

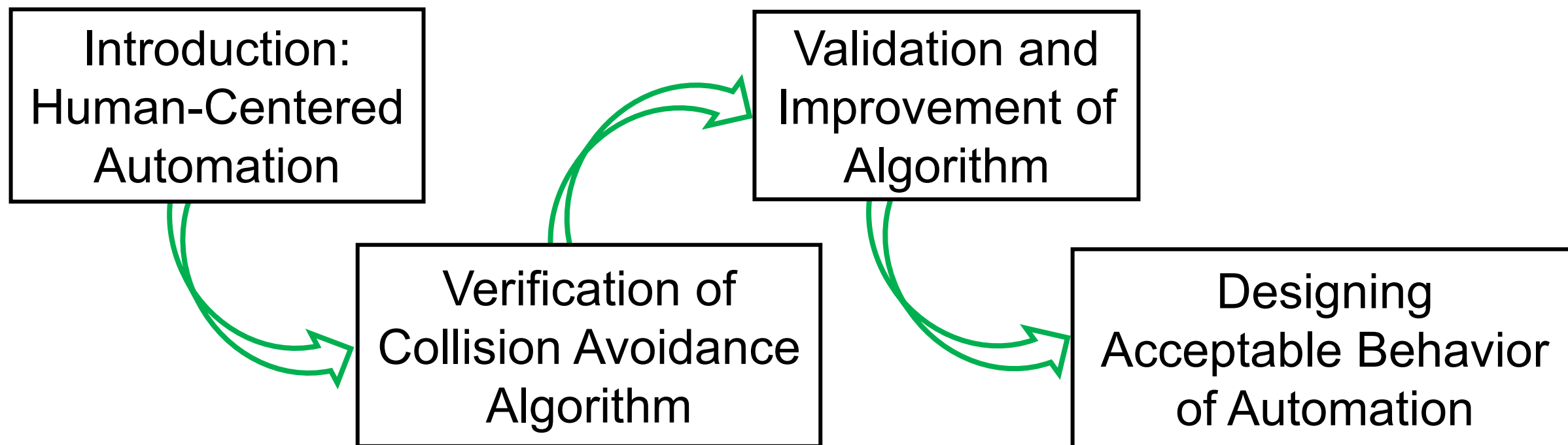
Development of collision avoidance algorithms based on success factor analysis of expert maritime captains using FRAM

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ClassNK

Supported by

Contents



Complexity of Navigation Task



- ◆ **Difficult to literally describe** how to realize safe-ship operation
 - although there exist many information and “know-how” (e.g., Text/Manual book, Regulations, Lessons learned from experience)
- ◆ **Many non-technical skills involved**, depending on specific context
 - Essential to understand “**what is going on in real fields of practice**” and “**why they work well**”

As a matter of practice

- ◆ **Great challenge for automation design** of safe-ship operations
- ◆ Decrease in the number of captains expected in the future, especially in Japan
 - **Must consider how to transfer the skills** effectively to future generations
 - “MEGURI 2040” Project supported by NIPPON FOUNDATION is on going

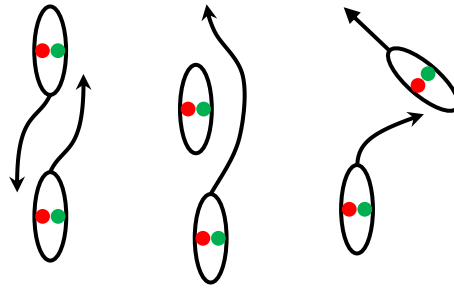
Extracting Collision Avoidance Strategies from Expert Practice

- ◆ Key elements of ship operation were collected from manuals, regulations, and experiments
 - Structured into a FRAM model representing real-world navigation
 - Analysis revealed core strategies for effective collision avoidance

