Manoeuvre Compatibility Networks to Support Autonomous Ship Decisions

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Introduction

Autonomous ship manoeuvring requires decisions about both course and speed. Previous research has evaluated joint path–speed control using deep reinforcement learning and Imazu benchmark scenarios.

In a three-ship encounter, a manoeuvre compatible with each neighbour separately may still leave the neighbours with mutually incompatible actions. Moreover, the existence of a compatible joint plan does not ensure that independently acting ships will select it. This motivates examining both manoeuvre compatibility and the coordination needed to implement a joint plan.

Research objective

To compare pairwise and network-based manoeuvre selection in AIS-derived three-ship encounters, and examine how communication among ships affects joint-plan selection.

Data & Selection

Data: 25.25 million AIS records across 112 days, April–August 2025.
Region: Danish AIS coverage, 54.55–55.10° N, 13.4–14.3° E.
Vessels: cargo, tanker and passenger ships; speed 3–25 kn.
Selection: three ships, initially ≥0.5 NM apart, with ≥2 approaching pairs predicted below 0.5 NM within 10 min.
Filters: AIS freshness and track quality, regional boundary checks, no fourth related vessel.

112 days · 2 encounters · 11 decision moments

27 manoeuvres per ship · 120 s manoeuvre transition

Network Method

Manoeuvre: course change and speed adjustment.
Node: one possible manoeuvre of one ship.
Edge: two manoeuvres maintain ≥0.5 NM separation throughout the 10-minute horizon.
Triangle: a compatible plan for all three ships.

$$Q(a) = d_B(a)\, d_C(a)$$

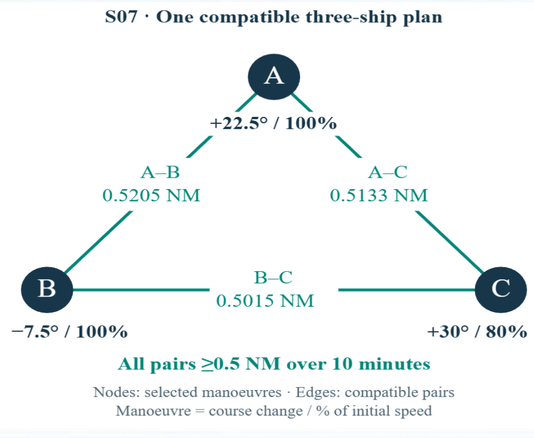
Pairwise: maximise combinations individually compatible with A.

$$N(a) = \sum_{b,c} E_{AB}(a,b) E_{AC}(a,c) E_{BC}(b,c)$$

Network: maximise fully compatible A–B–C triples.

Here, d counts compatible neighbour manoeuvres; E = 1 for a compatible pair and 0 otherwise. Both methods use the same eligible A manoeuvres.

Joint plan



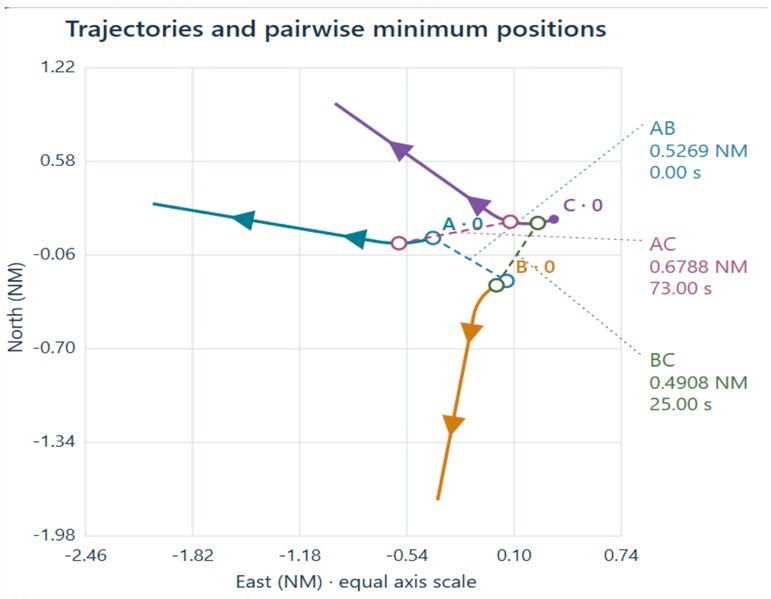
Results

Nine predefined manoeuvre sets were systematically evaluated, with course changes up to ±60° and speeds of 60–100% of initial speed.

