

The effects of pre-arrival vessel prioritisation strategies for port call coordination

Die Auswirkungen von Priorisierungsansätzen von Schiffen mithilfe von Vorabanmeldung auf die Hafenanlaufkoordination

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Abstract: This simulation study investigates the impacts of pre-arrival vessel prioritization strategies on port call coordination using a simulation model that integrates discrete-event and agent-based techniques. Motivated by the environmental and operational inefficiencies of the traditional first-come-first-served (FCFS) port policies, the simulation assesses how early and structured communication of arrival intentions, as first-announced-first-served (FAFS), can enhance berth allocation, improve resource utilization in the port, and reduce ship emissions. The model replicates a real port environment using empirical data and Python-based libraries evaluating multiple prioritization strategies under varying timing rules for port call announcements. Results demonstrate that structured pre-arrival announcements improve turnaround times and berth occupancy, particularly under strategies setting upper timing limits. However, results vary by terminal type and installed capacity. The findings underscore the need for improved digital infrastructure and cooperative governance to enable Just-in-Time (JIT) arrivals, highlighting the potential for simulation to support decision-making in port operations modernization.

1 Introduction

Maritime transport is key to our globalised world with more than 80 percent of internationally traded goods being transported by sea. Shipped volumes have grown nearly every year within the last decades and any interruption has been followed by a swift recovery (UNCTAD 2025). This development has been facilitated by the close collaboration of shipping companies, port authorities, terminal operators, customs, nautical services (among them pilots, tugboats, icebreakers, and linesmen), vessel traffic services, and many more. Now, the International Maritime Organization (IMO) and the European Union (EU) are implementing regulations to cut greenhouse gas emissions in the maritime sector (European Commission, 2025; Global Maritime Forum 2025). These cuts can only be achieved by transitioning to low-carbon fuels (only for short ranges, batteries are an option) and reducing the energy consumption

of both existing and future ships. Lower fuel consumption per nautical mile is achieved when vessels are operated on eco-speed, also leading to lower bunkering bills for vessel operators. The joint planning of when exactly a vessel enters and leaves the port also requires all involved parties to commit to time windows several days or at least hours ahead of time. It is often referred to as JIT arrival or port call optimization (see e.g. ITPCO 2022; DCSA 2025; Oberhauser Tavares Braga, Fjørtoft, und Hagaseth 2025). A smooth port call requires nautical services to be ready—if pilotage is compulsory, the pilot needs to board the vessel on time; if tugboat assistance is needed, they need to be ready and in place, etc. Only then vessels can smoothly enter and leave the port without any waiting times, allowing them to use eco-speed on their way to the port. Shipping companies compete with each other and besides freight rates, short delivery times are an important argument for customers. The agreed-upon arrival times of goods are then often part of contracts, including penalties for delays (Normann et al. 2025). Only a few ports offer such JIT arrivals at the moment and the data exchange between ship and shore is still at pilot stage (Bruno 2024; Port of Rotterdam 2025; Maritime and Port Authority of Singapore, 2025). Introducing just-in-time arrival principles at a port turns into a multi-party information and communication technology (ICT) project that comes with high costs. These costs rise further when the communication between the calling vessels and parties at the port move from radio communication to digital messages, which require the vessel owners to install new hardware on board (Rødseth 2025). Assessing the expected benefits is imperative before starting such large-scale project in more ports, pushing vessel owners to install new hardware, and fix the standards on digital information exchange. The new, more coordinated port call process needs to be put to test to make sure that the expected improvements materialise. To the best knowledge of the authors, the present simulation study is the first of its kind to quantify the expected improvements (also see Derin et al. 2024).

