceleration ($\theta_H < 90$ deg.)



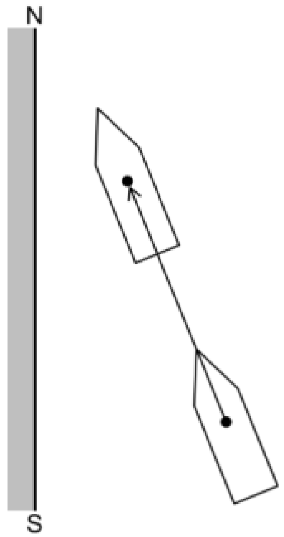
(c) U-turning acceleration ($\theta_H \geq 90$ deg.)

[Reference] Manoeuvring patterns of the approaching

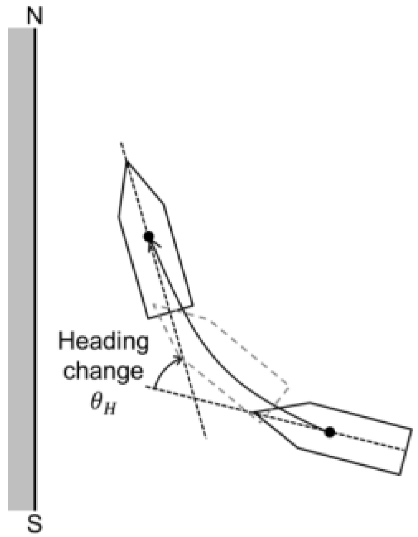
(a) Straight deceleration
Decelerating without turning

(b) Turning deceleration
Decelerating while turning

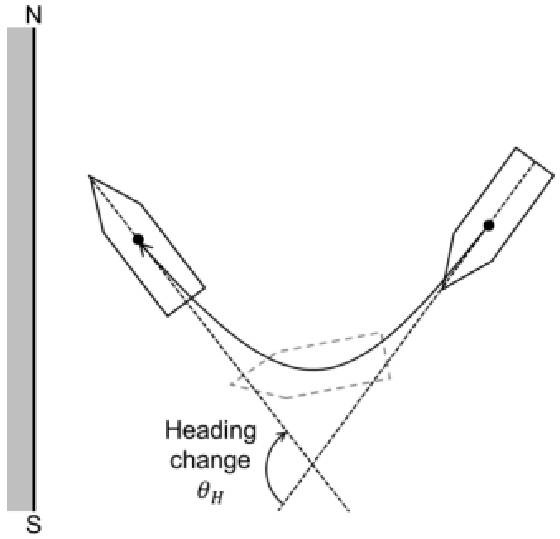
(c) U-turning deceleration
Decelerating while turning with large heading change



(a) Straight deceleration



(b) Turning deceleration ($\theta_H < 90$ deg.)



(c) U-turning deceleration ($\theta_H \geq 90$ deg.)

