Towards a Port Call Optimization IT Ecosystem: Deriving System Requirements through a Systematic Literature Review

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Abstract— **The coordination of port calls remains a significant source of inefficiency in maritime logistics, with well-documented consequences for operational costs and environmental performance. This paper presents a systematic literature review, complemented by a semi-structured interview with a port authority representative, to derive structured functional and non-functional requirements for a port call optimization IT ecosystem. The review yields fourteen requirements spanning data integration, data exchange governance, and maritime communication infrastructure. Key findings highlight interoperability, data sovereignty, resilience under poor connectivity, and usability as foundational concerns. The results are intended to provide guidance for the design of federated, governance-aware IT ecosystems that support port call optimization and to feed into an ongoing research project developing such a system.**

I. Introduction

Global maritime trade underpins the world economy, with over 80% of international goods transported by sea [1]. Yet a persistent and costly inefficiency characterizes port operations worldwide: vessels spend a disproportionate share of their operational time waiting at anchor or idle in port rather than sailing [2]. This can be reduced by a better port call organization. However, a port call involves a complex choreography of actors, resources, and processes. Shipping lines, terminal operators, port authorities, pilotage services, customs agencies, and cargo owners must all align their activities within tight and often unpredictable time windows. Delays in any single step cascade across the entire sequence, resulting in prolonged waiting times, suboptimal resource utilization, and avoidable fuel consumption [2]. A recent World Bank study estimates that inefficient port calls cost the global shipping industry billions of dollars annually and contribute to greenhouse gas emissions that regulators are increasingly seeking to curtail [3].

Port call optimization (PCO) addresses these inefficiencies through synchronized, data-driven coordination across all port stakeholders. Central to this is the Just-in-Time (JIT) arrival principle. Realizing this in practice requires seamless, real-time information exchange across organizational and technical boundaries at a level of precision that manual processes and siloed legacy systems simply cannot support. Digital tools capable of aggregating data from vessel-tracking systems, port management platforms, berth-planning tools, and weather services are therefore indispensable for port call optimization at scale. Despite growing international momentum on this topic, as reflected in initiatives by the International Maritime Organization, other international organizations, and various regional port community system deployments, there are still challenges. One of the challenges is the concrete software requirements for a holistic IT ecosystem that enables port call optimization, which remain to be explored from a systems engineering perspective.

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II. Research Method

This paper sets out to address that gap through a systematic literature review (SLR), conducted as part of the research project MISSION (EU HORIZON), which aims to develop such a digital tool. The review followed the established guidelines for software engineering systematic reviews proposed by Kitchenham [4], working through planning, conducting, and reporting phases with a transparent and repeatable protocol. The search was conducted in Scopus, combining a maritime domain anchor term with quality attribute keywords derived from a prior review of systems-of-systems quality attributes, mapped to the ISO/IEC 25010 quality standard. A staged screening process covering title screening (1.173 titles), abstract screening (94 titles), and full-text analysis (48 titles) ensured that only studies ($n = 9$) providing concrete, requirement-relevant content were included. The findings were distilled to 14 requirements presented in Table II.

To validate the review with practical experience, a semi-structured interview was conducted in February 2026 with a representative of a port authority, providing an operational perspective that helped ground the more abstract findings from the literature in day-to-day reality.

III. Interview

We conducted one semi-structured interview in February 2026 with a project partner from a maritime innovation organization closely involved in port digitalization and collaborative port-call solutions. We used the interview to validate and contextualize the requirements that we derived from the SLR. The interview lasted approximately 30 minutes and provided an operational perspective on current communication practices, coordination problems, and quality concerns in port call operations. Overall, the interview confirmed several of the requirements listed in Table II and highlighted safety as an overarching concern that spans the entire ecosystem.