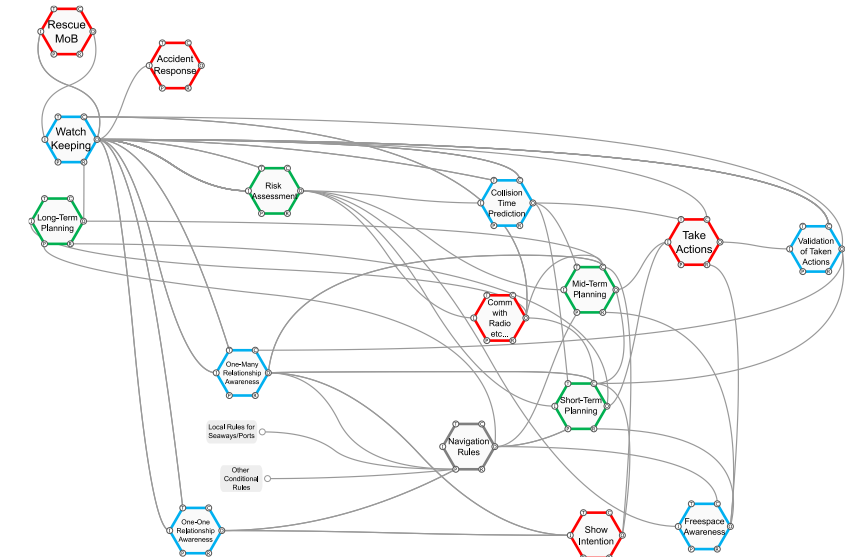
Technical/Instruction books



Int'l Navigation Rules



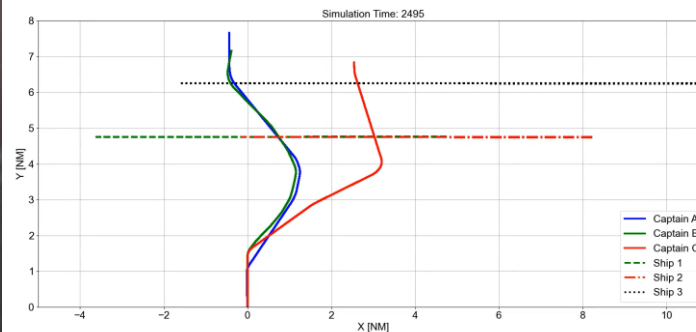
Modelling



Analysis

Collision Avoidance Strategies

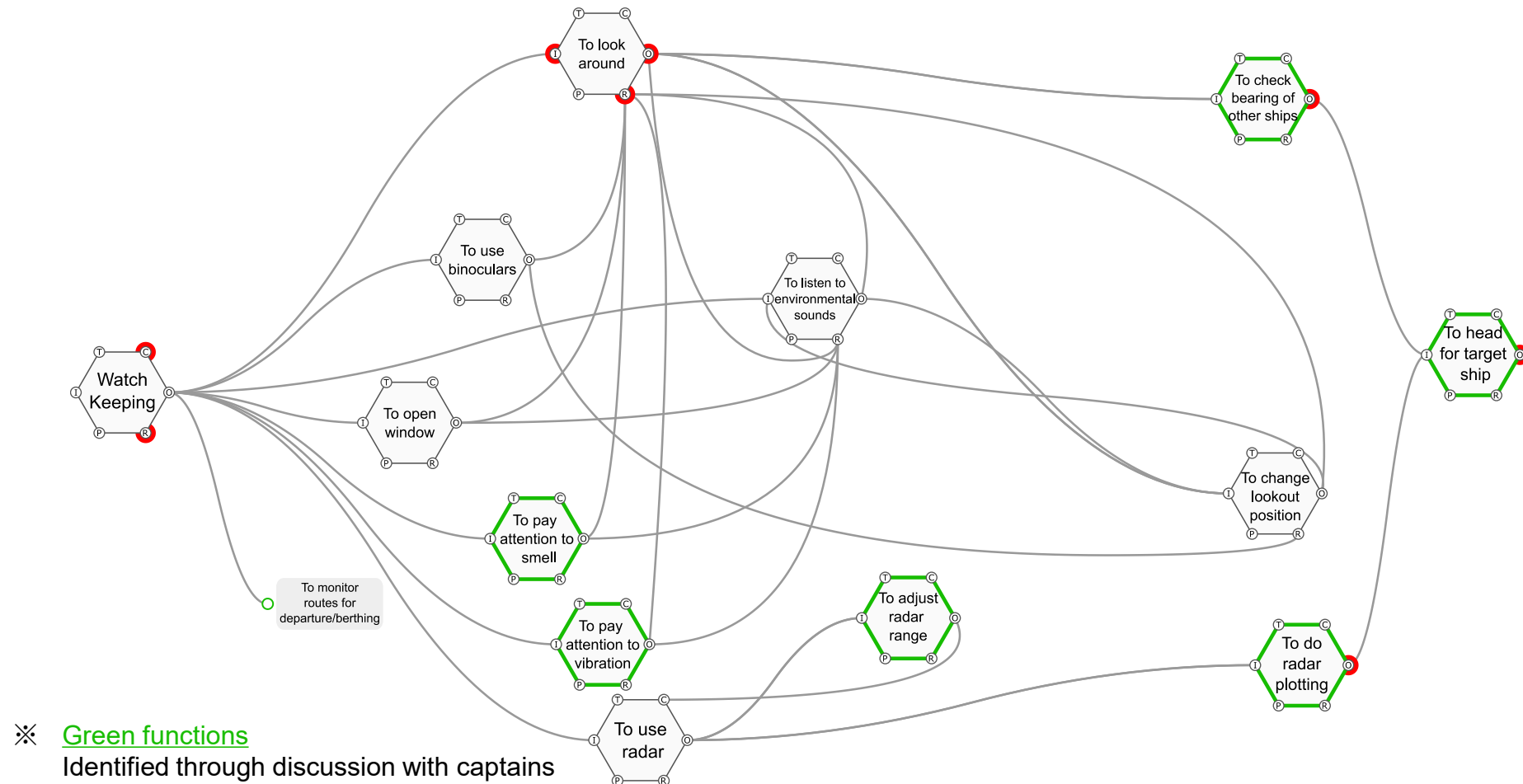
Simulation Based Experiment



Example: FRAM Model of Watch-Keeping Task

小型船舶の航行の安全に関する教則 pp. 21 1-1: Watch-keeping (originally written in Japanese)

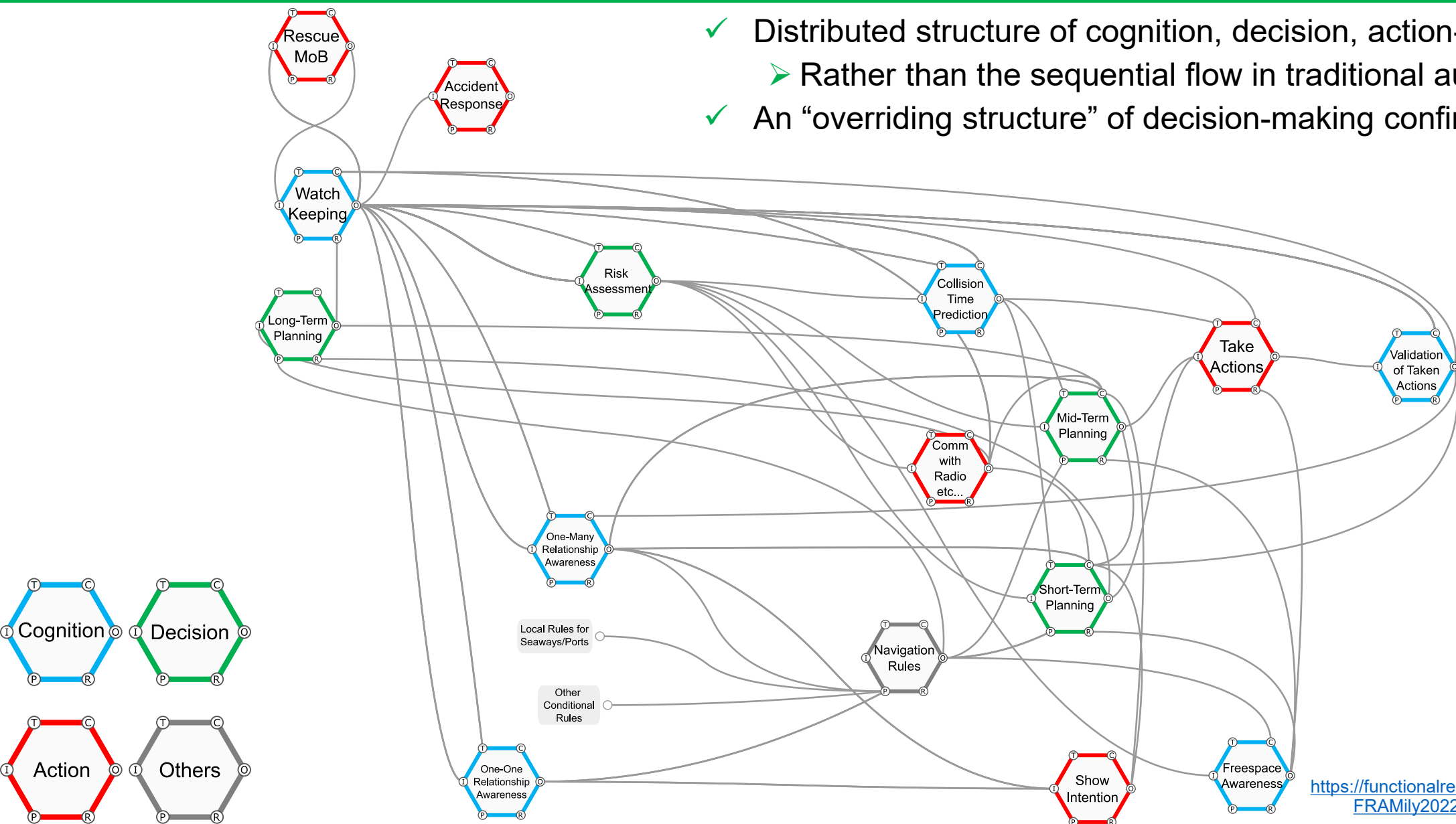
The crew **must always keep watching** for better situational awareness and collision avoidance, by using your vision, hearing and any other possible measures. Specifically, you have to **1) look around, 2) use binoculars, 3) listen to the environmental sounds, 4) open doors, 5) use radars**, depending on situations. You also need to **change lookout position** to cover blind spots.





FRAM Model of Ship Operation

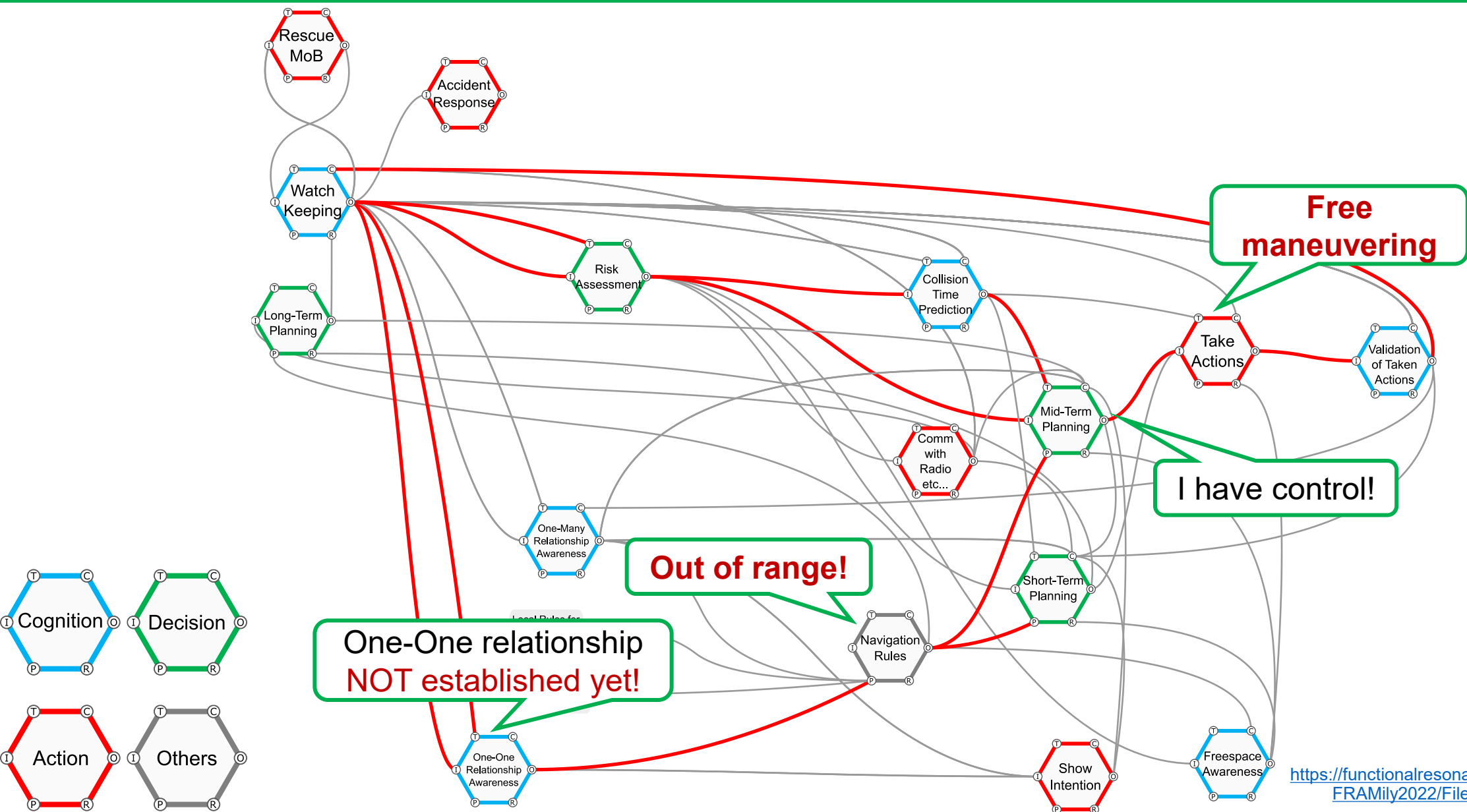
- ✓ Distributed structure of cognition, decision, action-related functions
 - Rather than the sequential flow in traditional automation design
- ✓ An “overriding structure” of decision-making confirmed



