Coupling Vessel Operations and Hinterland Traffic with SUMO and PySeidon

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Introduction

As part of this master's project at Hochschule Bremerhaven, the port's transport system is being modelled and analysed using the open-source framework **S**imulation Of **U**rban **MO**bility (SUMO). The aim is to develop a model to evaluate new strategies for intelligent maritime traffic management, as well as to investigate optimisation potential with respect to traffic flow. The project is currently in the active conceptual phase.

Port of Bremerhaven

As one of the four largest container ports in Europe and the largest auto terminal in the world, Bremerhaven serves as a central transshipment hub for intermodal freight in both imports and exports, making it an ideal simulation environment for our SUMO project. In peak years, more than two million vehicles are handled here, and in 2024 the figure stood at 1.25 million. In addition to pure transshipment, vehicles are also repaired, retrofitted and finished on site.

For the purposes of SUMO-based traffic modelling, satellite images like figure 1 serves as a key reference for defining network boundaries, verifying infrastructure topology, and calibrating the spatial relationships between the individual transport subsystems container terminal, automobile terminal, rail links, and fairway.

Figure 1: Satellite image of the Port of Bremerhaven showing the full extent of the port infrastructure [1].

Limitations of SUMO for Maritime Traffic

Simulating maritime traffic with SUMO is challenging because ships behave very differently from cars. SUMO was designed for lane-based traffic systems with simple movement rules, while maritime traffic is continuous, less constrained, and influenced by environmental factors.

Ships do not follow fixed lanes but move more freely within waterways. Their behavior depends on complex physical effects such as hydrodynamics, limited maneuverability, and external influences like wind and currents. These aspects are not well represented in SUMO.

Basic parameters like position, speed, and routes can be approximated using AIS data and simplified networks based on OSM. However, important characteristics such as realistic ship dynamics, port operations, and lock handling are missing. In particular, processes like waiting times and coordination at locks are difficult to model.

As a result, SUMO only provides a simplified and high-level representation of maritime traffic. A more realistic approach is to combine SUMO with external models, where SUMO handles the overall traffic flow and external systems simulate detailed ship dynamics, for example through co-simulation using TraCI.

Materials and Methods

SUMO [2] provides detailed modelling of land-side traffic dynamics, including truck and train movements, access times and congestion effects, but does not capture maritime port operations at the required level of detail. PySeidon [3] is an open-source, Python-based simulator for maritime port operations. In this setup, SUMO represents the land-side transport system, while PySeidon provides the water-side operational model.

Coupling Concept

The simulators are coupled through TraCI (*Traffic Control Interface*) and are advanced with a shared simulation time. At defined synchronization points, PySeidon provides water-side operational states, berth occupation and expected cargo-handling demand. SUMO returns aggregated land-side indicators, such as truck queues, train delays, access times and terminal throughput. These indicators are used as feedback for the maritime operation model, allowing land-side disturbances to affect berth readiness, cargo-handling duration and possible harbour-master decisions such as waiting at anchorage or selecting an alternative berth.

Scenario and Evaluation

The example scenario represents port operations in Bremerhaven. Freely available AIS data from [4] are used to derive representative vessel traffic patterns. Road, rail and terminal access infrastructure is derived from OpenStreetMap data and improved by cross-referencing with port maps and open-access orthophotos [5]. The coupled model is assessed under disturbances such as delayed trains, truck congestion or reduced terminal capacity, using key performance indicators such as berth utilization, vessel waiting time, cargo-handling duration and land-side delay as metrics for evaluation.

Outlook

The primary objectives of this project are to develop a simplified microscopic traffic simulation of the Bremerhaven AutoTerminal by combining SUMO and TraCI with external maritime platforms such as Pyseidon, approximating vessel movements via real-world data, while delegating realistic ship dynamics and port operation logic to dedicated external models, and acknowledging the inherent limitations of lane-based simulation for maritime traffic.
Once a stable simulation baseline is established, the focus will shift toward evaluating terminal performance through core indicators such as cargo throughput and vehicle waiting times, and deriving optimization strategies for port traffic coordination, with a further outlook toward harbor lock operations and emission analysis.

References

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