2 Background

In recent years, there has been increasing interest in innovative concepts for optimising port logistics—both in science and in maritime industry. The focus is particularly on strategies for dynamic prioritisation of ships before they arrive in ports. The aim of these approaches is to overcome the prevailing practice of the FCFS principle in order to enable more efficient handling. The relevance of these innovation efforts is particularly evident with regard to the diverse interests of the parties involved. Port operators benefit from improved resource utilisation and a reduction in infrastructural bottlenecks with high traffic density. Shipping companies and ship operators, on the other hand, are striving for greater predictability of lay times and optimisation of fuel consumption—in particular through speed-adaptive modes of operation in the sense of a JIT arrival concept. The environmental benefits of coordinated port call systems are substantial and well-documented. Research indicates that containerships can reduce fuel consumption and CO₂ emissions by up to 15% per voyage through JIT arrival implementation (International Maritime Organization 2025). More conservative estimates suggest that if all incoming containerships at major ports had known their arrival times 12 hours in advance, shipping emissions could be reduced by 4% in the final approach phase alone. A desktop exercise comparing traditional "hurry up and wait" operations with JIT arrival scenarios demonstrated 23% less fuel consumption when vessels received multiple updates on

their requested arrival times (GEF-UNDP-IMO GloMEEP Project and members of the GIA 2020). Moreover, the adoption of JIT arrival also faces significant resistance from the industry due to contractual, operational, and competitive concerns, with parties reluctant to change well established procedures.

Various international initiatives from science, industry and politics are currently working intensively on improving the coordination of ship arrivals. For example, the International Taskforce Port Call Optimization (ITPCO) is promoting the standardisation and exchange of relevant call information in order to minimise lay times and make processes more efficient (ITPCO 2022). The Digital Container Shipping Association (DCSA) is developing technical standards for JIT calls aimed at adjusting speed and reducing emissions (DCSA 2025). A notable example of successful port call coordination is the Hamburg Vessel Coordination Center (HVCC), serving as a central and neutral coordination point for large vessels, feeder ships, and barges calling at Hamburg, coordinating approximately 2,500 ocean vessels and 4,000 feeder terminal calls in 2024 (HVCC Hamburg Vessel Coordination Center 2025). Established in 2015 as a joint venture between terminal operators Hamburger Hafen und Logistik AG (HHLA) and Eurogate Container Terminal Hamburg GmbH, the HVCC model illustrates how competing terminal operators can collaborate effectively when presented with clear operational benefits and neutral coordination mechanisms.

Parallel to these international industry initiatives, the scientific community is also working intensively on the development and analysis of approaches to improve the coordination of port calls. For example, Mubder et al. (2024) investigate how berth allocation policies can be adapted to promote arrival of ships, with the aim of increasing the efficiency of port operations by handling ships faster and reducing waiting times. The strategy focuses on integrating JIT methods into the existing port infrastructure and logistics to optimise operations. The methodology used includes mathematical modelling and simulation of port operations to analyse and improve berth allocations. Some ports have already launched pilot projects to implement JIT strategies, but there is a lack of comprehensive long-term studies that fully capture the practical impact of these strategies. Furthermore, Zheng et al. (2024) address the integrated optimisation of ship sequencing and berth allocation for bulk carriers in a comprehensive port. The aim of the study is to improve the efficiency of port operations by optimising both the sequence of ship arrivals and berth allocation, while also considering the shifting of ships to minimise conflicts and delays. The research gap that this paper addresses lies in the lack of holistic consideration of these factors in previous models, which may lead to less efficient solutions in more complex port environments.

3 Method

A combination of discrete-event and agent-based simulation is employed to model the port call processes. This hybrid approach enables the representation of both process-level dynamics and communication and decision-making by individual stakeholders. Due to the lack of a suitable off-the-shelf simulation tool for port call optimization, a custom-tailored simulation environment is developed. This environment is implemented using Python in combination with SimPy, a discrete-event simulation

library. The simplified layout and the flow of entities of the simulated port is depicted in Figure 1.