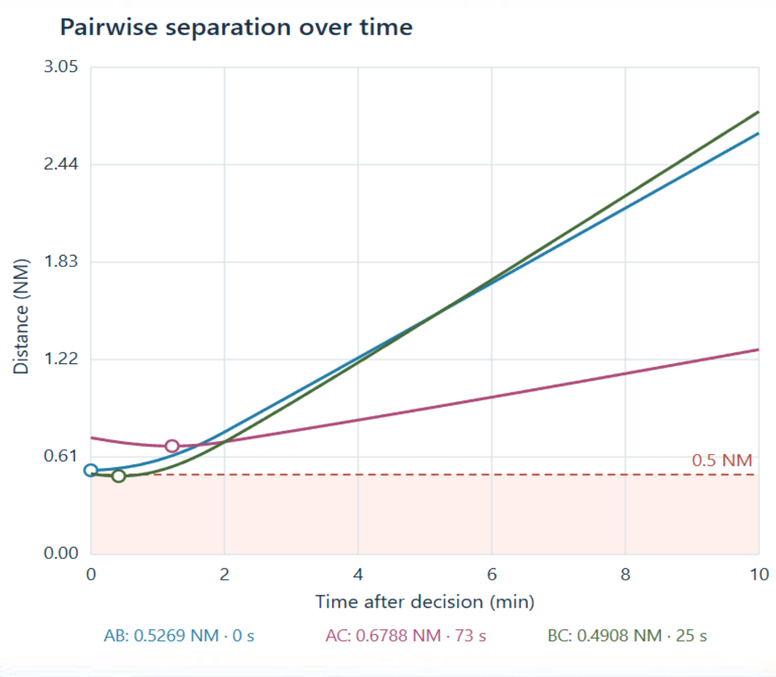
At 12:36:00 UTC, with 27 manoeuvres per ship, pairwise selection chose **+30°,** admitting **0** joint plans**.** Network selection chose **+22.5°**, admitting 9 joint plans.

Later AIS state: 12:36:30 UTC (S14)

No compatible three-ship plan was found in any of the nine tested sets. The plots show the manoeuvre combination with the best B–C separation.

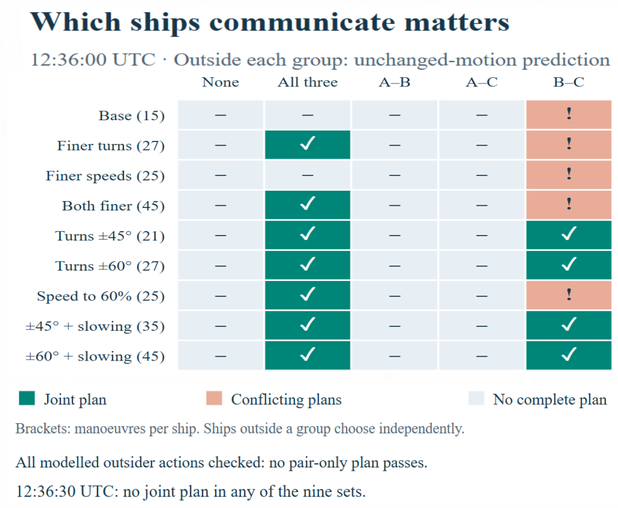


Despite substantial course changes, B–C separation fell to **0.4908 NM** after **25 s,** below **the 0.5 NM** threshold. Communication alone cannot resolve this incompatibility within the tested manoeuvre sets.



Communication

Full coordination: 7/9 sets; B–C only: 4/9; other modes: 0/9, assuming unchanged motion outside each group. Communication is reliable and immediate. The nine sets are model variants, not independent encounters.



Alternative course and speed changes were applied to AIS-derived vessel states, and trajectories were recalculated over 10 minutes. The 14 scenarios below illustrate how individual and coordinated manoeuvres affect the minimum separation between each pair of ships.



Interpretation and Limitations

Detailed comparisons concern two AIS states from one encounter. Joint-plan availability does not guarantee coordinated execution. Small separation margins, simplified motion, idealised communication, untested AIS uncertainty and unverified navigation-rule compliance limit interpretation. The results do not establish operational safety.

Acknowledgment

This project has received funding from the Research Council of Lithuania (LMTLT), agreement No S-MIP-24-117.