<https://functionalresonance.com/framily-meetings/FRAMily2022/Files/Presentations/index.html>



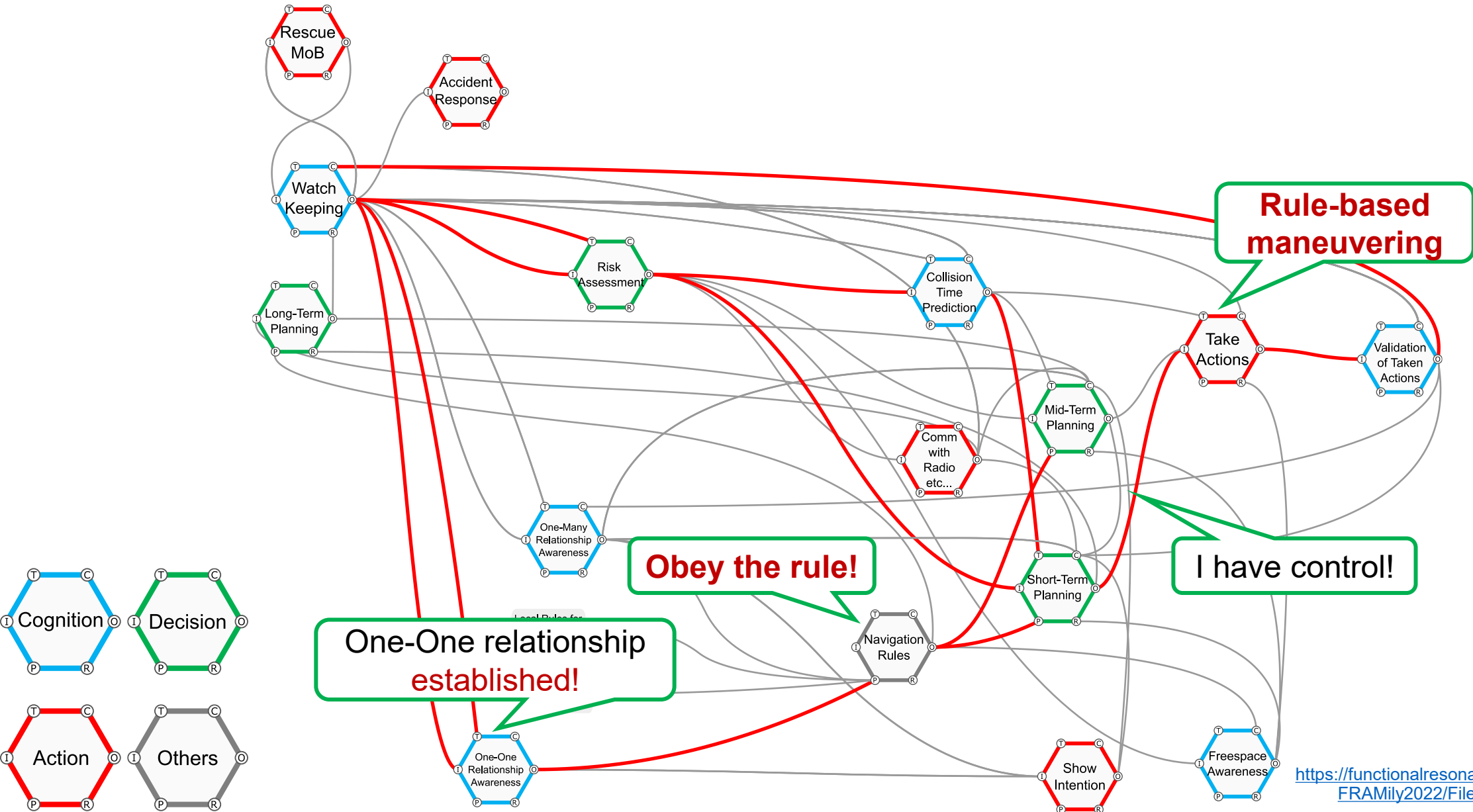
Beyond Navigation Rule Range



<https://functionalresonance.com/framily-meetings/FRAMily2022/Files/Presentations/index.html>



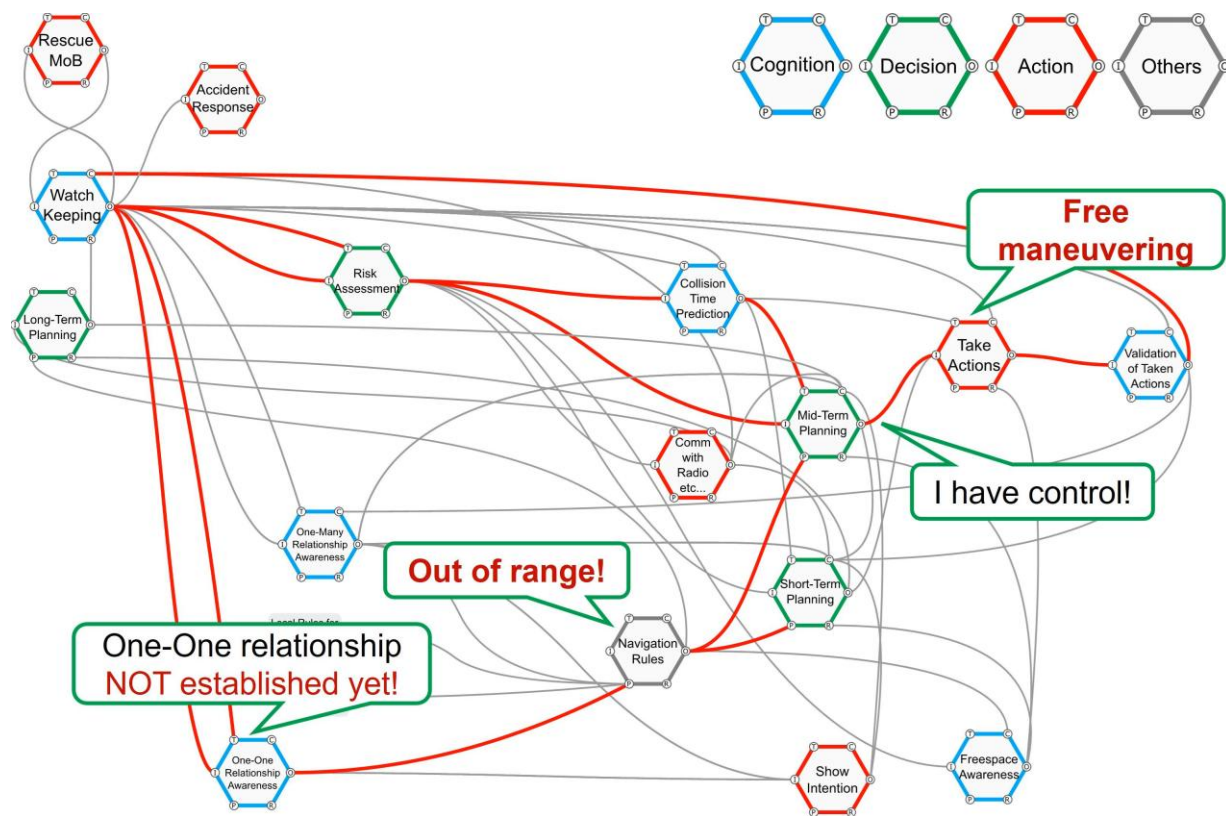
Within Navigation Rule Range



<https://functionalresonance.com/framily-meetings/FRAMily2022/Files/Presentations/index.html>



