From reactive to responsive

by Oliver Schmitz, *Research Associate*,
and Emin Nakilcioğlu, *Research Associate, Fraunhofer Center for Maritime Logistics and Services (CML)*

As container logistics grows increasingly complex, the ability to anticipate and respond to disruptions becomes a defining factor in terminal performance. The KILOG project (Künstliche Intelligenz für Logistikoptimierung in deutschen Häfen/Artificial intelligence for logistics optimization in German ports) explores how artificial intelligence (AI) can strengthen operational precision and resilience at the Altenwerder (CTA) and Burchardkai (CTB) container terminals of HHLA. Funded under the IHATEC II program (Innovative Hafentechnologien/Innovative port technologies), the project addresses intermodal use cases such as rail slot optimization, predictive maintenance, and container availability forecasts. This article focuses on two of those initiatives: a container flow forecast that predicts yard blockages before they occur and on a pipeline, based on a large language model (LLM) that consolidates ship arrival information from heterogeneous sources. Together, they reduce manual effort, enhance planning reliability, and provide the foundation for scalable, data-driven decision-making across terminal operations.

Global supply chains have entered a phase marked by growing complexity, data fragmentation, and operational uncertainty. Ports and terminals, as pivotal nodes in this system, face increasing pressure to synchronize planning decisions with ever-changing cargo flows. Within this context, HHLA's CTA and CTB in the Port of Hamburg are taking decisive steps toward more responsive and data-driven operations through KILOG, which unites expertise from HHLA, Fraunhofer CML, and Hamburg Port Consulting (with Modility and Metrans contributing their intermodal experience).

The project's goal is to make terminal operations more predictive, adaptive, and sustainable by pairing algorithmic forecasting with LLM agents that structure and interpret real-world data on the spot. The focus is not on replacing established systems but on augmenting them, embedding AI-driven intelligence directly into daily decision-making. Achieving this requires a foundation of clean & reliable data, well-integrated interfaces, and clear governance to ensure trust and continuity in critical operations.

Through two concrete use cases – a container flow forecasting system and an LLM-powered ship arrival data pipeline – KILOG shows how targeted, human-centered AI applications can translate research into operational value, improving both efficiency and decision reliability across maritime logistics.

Resource-unlocking structure built on ground truth

Ship arrival data comes in many formats: spreadsheets with varying layouts, PDFs, emails, websites, and APIs. It changes frequently and must be kept up to date. In most terminals, assembling and maintaining a single, reliable picture of arrivals is still manual work, which is time-consuming, repetitive, and prone to inconsistencies.

KILOG deploys specialized LLM agents to ingest and understand these diverse sources, extract relevant fields, and structure them into a trustworthy dataset. A dedicated pipeline supports the agents with parsers for different media, connectors to source systems, and rules for reconciling discrepancies into a defensible ground truth. To improve performance in maritime contexts, the agents are fine-tuned on domain-specific data and guided with carefully crafted prompts and contexts. We benchmark different LLMs to balance accuracy, robustness, latency, and cost.

Crucially, operational trust is built through a human-in-the-loop validation system. Experienced maritime professionals review edge cases, provide continuous feedback, and capture nuanced domain knowledge, ensuring that data anomalies are detected before they affect mission-critical downstream decisions. This collaborative loop has proven essential to adoption, giving confidence in the AI's outputs and transparency in its logic to the operational teams.

The consolidated data set is delivered to a dashboard for OP teams and written to the data lakehouse, where it supports AI use cases as well as various stakeholders relying on precise ship arrival information. As updates propagate in near real time, schedulers move from manual wrangling to oversight and exception handling. The payoff extends beyond speed and reduced effort: skilled staff reclaim time for strategic thinking while automated agents handle routine data extraction; data quality and traceability improve significantly; and the same agent-based framework can be applied to other workflows (processing invoices, packing lists, or work orders), ensuring consistent, auditable information flows across shipping operations.

Completing the picture – with intelligent granularity & dynamic action

Terminal yards pulse with constant motion – containers flowing in from ships, trucks, and trains, then departing through another mean of transport. Yet, for all this orchestrated movement, yard planning has traditionally relied on seasoned intuition rather than granular intelligence. Existing research often focuses on long-term predictions, such as monthly, weekly, or daily forecasts, which help with broad planning but lack the precision needed to prevent localized pressure, blockages, or cascading congestion.