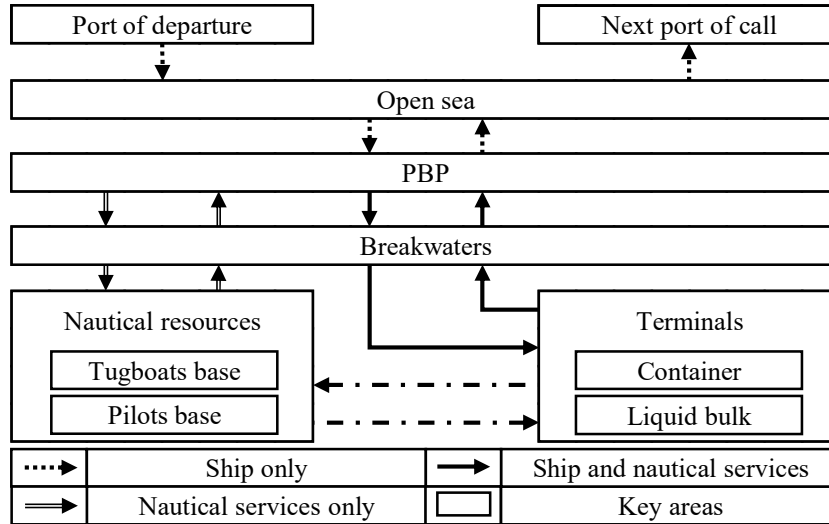


Figure 1: The port from a conceptual perspective

The system employs ships, tugboats, pilots and berths as entities that perform tasks in key areas of the port. All ships arrive from the open sea, sailing towards the pilot boarding place (PBP). Anchorage areas are not yet integrated, so a simplification is made to consider that all vessels arrive and wait at the PBP until they are served. The port has a breakwater on its entrance, with two lanes: one for arrivals and one for departure. All vessels must go through it, but only one cargo ship can pass in each direction at a time. For this, each lane of the breakwater is modelled as a resource of the port, with maximum of one user. Two terminals are modelled: a container and a liquid bulk terminal, operating, 7 and 17 discrete berths, respectively. The berth quantity is directly extracted from the original port call data used, containing the individual berths visited by the vessels, discussed in the next paragraphs. The key assumptions on time consumption are listed in Table 1. The berthing times have been deduced from the open data the port publicly has shared for the year 2024 (Port de Barcelona, 2025) and fitted with the SciPy.stats Python package. Extreme berthing times beyond 5 days are clipped, both for the input data and for the sampled berthing times during simulation. The time vessels need to move inside a port are deduced from ship position data recorded from the Automatic Identification System (AIS) streaming provider aisstream.io using web sockets in early 2025. The ship position data is then interpreted by means of geofencing, i.e., checking for how long a ship has stayed in which polygon. The main areas of interest are the PBP and the berths of the terminals. Sailing times towards the port are estimated given the previous port's name as shared in the publicly available port call data (see above) in combination with the distances from the previous port to the called port as provided by the scgraph Python package.

To convert the distance into times, an average speed of 14 knots independent of any vessel properties has been assumed. In the next step, for each vessel calling the port,

a sailing time has been sampled from the distributions based on whether the port lies in a country that belongs to the Mediterranean region (incl. the Black Sea), the North Range, or another region beyond that (such as USA and Middle East). Sailing times in the Mediterranean are kept between 0.5 and 5 days and for other ports, at least 5 days of sailing time are assumed, leading to clipping of extreme values. At any given moment, the port counts with 7 tugboats and 6 total pilots for providing nautical services, based on information provided by the same data portal. At this stage, however, delays during the sail time and other sources of uncertainty during the execution of processes have not yet been integrated.

Table 1: Assumptions on time consumption

Period	Distinction criterion	Distribution Statistics [hours]
Berthing time	Small container vessel	Lognormal avg =20.01, std=15.48
	Medium container vessel	Lognormal avg=21.41, std=12.46
	Large container vessel	Lognormal avg=33.71, std=22.64
	Small bulk vessel	Lognormal avg=27.65, std=18.77
	Medium bulk vessel	Lognormal avg=38.61, std=24.01
	Large bulk vessel	Lognormal avg=45.93, std=26.80
Moving in port	Any vessel	Lognormal avg=0.44, std=0.15
Sailing time to port	Mediterranean port	Lognormal avg=58.92, std=62.50
	Port in North Range	Triangular avg=72, a=60, b=84
	Other port	Gaussian avg=314.40, std=73.44

Figure 2 shows, on the right, the major checkpoints of the modelled port call, as experienced by the ships. While, on the left, the duration of stages, which are defined between each consecutive checkpoint, is identified. These are logged throughout the simulation and can be used to compare the flow of the ship entity between experiments and across terminals. The keeping of these checkpoints is within the responsibilities of the Port Call Coordination Centre (P3C), through an auxiliary call-specific *port call operations envelope*, which employs these checkpoints to track the progress of the port call, and act as coordination points among the multiple entities performing processes.

