Learnings from Air Traffic Management Optimization Strategies adapted to the Maritime Domain

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Motivation

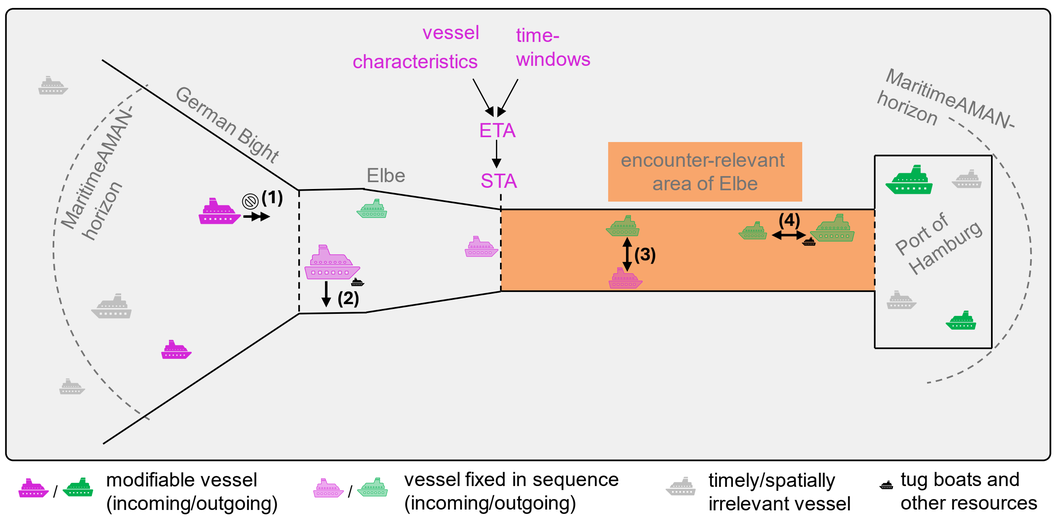
Air Traffic Management offers a wide range of proven concepts and systems designed to ensure safe, efficient, and balanced air traffic flow in contrast to other transport domains. The conceptual transfer of aviation arrival management (AMAN) to the maritime domain resulting in a MaritimeAMAN proposes a coordinated solution for the port approach based on a proven aviation concept. Nevertheless, the MaritimeAMAN faces different constraints when constructing a valid sequence of vessels.

Hypothesis

The First-Come-First-Serve (FCFS) strategy commonly used as sequencing strategy for arrival management in aviation is not suitable for the MaritimeAMAN with regard to the average delay per vessel, because of:

- additional constraints like time-windows representing tide restrictions and resource availability,
- incoming and outgoing vessels form a dependent sequence through the port approach.

Setting



Simplified depiction of the port approach of the Port of Hamburg and all relevant constraints (1) – (4) considered in the sequencing by the MaritimeAMAN; highlighted in orange the encounter-relevant area for which the sequence is calculated.

Vessels within the MaritimeAMAN-horizon are considered.
The Estimated Time of Arrival (ETA) at the encounter-relevant area depends on a vessel's characteristics and its individual entry time-windows based on tide restrictions and resource availability.
The MaritimeAMAN calculates the Scheduled Time of Arrival (STA) according to the sequencing strategy. Once a vessel enters the Elbe, its STA cannot be alternated.

Constraints

(1) Vessels cannot increase their speed.

(2) Consideration of entry time-windows representing tide restrictions and resource availability.

(3) Width restrictions in encounter-relevant area.

(4) Safety distance between following vessels.

Sequencing Strategies

Baseline Strategy: **First-Come-First-Serve**

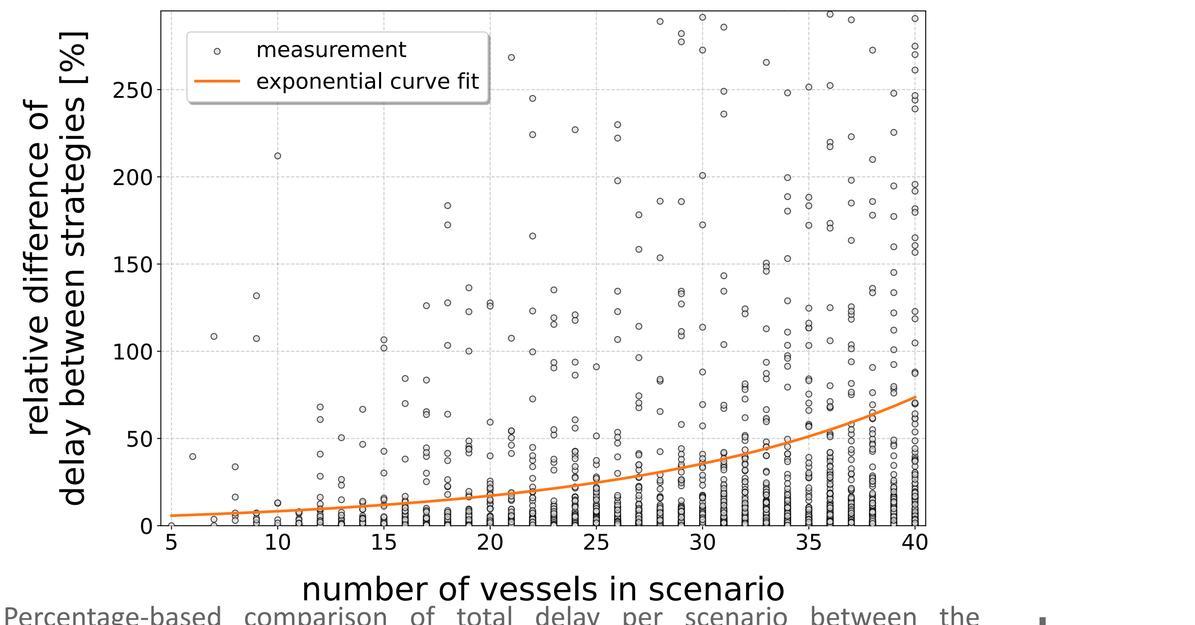
- simplest strategy, similarly used by AMAN
- vessels sequenced in order of ETA
- resulting sequence fulfills constraints
- strategy does not swap vessel order, even when advantageous

Our Strategy: **Minimize Total Delay**

- advanced strategy
- solves optimization problem using constraints
- vessels sequenced in smart order to minimize total delay
- swaps vessel order when advantageous for overall traffic flow

Results

Both sequencing strategies are applied to the same 10,000 scenarios generated through Monte-Carlo-Simulation regarding the number of vessels and their characteristics. Over all scenarios, the strategy FCFS results on average in 25.7 % more delay per vessel than Minimize Total Delay.
As depicted to the right, the difference in delay indicates an exponential behaviour with an increasing number of vessels per scenario. Additionally, the specific configuration of the vessels' time-windows influence the outcomes significantly, affirming the stated hypothesis.



Percentage-based comparison of total delay per scenario between the sequencing strategies FCFS and Minimize Total Delay.