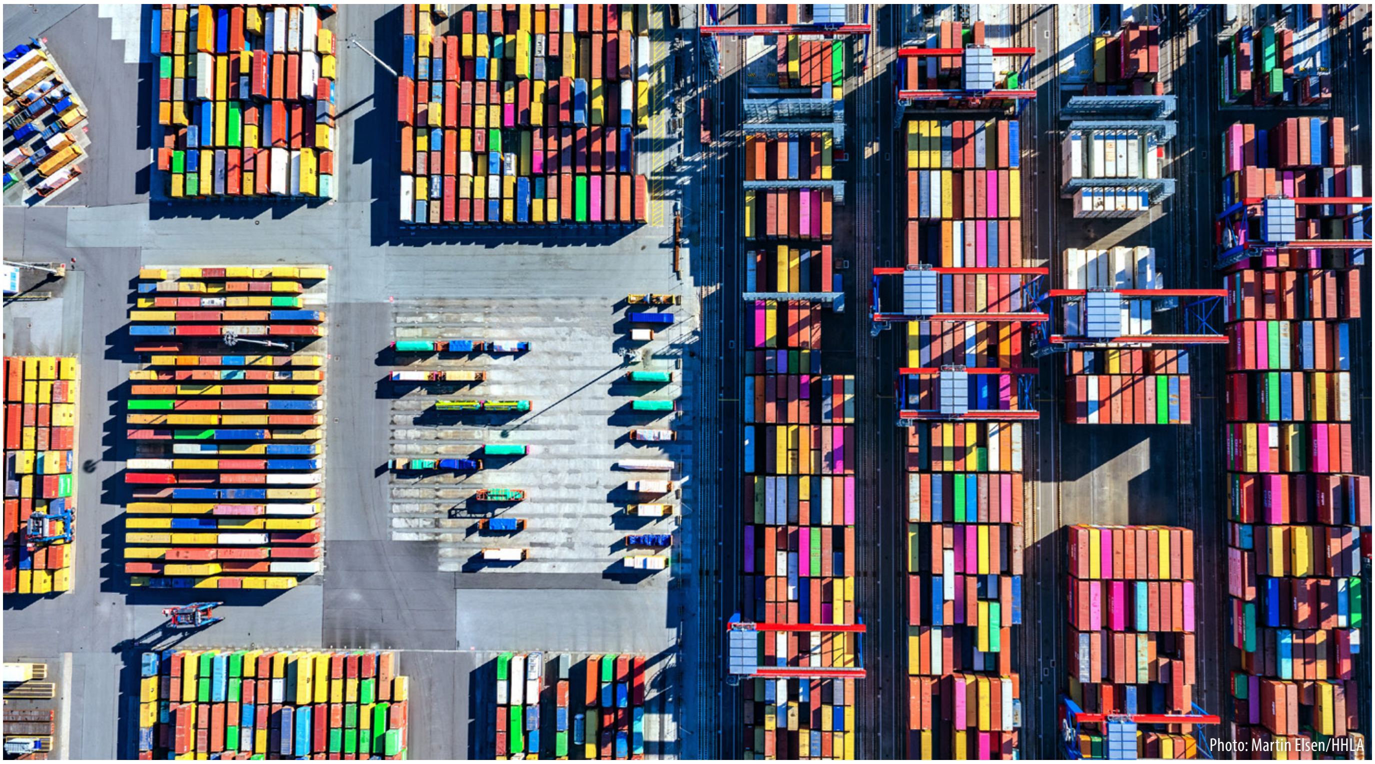

Photo: Martin Elsen/HHLA

KILOG's forecasting engine provides near-real-time insights for yard operations: hourly predictions spanning 48-hour horizons, drilling down to individual yard blocks. The system processes multiple data streams simultaneously: terminal-operating-system signals capturing block utilization and equipment status; vessel schedules enriched with live ETAs and cargo manifests; and truck appointment systems revealing ground transport patterns. Weather data, holiday calendars, and disruption reports complete the intelligence picture, creating forecasts that adapt continuously as conditions evolve.

Advanced algorithms, tested and benchmarked across different modeling approaches, process this data stream into actionable intelligence. The models learn from operational patterns while incorporating live feedback loops, ensuring predictions track reality rather than theoretical schedules. Integration with optimization tools enables automated responses: equipment redeployment ahead of demand spikes, container routing adjustments to prevent blockades, and resource scheduling that anticipates rather than reacts.

With our forecasting framework in place, planners shift from reactive problem-solving to proactive orchestrators, repositioning resources ahead of demand surges, rerouting containers around predicted bottlenecks, and smoothing operational flows through strategic intervention. This transforms disruptive variability from an operational threat into a managed part of the plan.

Solid & clear design – ready to scale!

KILOG proves that the step from reactive to responsive operations is achievable when AI is grounded in solid data foundations, human-centered design, and clear governance. Granular yard forecasts turn uncertainty into manageable variation, while LLM agents convert fragmented, unstructured data into dependable, high-quality information.

The project's next phase will deepen integration with optimization systems, expand into adjacent use cases (such as container availability forecasting and predictive maintenance) and scale across terminals and transport modes. As these systems mature, scalability and sustainability emerge as shared outcomes: consistent forecasting frameworks and data pipelines streamline operations, reduce idle time and emissions, and strengthen the resilience of entire logistics networks.

Ultimately, KILOG offers a blueprint for AI adoption in the maritime sector; one built on trust, transparency, and measurable operational impact. In a sector where slight delays can ripple through complex chains, timely, trustworthy information is not just helpful – it is decisive. ■

Oliver Schmitz completed his bachelor's degree in supply chain management at the University of Duisburg-Essen and then got a master's in business administration with a focus on operations research and production management. Since June 2021, he has been working as a research associate at Fraunhofer CML, where he is primarily involved in optimizing various processes in terminals (e.g., through AI-based forecasting of container dwell times or the development of various algorithms for optimizing container handling). Furthermore, Schmitz has a deep understanding of intermodal supply chains and has already successfully collaborated with a variety of stakeholders in this field.

Emin Nakilcioğlu completed his B.Sc. in mechanical engineering at Istanbul Technical University and his M.Sc. in mechatronics at the Hamburg University of Technology. During his graduate studies, he specialized in intelligent systems, robotics, and deep learning. Since August 2020, Nakilcioğlu has been a research associate at Fraunhofer CML, contributing to AI- and data-driven digital innovations in maritime logistics. His work focuses on developing solutions for automatic speech recognition, natural language processing applications, time-series forecasting, and workload prediction, alongside providing software development and technical support for maritime-specialized projects.