FRAM Model into Algorithm



Model-to-Logic Conversion

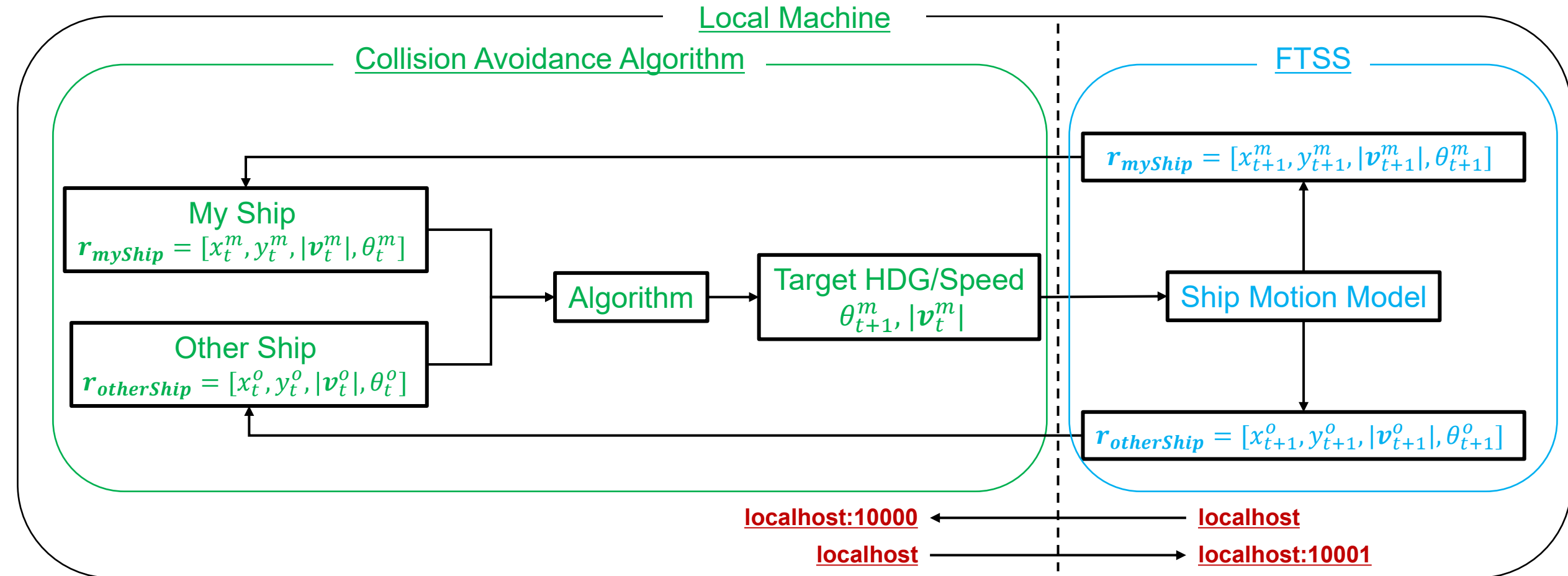
<https://functionalresonance.com/framily-meetings/FRAMily2022/Files/Presentations/index.html>

Phase	Strategy
Pre-regulatory phase	Free maneuvering without regulatory constraints
Regulatory compliance phase	Maneuvering must comply with COLREGs and navigational rules
Emergency phase	Immediate evasive action takes precedence over compliance with rules

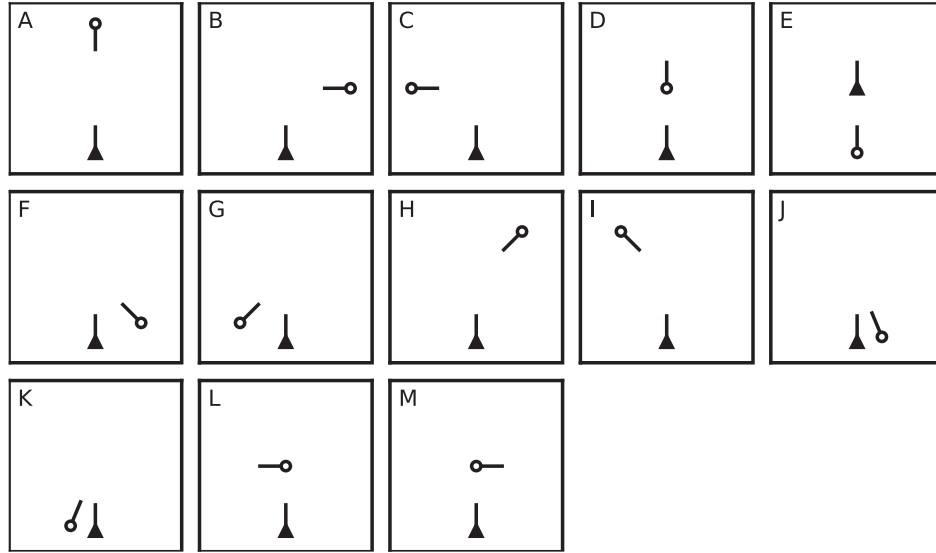


Integration with Fast Time Ship Simulator (FTSS)

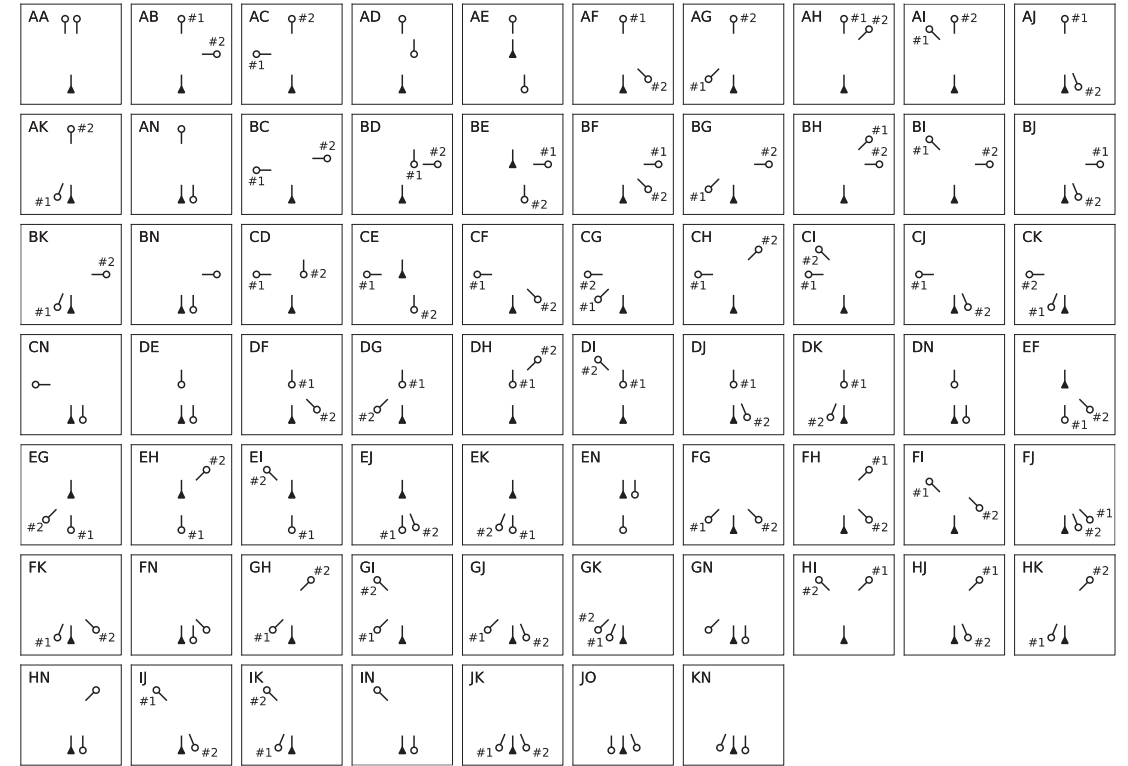
- ✓ FTSS: developed by National Maritime Research Institute
 - Simulates ship motion based on maneuvering commands from the algorithm



Validation Scenarios for Collision Avoidance Algorithm



<https://doi.org/10.1016/j.oceaneng.2024.117506>



- ◆ Scenario library by Sawada et al. covers over 90% of collision geometries observed in Japanese coastal waters.
- ◆ 84 encounter cases including single and multi-ship interactions.