The P3C is a concept being developed under the DYANPORT project, which serves as a communication and coordination hub across port stakeholders, and acts as a single point-of-contact for port calls between the port and its call-relevant stakeholders, and the ship and its representatives. For this study, the same port call process is shared across multiple experiments. Once the ship enters the system, it immediately performs the *port call announcement*. This triggers a reservation of a berth at the desired terminal, through the implementation of a berth planner, starting at a time greater than the estimated time of arrival of the ship, and with the median duration expected based on the assumptions in Table 1.

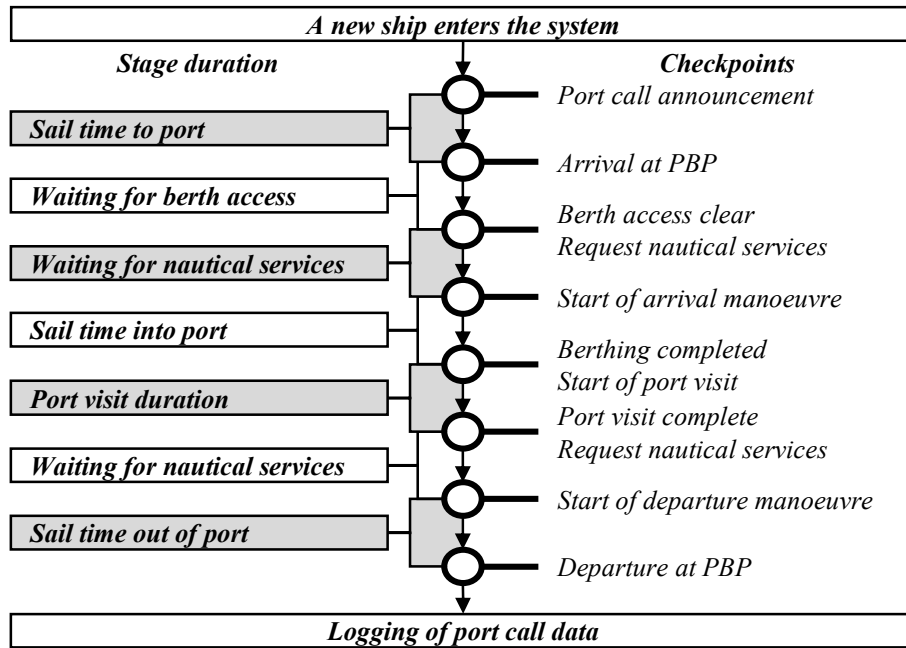


Figure 2: Major checkpoints and stage durations of the port call process, as experienced by the ship entity

The real duration of the berth visit is drawn from the assumptions at a later stage, during the port visit itself. The port sets priorities that define the order in which vessels perform the *port call announcement*. They establish (or dismiss) lower and upper limits for how soon before the *arrival at PBP*, should the *port call announcement* be performed. Once the port call announcement is made, the ship continues on to cover all checkpoints of the process. Tugboats and pilots are, at this stage, requested as FCFS, upon reaching the *berth access clear* checkpoint during arrival, and the *port visit complete* for departure.