[Reference] Manoeuvring patterns of the berthing

(a) Crabbing
Moving laterally at zero forward speed without altering heading

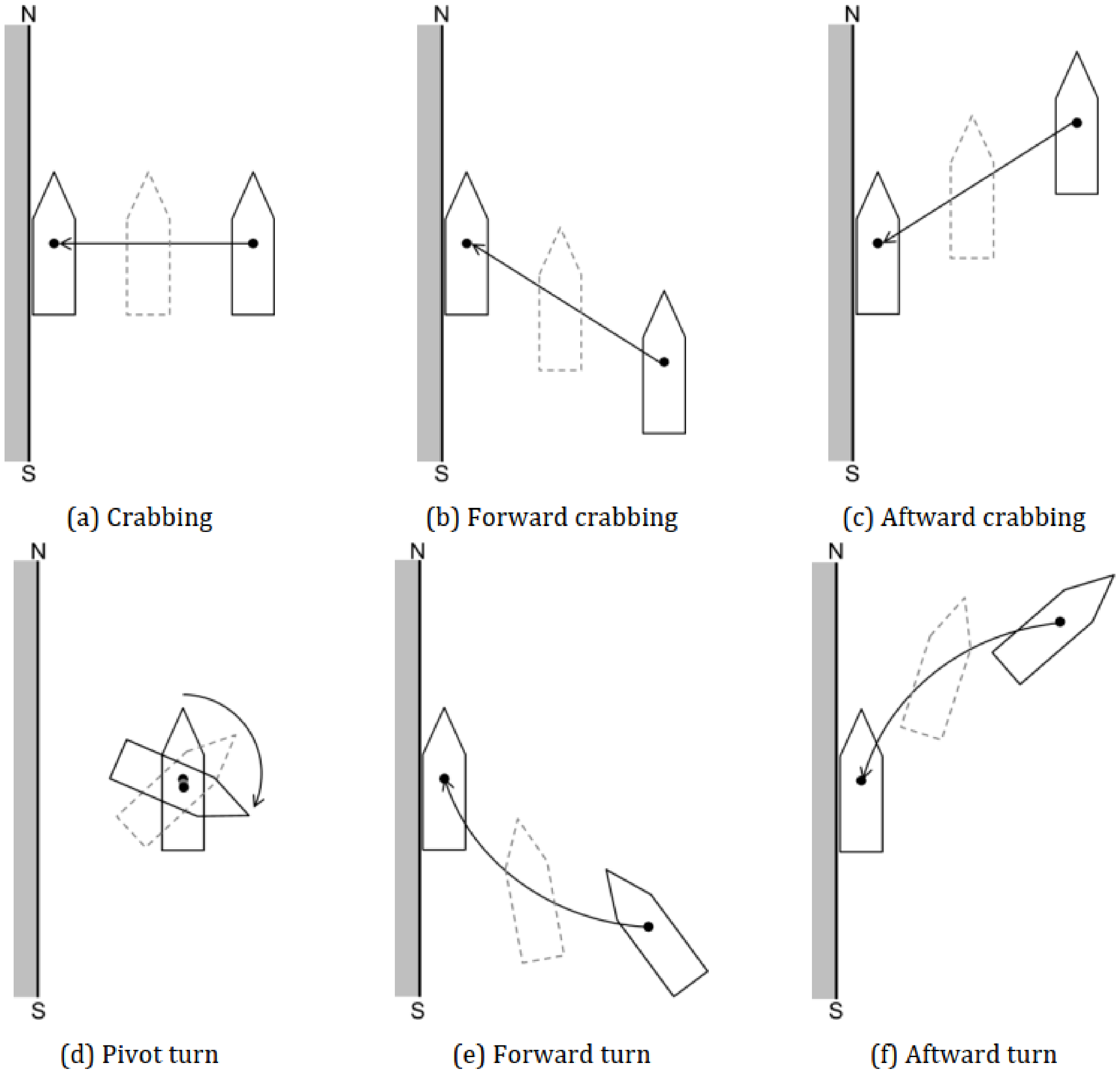
(b) Forward crabbing
Moving laterally at slow forward speed without altering heading

(c) Aftward crabbing
Moving laterally at slow aftward speed without altering heading

(d) Pivot turn
Turning at zero forward speed

(e) Forward turn
Turning at slow forward speed

(f) Aftward turn
Turning at slow aftward speed



Example (settings)

Target ship is a coastal container ship with a bow thruster.

- Target ship
  - Coastal container ship (749 GT, assuming the Japanese MASS project)
  - One rudder, one CPP (Controllable Pitch Propeller) and one bow thruster
  - **Some manoeuvring patterns are impossible to be performed by this ship**

- ODD (Operational Desing Domain) of MCS
  - Maximum wind speed: 10 m/s
  - Maximum current speed: 1 knot
  - This system can handle with the automatic berthing/unberthing

- Other
  - The direction of quays in simulation scenarios is fixed to be the north-south direction.

Example (combination of manoeuvring patterns)

Possible patterns are chosen and combined to passage plans.