Validation using Ship Handling Simulator (SHS)

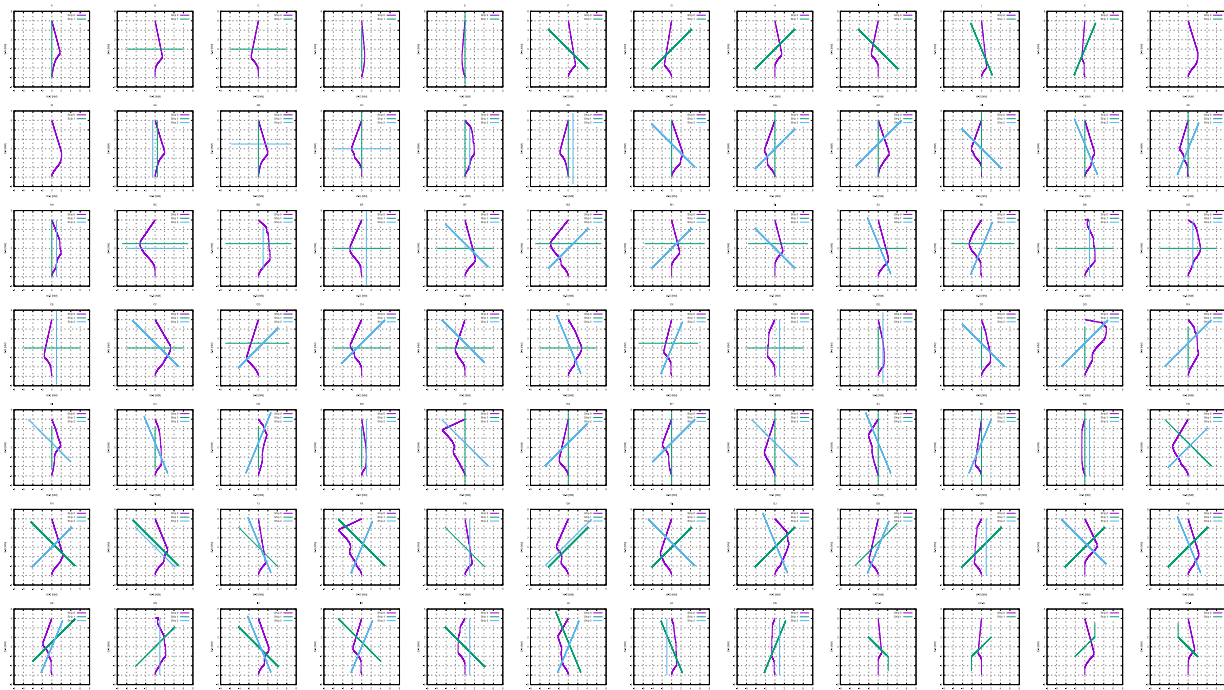


https://www.nmri.go.jp/en/study/research_organization/data_system/group6_1.html

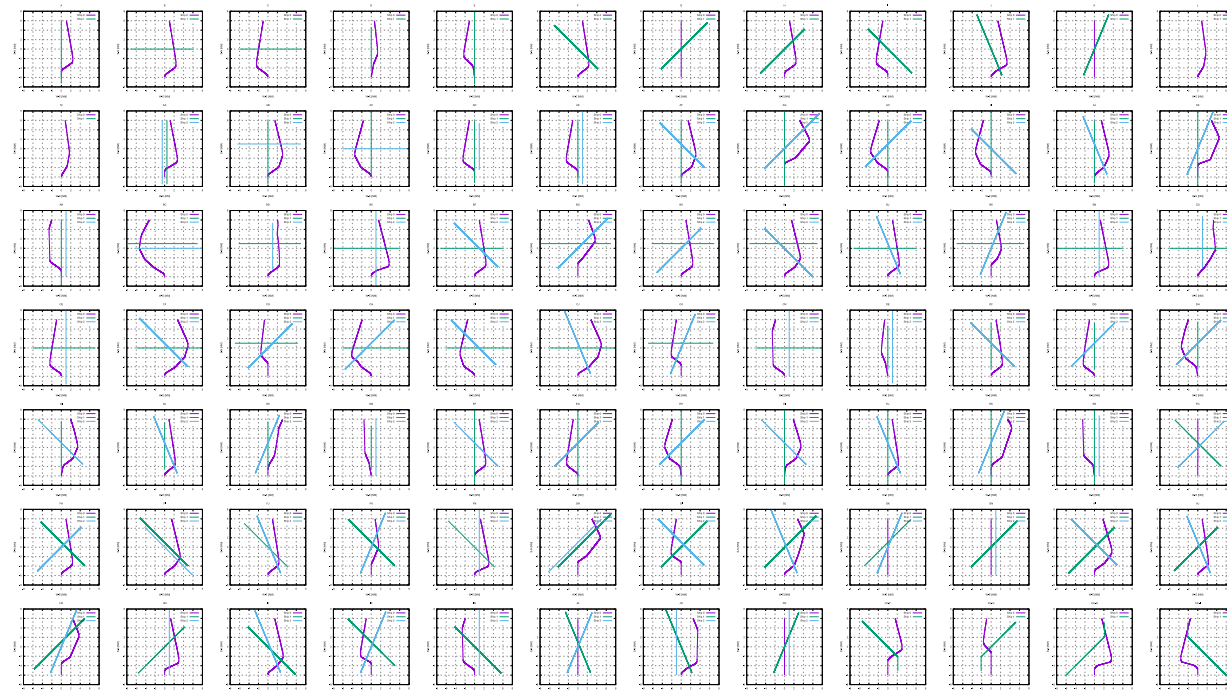
- ◆ Capable of replaying FTSS simulation results on a 360-degree screen
 - Algorithm behavior in selected scenarios was presented to two expert captains
 - Verification and validation, including algorithm improvements, were iterated twice