The interviewee emphasized that vessel safety has priority in port-related operations. In addition to safety, the interviewee described flexibility and efficiency as central objectives in delivering port authority services. This observation indicates that a PCO ecosystem should improve coordination and resource

Reference Architecture Element	Requirement	Description	Source
Data systems used in port calls	Interoperable interfaces	Avoid point-to-point integrations by requiring standardized, interoperable interfaces for seamless exchange.	"do not have standardized and interoperable interfaces that are required for a seamless data exchange." [5]
Data systems used in port calls	Integrated traffic picture and decision-support data integration	Integrate sensor/AIS feeds and analyze traffic data to provide actionable information to relevant ships/actors.	"various sensors (sensing devices such as CCTV, Radar, DF, MET, etc.) and AIS are installed" [6] "collecting/integrating/analyzing the various data related to marine traffic control and then providing the data to the applicable ships." [6]
Data systems used in port calls	Low-latency processing via edge computing	Place computation closer to data sources/users to reduce latency and support real-time port-call coordination services.	"reduced latency compared to remote cloud servers" [7] "real-time communication, and privacy protection" [7]
Data exchange patterns	Federated identity and secure authorization	Provide ecosystem-wide identity, authentication, and authorization, plus discovery/registry functions to scale secure interactions.	"crucial prerequisite for trustworthy data exchange is the possibility of secure authentication and authorization between maritime actors." [5]
Data exchange patterns	Tolerance to intermittent connectivity and high latency	Design workflows for intermittent links and high latency (asynchronous exchange, buffering, retries).	"interrupted connections or high latency times (about 700 ms)" [5] "The available bandwidth on the open sea varies from just a few kilobits per second to several megabits per second." [5]
Data exchange patterns	Data sovereignty and fine-grained access control	Ensure each stakeholder controls its own data and can specify access conditions (who/what/when).	"maintain full control over their data at all times and decide for themselves which stakeholders can access their own data under which conditions." [5]
Data exchange patterns	Privacy-preserving collaboration	Enable collaboration/optimization without exposing sensitive commercial data; privacy protection as a first-class concern.	"collaborative model training without exposing sensitive commercial information." [8] "real-time communication, and privacy protection" [7]
Data exchange patterns	Integrity and auditability of shared operational data	Provide integrity guarantees and auditable traces for shared data exchanges (e.g., immutable logs / cryptographic mechanisms).	"ensures data integrity and immutability through cryptographic protocols and smart contracts" [8]
Maritime communication systems	QoS / prioritization for critical traffic	Prioritize high-importance traffic under constrained maritime connectivity and multiple bearers.	"prioritizing high-importance traffic while load-balancing among multiple long-haul bearers" [9]
Maritime communication systems	Distributed maritime network management	Operate maritime networking with distributed management approaches that reduce dependence on centralized control.	"network management in maritime net-works should be efficient and distributed" [9]
Maritime communication systems	Continuous ship connectivity and VTS communication support	Support continuous ship connectivity and communication among ships and with shore-side traffic services (VTS).	"reliable and cost effective communication carrier to assure a continuous ships connectivity." [10] "need to communicate with each other, with the vessel traffic system (VTS)" [10]
Data systems used in port calls	Scalable and adaptable deployment	Ensure that the solution is able to be deployed in small, medium and large ports	"Further research should focus on testing the concept in small and mediumsized ports, which will facilitate its scaling in the broader maritime context of sustainable development"[11]
Data exchange patterns	Operational reliability and performance	Ensure operational reliability and performance while processing multiple data streams at scale	"requires systems capable of ingesting, processing, and analyzing different data streams at scale while maintaining operational reliability in an environment where connectivity and conditions rapidly change"[12]
Data systems used in port calls	Usability/human factors	Ensure that the interface for the software system is user-friendly for all stakeholders	"The system should provide a user-friendly interface for terminal operators and other stakeholders."[13]

TABLE I

IDENTIFIED REQUIREMENTS

use, but never at the expense of operational safety. Although Table II does not list safety as a standalone requirement, the interview suggests that safety should act as a cross-cutting design principle that constrains all other optimization goals.

The interview also confirmed the importance of service continuity and robustness. The interviewee stated that terminals require high service availability. This finding supports the requirement *Operational reliability and performance*, as a PCO ecosystem should reliably process and provide operational information even when operating conditions change. The finding also reinforces *Continuous ship connectivity and VTS communication support*, since service availability depends directly on the quality and continuity of communication between vessels, port actors, and shore-side authorities.