Unberthing	Leaving	Harbour in/out	Approaching	Berthing
Possible pattern (e)	Possible patterns (a), (b), (c)	Possible pattern (a)	Possible patterns (a), (b), (c)	Possible pattern (e)

Comprehensively combining these patterns

Passage plan 1

(e) — (a)+(c) — (a) — (a)+(b) — (e)

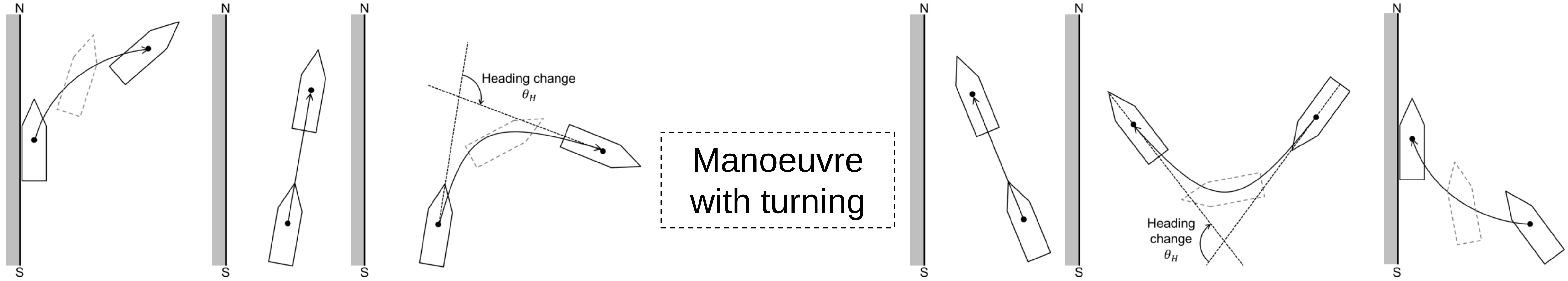
Passage plan 2

(e) — (a)+(b) — (a) — (a)+(c) — (e)

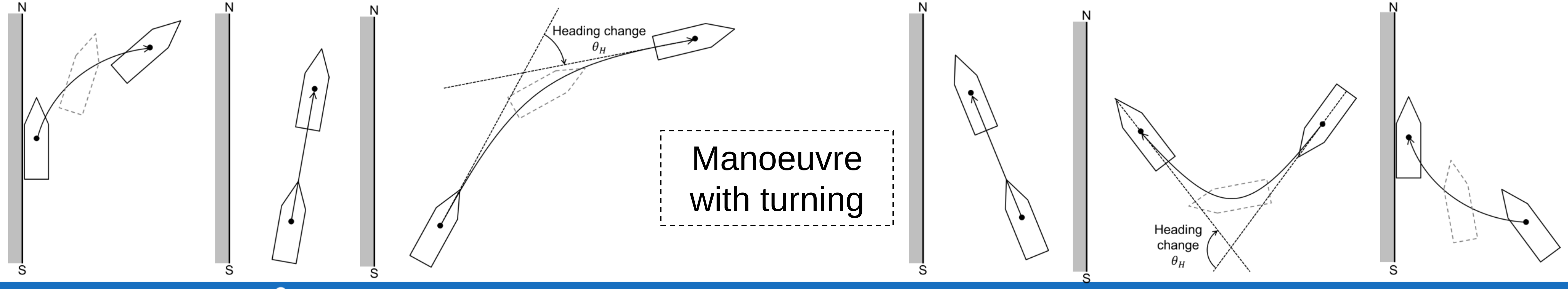
[Reference] Combining patterns for passage plan 1&2