Table 2: Experiments

N°	Time between port call announcement and arrival at PBP	Strategy
1	Spontaneous arrival, no time	FCFS
2	Fixed: 24h before	FCFS
3/4/5	Lowest between departure from last port & 24h/48h/72h in advance	FAFS
6	At departure from last port	FAFS
7/8/9	Highest between departure from last port & 24h/48h/72h in advance	FAFS

Table 2 describes the experiments conducted. They model different approaches for establishing lower and upper limits for the timing of *port call notification*, in relation to the *arrival at PBP*, becoming then a FAFS strategies. Experiment number 1 models

a scenario in which the port accepts direct arrival of vessels, thus the possible strategy here is FCFS. This option is close to a common practice in certain trades, most notably on liquid bulk due to fast fluctuations of cargo value, which might prompt a quick change of orders to call at a nearby port. Experiment 2 requires all vessels that wish to call the port to announce it precisely 24 hours before the estimated time of arrival. This is yet another common practice so that ports can have a fixed agenda for the upcoming days, but still operates as FCFS. Experiments 3, 4 and 5 set an upper limit, requiring announcement to be done not earlier than it. Experiment 6 removes these limits, and requires vessels to announce upon departure from previous port, regardless of how early that is. Experiments 7, 8 and 9 set a lower limit, requiring announcement to be done not later than it. Together, these experiments are meant to cover a wide range of possibilities, while setting the base to expand the analysis to account for more factors. Each experiment is simulated 50 times, with historical port call data from a period of 30 days. Further work will expand this period.

4 Results and Discussion

The main findings are time-related, based on the discrete-event simulation side of the implemented logic. Figures 3 and 4 present key stage durations and overall turnaround time (stages between *arrival at PBP* and *departure at PBP*) for container and liquid bulk terminals.

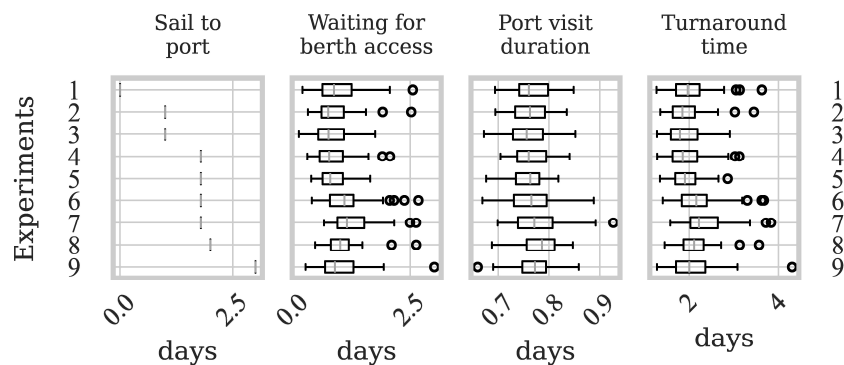


Figure 3: Main time metrics for ships visiting the container terminal

Four intermediate stages are omitted due to negligible variation under current logic. Once delays, changes in schedule and other types of exceptions are added into the simulation, significant variation is expected. Berth access wait time shows the greatest disparity, driven by the larger number of berths in the liquid bulk terminal. However, berth assignment is also constrained by terminal-specific layout restrictions, highlighting a need to refine input data or simulation logic, meaning that not every berth is a potential candidate for any vessel. This berth access wait time includes anchorage periods and illustrates potential gains from JIT strategies, supporting eco-sailing and emission reduction. Port visit durations are relatively consistent, but turnaround time varies slightly—especially at the container terminal—indicating upper announcement time limits (Experiments 3–5) as most effective. In contrast, liquid bulk results are dominated by berth availability