Simulation Result: Overview

Iteration 1



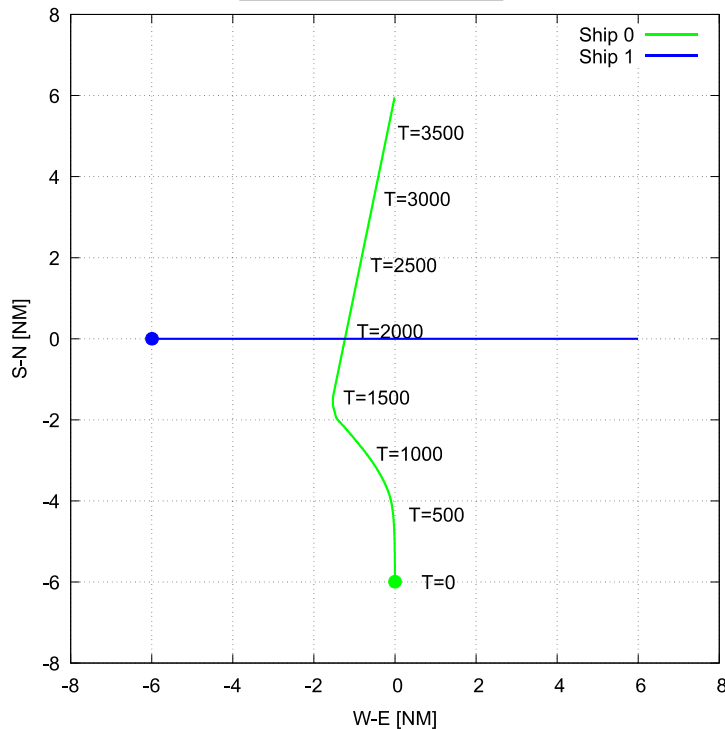
Iteration 2



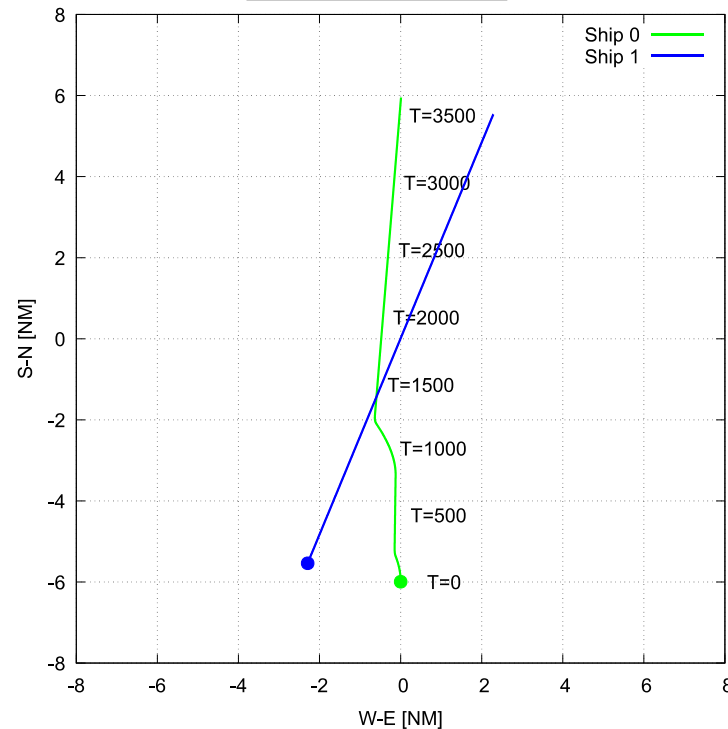
- ◆ 84 scenarios tested across two iterations — no collisions occurred
- ◆ Not just about avoiding collisions — captains evaluated behavior using SHS
 - Key comments from Iteration 1&2 will be presented in the following slides

Simulation Result: Iteration 1

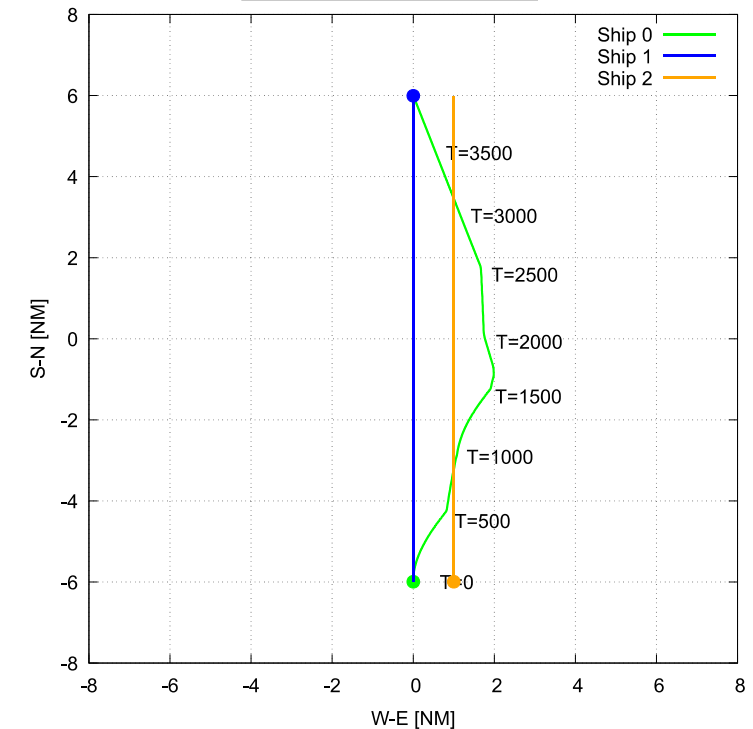
Scenario C



Scenario K



Scenario AN

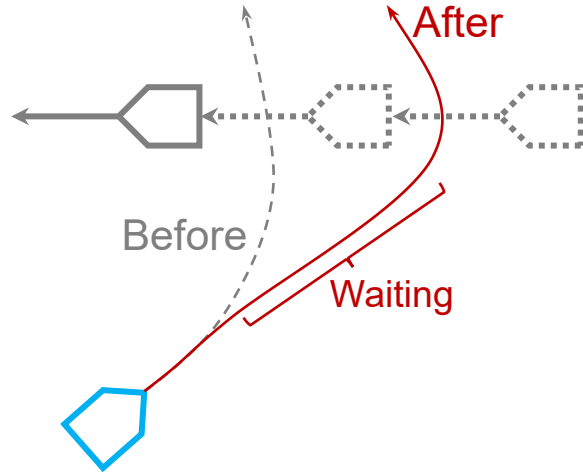


Comments by Captains

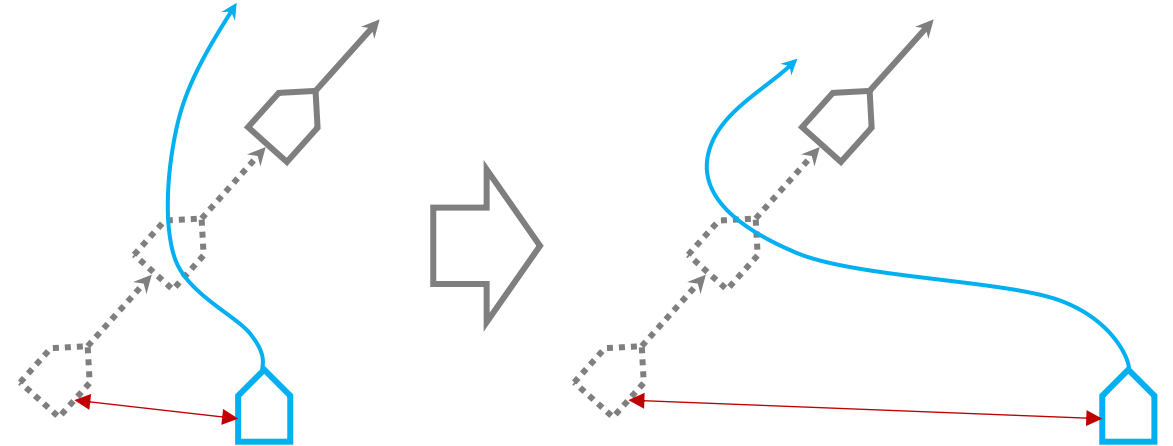
- ◆ A 100-meter-long tanker should maintain a distance of more than 1NM from other ships
- ◆ In Scenario C and K, the own ship turned left despite being the stand-on vessel
 - Seems to be gaps between theory and practice
- ◆ In Scenario AN, the initial turn was too small, and the subsequent correction appeared hesitant

Logic Updates Based on Captains' feedback

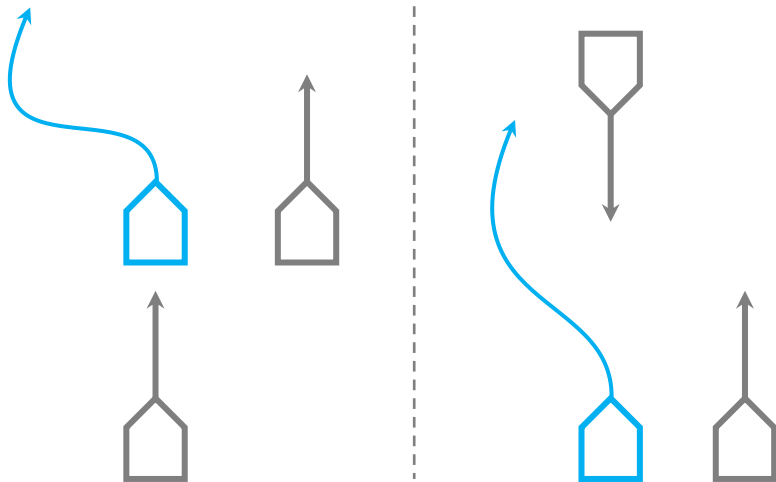
Introduced waiting period after each CAM