Unberthing | Leaving | Harbour in/out | Approaching | Berthing

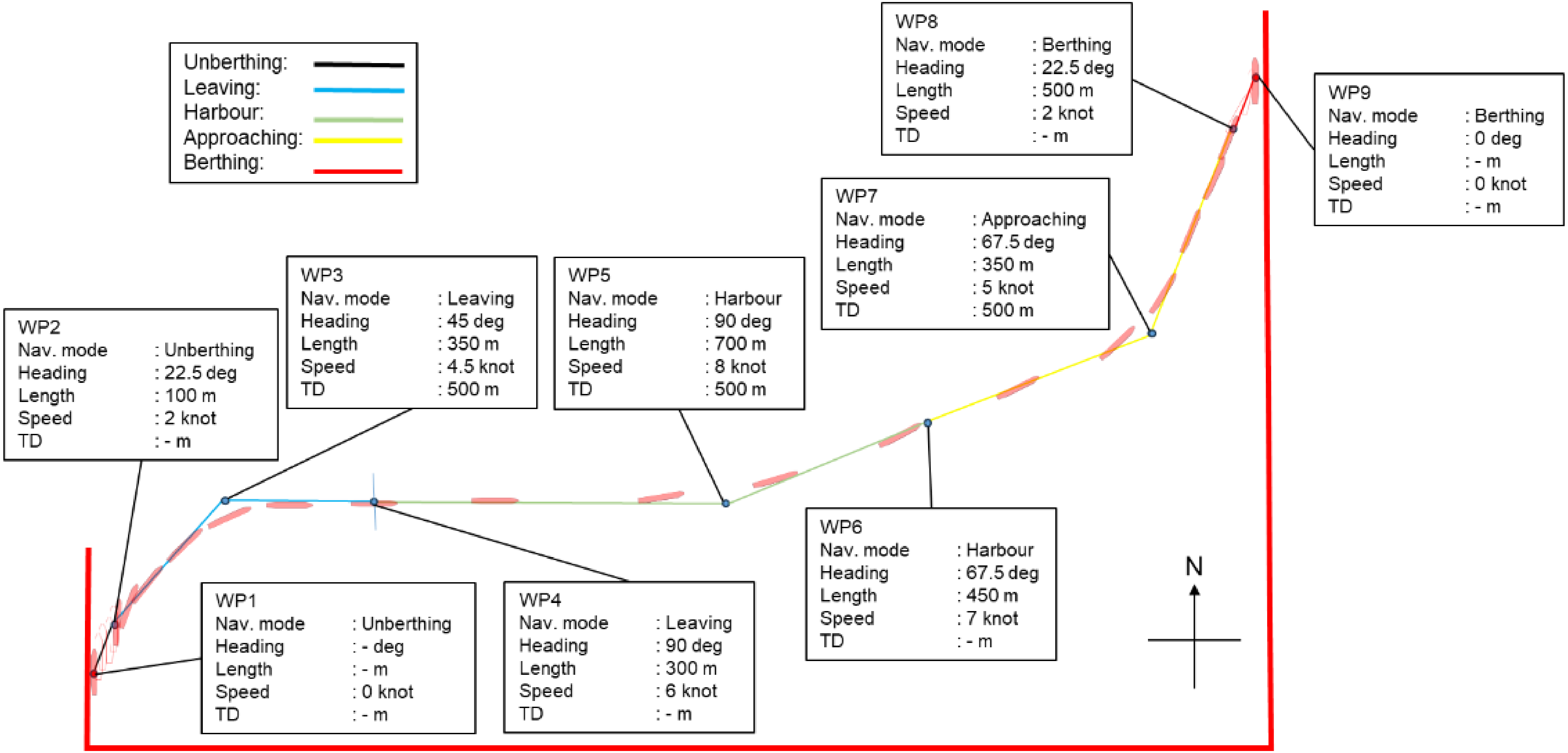
(e) — (a)+(c) — (a) — (a)+(b) — (e)