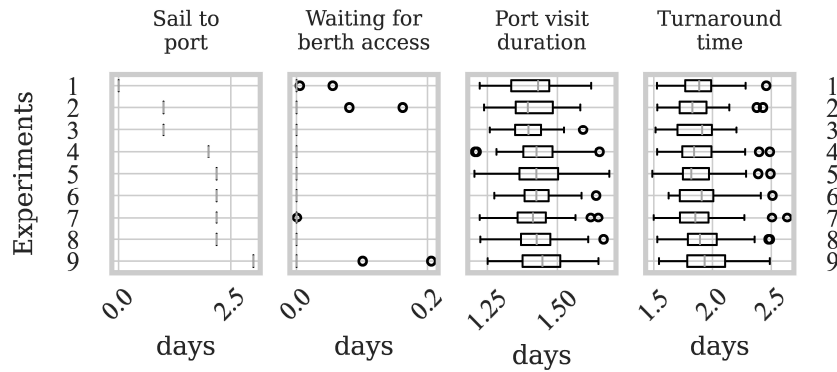


Figure 4: Main time metrics for ships visiting the liquid bulk terminal

Figure 5 shows the median of berth and nautical service occupancy, suggesting optimisation potential via improved scheduling adherence. For this metric, higher occupancy is one of the usual goals when optimising port operations, as long as delays are kept in control. The resulting occupancy of nautical resources is very low, so much that in Figure 5 the axis is limited to 25%.

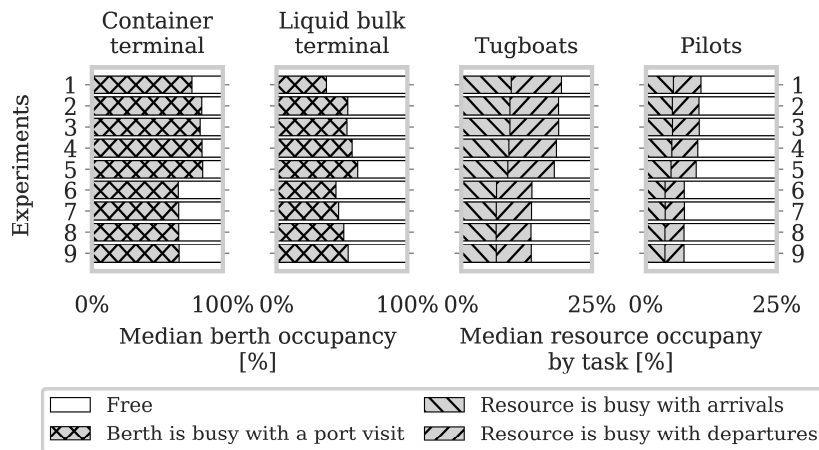


Figure 5: Median occupancy of berths and nautical services

While a similar issue to the aforementioned for the berths might be in play, on this case, the high availability is most likely caused by the limited complexity of their operations. Shifts, maintenance, and other processes must be implemented to reach a more realistic figure. Moreover, the quantity of these resources is based on the quantities of an existing port, with additional terminals to be served, which are not yet integrated, or accounted for on the availability of resources. Nonetheless, for nautical services, higher availability can be the goal for optimisation, promoting lower waiting periods. The jump between the trend set through Experiments 1 to 5, then the one

from 6 to 9, can be attributed to the disparity in across the experiments are related to the limited dataset used. Longer running and more complex experiments — multiple months of data and wider variety of terminals — with improved logic and warm-up period are planned as next phase. Additionally, sensitivity analysis of the effects of variations in each port call phase will be carried.

5 Conclusion and Outlook

The port call process is a complex set of operations that, in practice, require close human coordination and collaboration to be performed. Furthermore, the logic behind the regulations applied, showcased in this study in the form of early announcement and prioritisation strategies, are developed during many years of port operations, through the analysis and of their operations. Thus, a matching level of complexity is to be expected when modelling such scenarios. Nautical safety is a crucial part of port operations, being the primary factor guiding maritime traffic management. This requires the coordination and decision-making of several skilled actors to be represented in simulation, as well as the possible physical interactions between entities. More accurate representation of the shifts is possible to be integrated with the simulation model, leading to more accurate traffic flows and resource utilisation. Further work is planned to continue to take advantage of the flexibility offered by using Python and Simpy, for expanding this model and its analysis for more ports, exploring further types of terminals, berths and nautical resources, while serving as an open canvas for exploring more complex logical chaining of events. By doing so, the analysis will also be extended to, in accordance with the United Nation's sustainable development goals, evaluate potential emissions savings by reducing behaviours such as “hurry up and wait” and unnecessary time spent on anchorage, while advocating for better and more reliable communication and coordination between all port stakeholders and the vessels calling there.