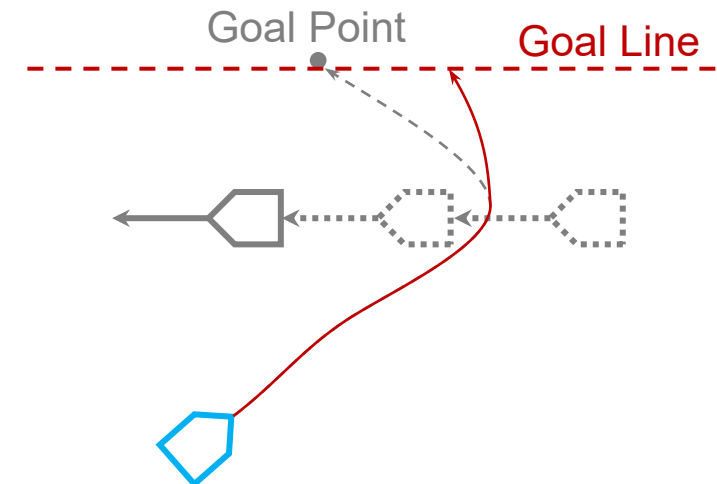
Extended lower threshold of the Pre-regulatory phase



Revised turning direction logic to avoid congested areas

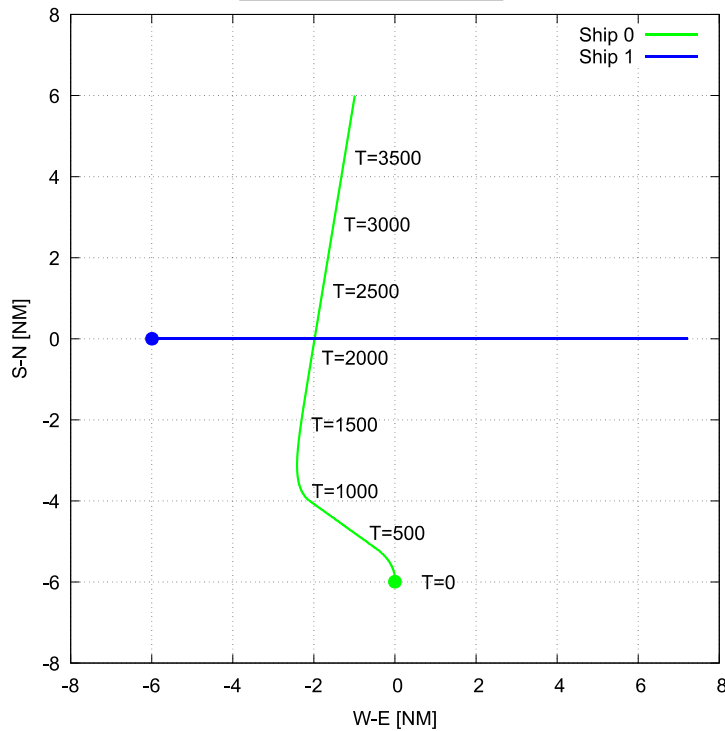


Set "goal line" beyond the destination

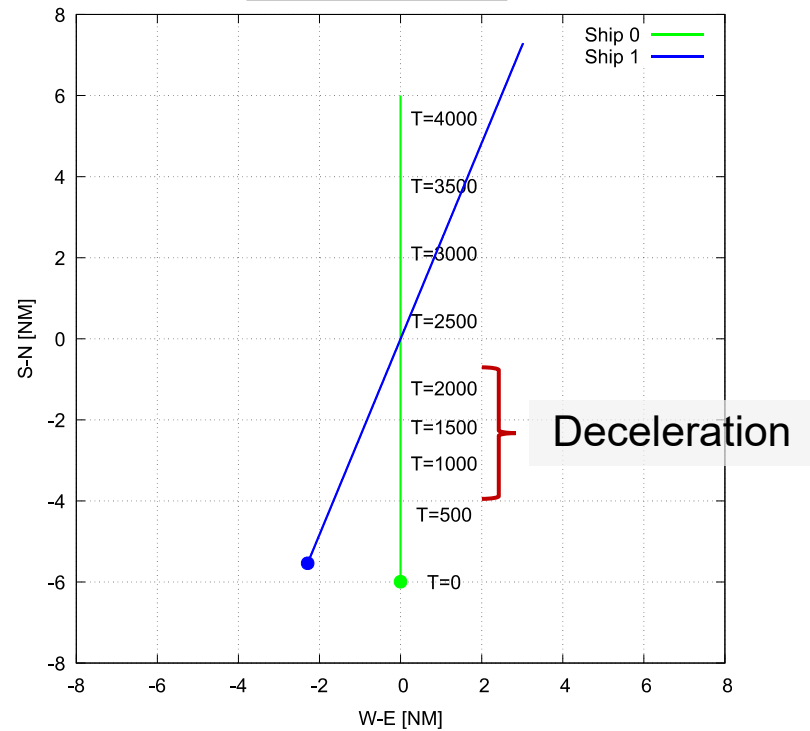


Simulation Result: Iteration 2

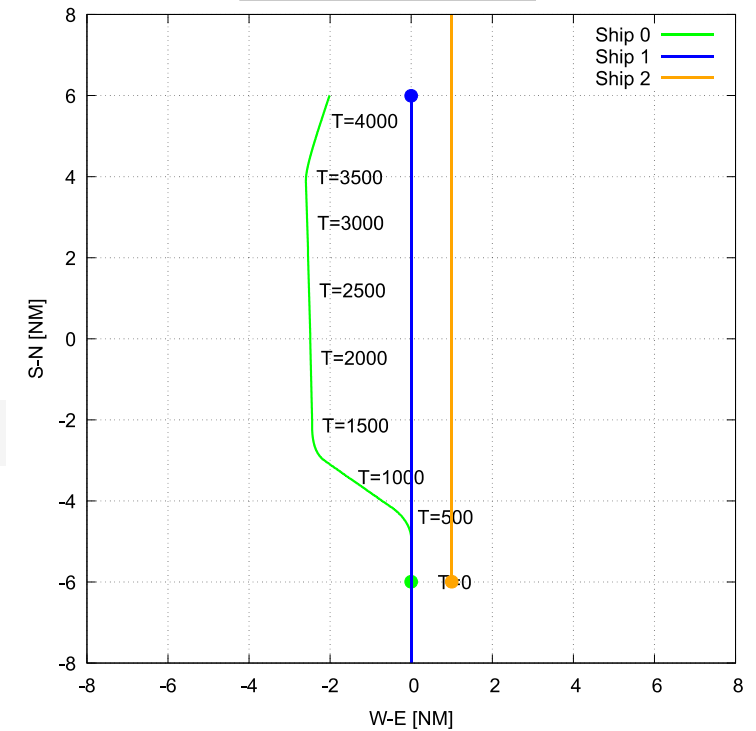
Scenario C



Scenario K



Scenario AN



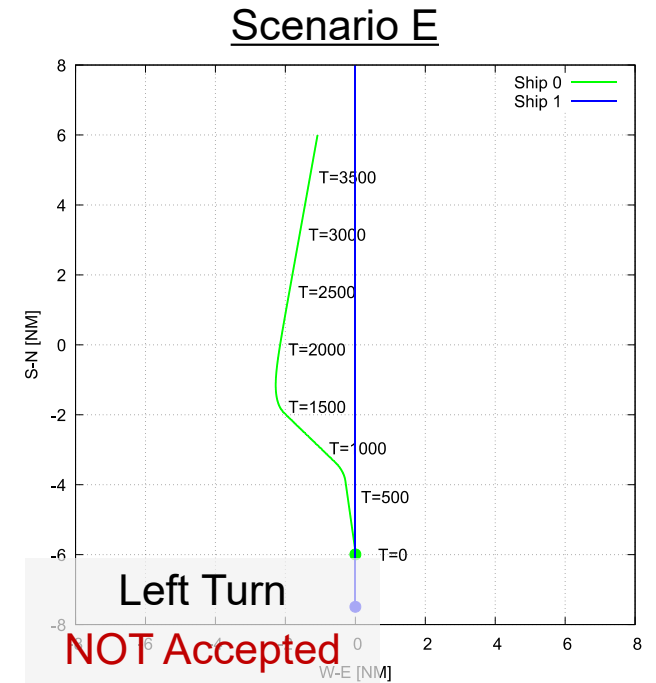
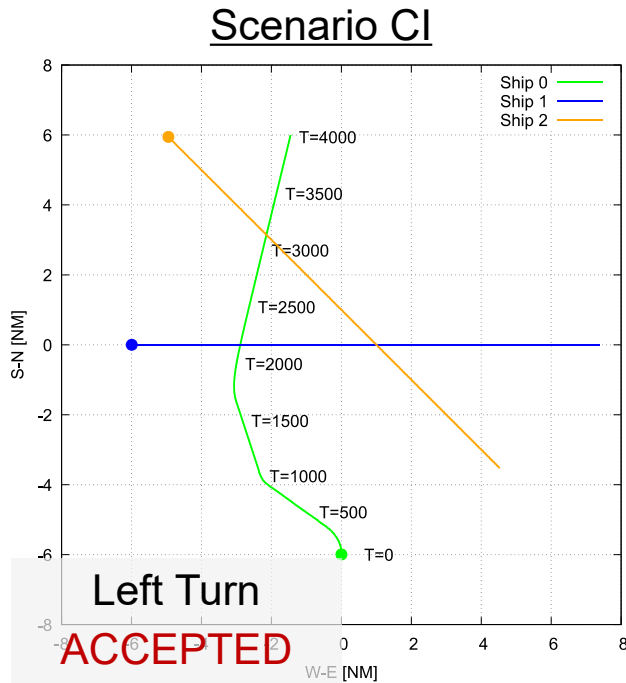
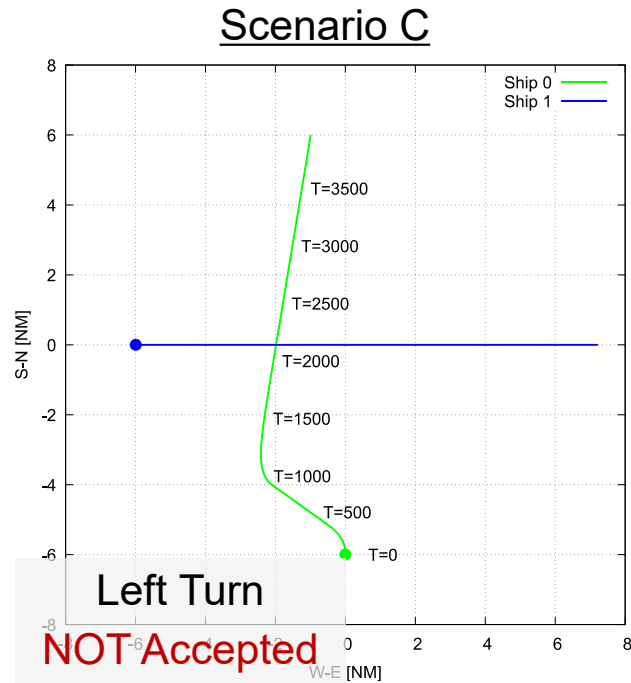
Comments by Captains

- ◆ Frequent portside turns and decelerations were still observed
 - Their acceptability remains context-dependent, and we need further discussions about this.
- ◆ Unnecessary decelerations occurred before crossing ahead, potentially increasing collision risk



What Makes Behavior “Acceptable”?

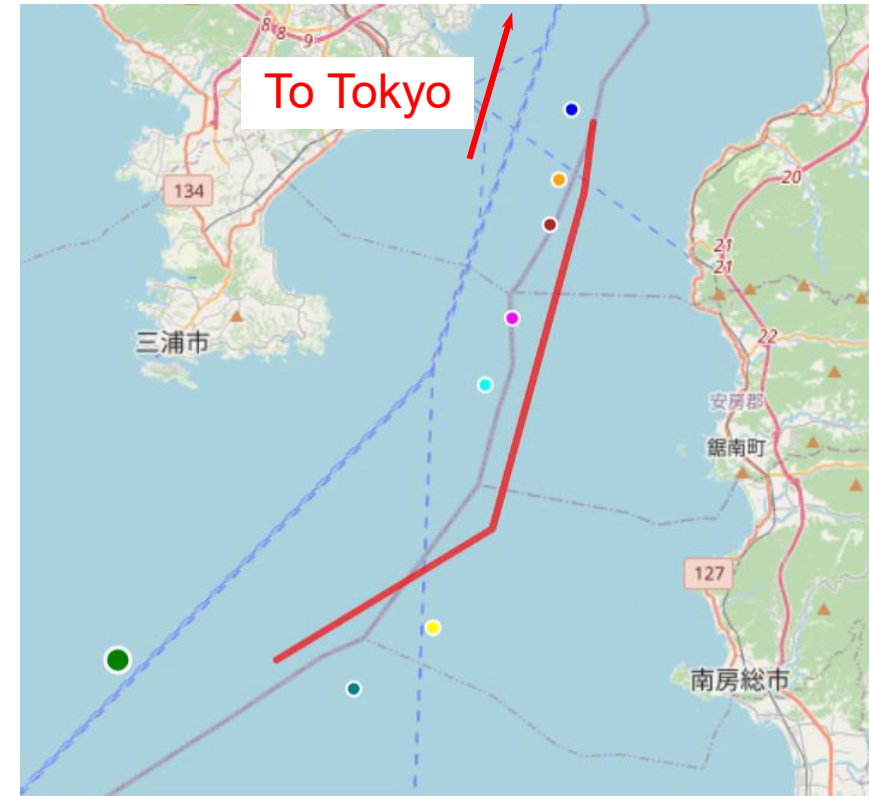
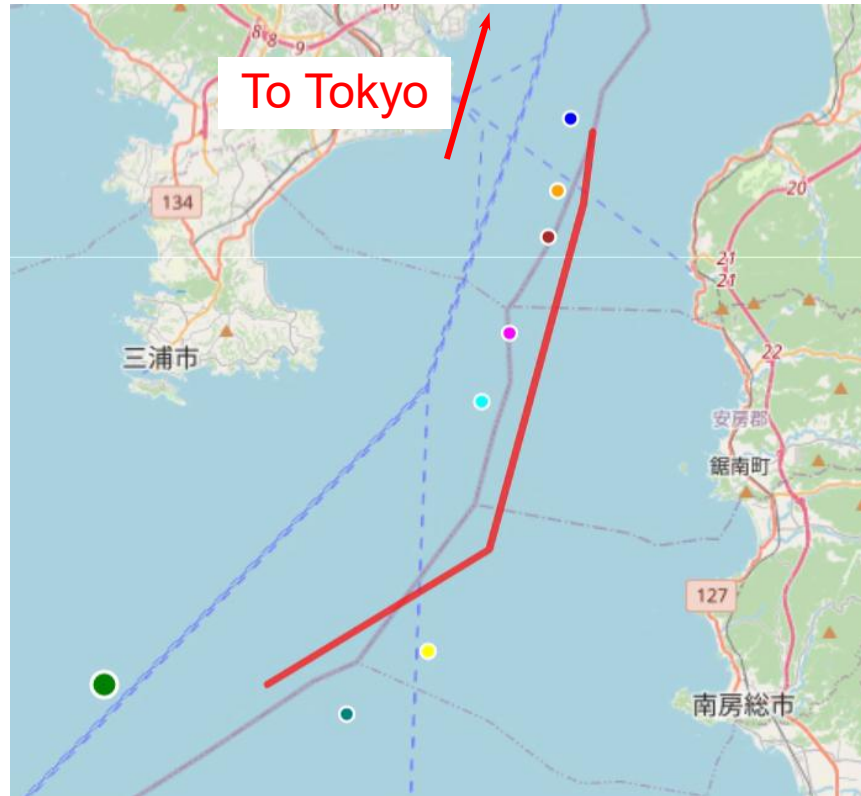
- ✓ Quantitative success $\neq$ Human acceptability
 - Meeting quantitative criteria doesn't guarantee human acceptability
- ✓ Context-dependent acceptability
 - The boundary between pre- and post-COLREGs behavior is context-dependent and hard to define



- ✓ Acceptable behavior must be co-created by logic and human judgment
- ✓ Safety requires more than one ship acting correctly—it emerges from mutual coordination

Future Work: Toward Real-World Deployment

Example result from a preliminary test in a real-world Tokyo Bay scenario



- ◆ Future work will focus on applying the system to real-world scenarios
 - Initial results from Tokyo Bay show potential for real-world deployment

Acknowledgements

This work was conducted as a commissioned project by Japan Ship Technology Research Association (JSTRA) and supported by the quantification project of seafarers' maneuvering ability and the project of safety analysis related to MEGURI2040 sponsored by The Nippon Foundation.

We also thank to the researchers and captains of

- ◆ Tokyo University of Marine Science and Technology
 - ◆ Japan agency of Maritime Education and Training for Seafarers
 - ◆ Marine Technical College
 - ◆ Tokyo Bay Licensed PILOTS' Association
- for the corporations of interviews and discussions.



Thank you for your attention!
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