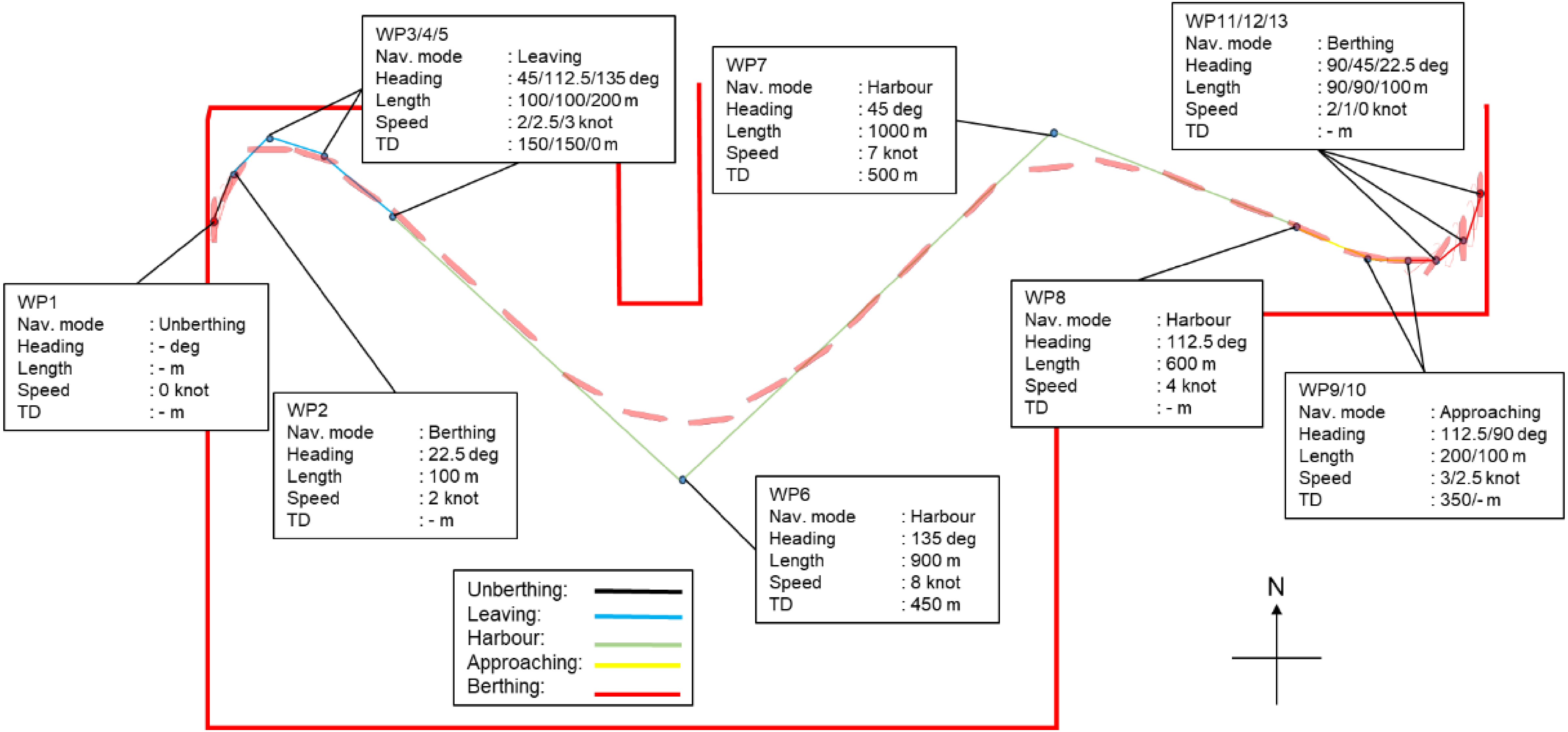
(e) — (a)+(b) — (a) — (a)+(c) — (e)



[Reference] Passage plan 1



[Reference] Passage plan 2



Example (environmental condition)