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References

- Bruno, M.: Port of Gothenburg kicks off digital vessel arrival platform, 2024. Port Technology International. <https://www.porttechnology.org/news/port-of-gothenburg-kicks-off-digital-vessel-arrival-platform/>, accessed 23 May 2025.
- DCSA: DCSA, 2025. Digital Container Shipping Association. <https://dcsa.org/>, accessed 23 May 2025.
- Derin, Y.; Braga, J.; Kastner, M.; Jahn, C.: The art of orchestrating nautical services in a port call: a literature classification. *Journal of Physics: Conference Series* 2867 (2024) 1, 012049. <https://doi.org/10.1088/1742-6596/2867/1/012049>

- European Commission: Decarbonising maritime transport – FuelEU Maritime, 2025. https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en, accessed 4 May 2025.
- GEF-UNDP-IMO GloMEEP Project and members of the GIA: Just in time arrival guide – barriers and potential solutions, 2020. London: International Maritime Organization; Global Industry Alliance (under IMO-Norway GreenVoyage2050). <https://greenvoyage2050.imo.org/wp-content/uploads/2021/01/GIA-just-in-time-hires.pdf>, accessed 17 July 2025.
- HVCC Hamburg Vessel Coordination Center GmbH: HVCC Hamburg Vessel Coordination Center. <https://www.hvcc-hamburg.de/en/>, accessed 17 July 2025.
- International Maritime Organization: What’s New, 2025. IMO Media Centre. <https://www.imo.org/en/mediacentre/pages/whatsnew-1718.aspx>, accessed 17 July 2025.
- ITPCO: Port call optimization, 2022. <https://portcalloptimization.org/>, accessed 23 May 2025.
- Maritime and Port Authority of Singapore: MPA-POR green and digital shipping corridor call for proposals, 2025. <https://www.mpa.gov.sg/maritime-singapore/innovation-and-r-d/call-for-proposals/mpa-por-gdsc-cfp>, accessed 6 May 2025.
- Mubder, A. A. A.: The implementation of berth allocation policies that enable just-in-time arrival in port calls. *International Journal of Physical Distribution & Logistics Management* 54 (2024) 6. <https://doi.org/10.1108/IJPDLM-11-2023-0442>
- Normann, K. J.; Juul Pedersen, K.; Moller, B.; Pedersen, J.-T.; Riialand, A.; Fjortoft, K. E.: D3.1 multi-party cooperation and goal alignment for voyage optimisation, 2025. <https://dynaport.eu/download/d3-1-multi-party-cooperation-and-goal-alignment-for-voyage-optimisation>, accessed 23 May 2025.
- Oberhauser Tavares Braga, J.; Fjortoft, K.; Hagaseth, M.: D6.1 – report on the system definition “port call processes” – Dynaport, 2025. <https://dynaport.eu/download/d6-1-report-on-the-system-definition-port-call-processes>, accessed 23 May 2025.
- Port de Barcelona: Portal Open Data del Port de Barcelona, 2025. <https://opendata.portdebarcelona.cat/es/>, accessed 11 May 2025.
- Port of Rotterdam: Rotterdam and Singapore strengthen collaboration on green and digital shipping corridor, 2025. <https://www.portofrotterdam.com/en/news-and-press-releases/rotterdam-and-singapore-strengthen-collaboration-green-and-digital-shipping>, accessed 23 May 2025.
- Rødseth, Ø. J.: Maritime ICT reference architecture: D5.X ship and port ICT architecture, 2025. <https://dynaport.eu/download/d5-x-maritime-ict-reference-architecture>, accessed 23 May 2025.
- UNCTAD: Shipping data: UNCTAD releases new seaborne trade statistics, 2025. <https://unctad.org/news/shipping-data-unctad-releases-new-seaborne-trade-statistics>, accessed 23 May 2025.
- Zheng, H.; Wang, Z.; Duan, S.: Integrated optimization of vessel sequencing and bulk carrier berth allocation with shifting in a comprehensive port. *Ocean Engineering* 316 (2025) (without page numbers). <https://doi.org/10.1016/j.oceaneng.2024.119891>