Combination of wind speed/direction and current speed/direction

Combination table

Detailed examination for the wind direction

Total: 27 conditions

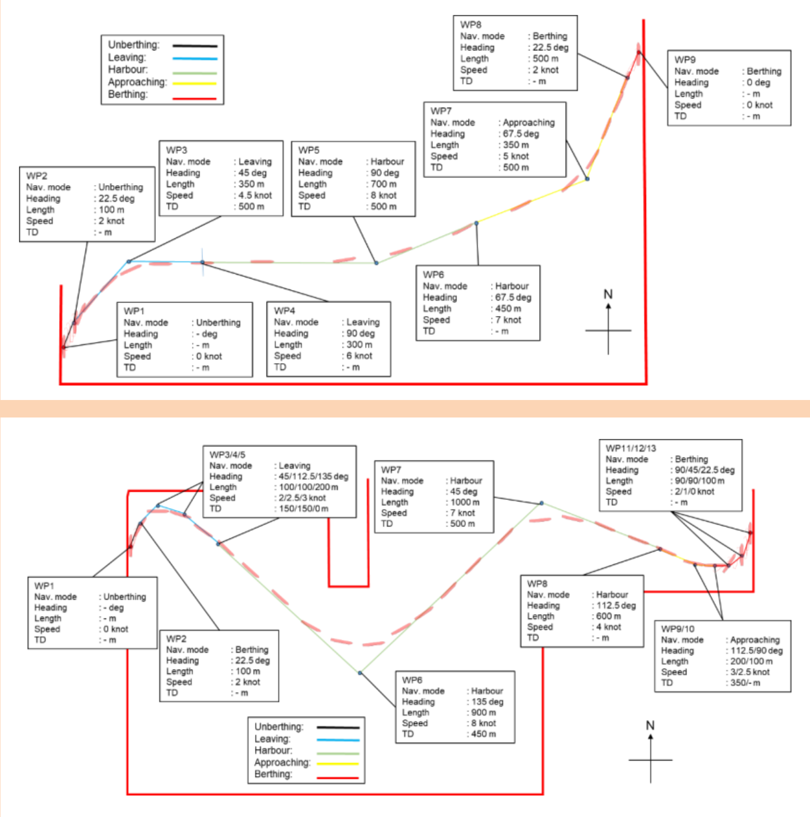
Average wind speed [m/s]	0.0		6.0	8.0		10.0
Num. of Directions	N/A		4 (N, S, E, W)	4 (N, S, E, W)	4 (NE, NW, SE, SW)	4 (N, S, E, W)
Num. of current types	1 (0 knot)	2 (N, S)	1 (0 knot)	3 (0, N, S)	1 (0 knot)	1 (0 knot)
Num. of combinations	**1**	**2**	**4**	**12**	**4**	**4**

Red: No environmental condition
Blue: Only effect by the wind or the current
Green: Combination of the wind and the current

Example (Simulation scenarios)

54 simulation scenarios of series of simulation for verification

Passage plan 1&2



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Environment condition

✓ 27 combinations

Total: 27 conditions

Average wind speed [m/s]	0.0		6.0	8.0		10.0
Num. of Directions	N/A		4 (N, S, E, W)	4 (N, S, E, W)	4 (NE, NW, SE, SW)	4 (N, S, E, W)
Num. of current types	1 (0 knot)	2 (N, S)	1 (0 knot)	3 (0, N, S)	1 (0 knot)	1 (0 knot)
Num. of combinations	**1**	**2**	**4**	**12**	**4**	**4**

Red: No environmental condition
Blue: Only effect by the wind or the current
Green: Combination of the wind and the current

= 54 simulation scenarios*

** When the part of simulation such as berthing/unberthing is required, the numbers are increased.*

Summary

This study proposes a method for creating simulation scenarios.

- Our key ideas are:
  - Simulation scenario is defined as a combination of the passage plan and environment conditions.
  - Passage plan is created by combining manoeuvring patterns developed by general manoeuvres for each navigational mode.
  - Wind and current are considered as environment conditions.

- Our method is devised in such a way that the number of scenarios does not increase exponentially while ensuring the comprehensiveness of scenarios.

- Future research topics
  - Simulator requirements (challenge 2)
  - Evaluation method for simulation results (challenge 3)