A central theme in the interview concerned the gap between existing digital infrastructure and actual operational practice. The interviewee explained that, although an information-exchange platform already exists, actors still conduct much of their communication by telephone and radio. The interviewee therefore stressed the need to further digitalize communication. This observation strongly supports the requirement *Interoperable interfaces*, because the continued reliance on manual and voice-based communication shows that digital integration remains incomplete. The finding also relates to *Integrated traffic picture and decision-support data integration*, since digital communication forms a prerequisite for collecting, combining, and analyzing operational data across stakeholders. In practical terms, the interview indicates that a formal exchange platform alone is insufficient when critical coordination still relies on fragmented, largely manual channels.

The interviewee further explained that English serves as the common language of communication, but that poor radio reception and limited English proficiency often lead to misunderstandings. This finding supports *Usability/human factors*, because a PCO system should reduce ambiguity and support users with different linguistic and operational backgrounds. The same point also reinforces *Continuous ship connectivity and VTS communication support*, because degraded radio quality directly affects ship–shore coordination. More broadly, the interview suggests that digital communication mechanisms could reduce the ambiguities that currently arise in voice communication.

The interview also highlighted that vessels and authorities currently use the same communication channels for all types of operational exchanges. This observation underscores the relevance of *QoS/prioritization for critical traffic*. When multiple communication needs share the same channel, a future digital ecosystem should distinguish between routine and safety-critical exchanges and prioritize traffic by urgency and operational importance.

Regarding security, the interviewee noted that no real technical authentication currently exists. Instead, crews announce the vessel name roughly one hour before arrival, and operators check this information against expected arrivals. This practice directly supports the requirement *Federated identity and secure authorization*. At present, operators rely mainly on procedural verification and trust rather than on robust technical authentication. Although the interviewee reported no known cases of jamming or interception to date, the interview suggests that current arrangements may become insufficient as the ecosystem handles more automated, potentially more sensitive digital exchanges.

Finally, the interviewee stated that actors cannot analyze data across organizational boundaries because information is not shared. This point provides one of the clearest validations of the requirements in Table II. It directly supports *Integrated traffic picture and decision-support data integration*, because the absence of shared data prevents joint situational awareness and coordinated optimization. At the same time, it relates to *Data sovereignty and fine-grained access control* and *Privacy-preserving collaboration*. The interview suggests that the lack of data sharing reflects not only a technical limitation but also an organizational and governance problem. Stakeholders currently work in separate information silos, which prevents joint analysis and coordinated decision-making. Consequently, a future PCO ecosystem should enable controlled, trustworthy sharing mechanisms that preserve stakeholder control over data while enabling ecosystem-level optimization.

IV. Discussion

The outcome of the review is a categorized framework of 14 requirements, organized across three broad architectural areas derived from a deliverable from the sister project of MISSION, called DYNAPORT [14]: data systems used in port calls, data exchange patterns, and maritime communication systems. In Table II, these requirements are listed and sorted by architectural area. A short description in the table and the referenced sources are also listed. These requirements cover a wide range of concerns, from the need for standardized interfaces and integrated traffic data to secure identity management, privacy-preserving data sharing, resilience under poor connectivity, and usability for operators working in demanding real-world conditions.

The literature indicates that data exchange remains a challenge that has not yet been solved. There are, for one, the technical obstacles of interoperable interfaces and data harmonization, but also the governance challenge of data ownership and the willingness to share the data. Without these, the coordination of the port call process remains a time-consuming manual task.

The interview reinforced this finding starkly, then despite the existence of a digital exchange platform, critical coordination still relies on voice communication via radio, telephone, and email. This suggests that technical interoperability alone is insufficient without accompanying process digitalization and stakeholder adoption. Also, data sharing remains a problem, and the interview confirmed that cross-actor data analysis is currently impossible, not merely for technical reasons, but due to absent governance and trust mechanisms. This positions data sovereignty and privacy-preserving collaboration not as peripheral concerns but as prerequisites for ecosystem participation. Federated solutions, strict, fine-grained access policies, and data usage traceability can enable this kind of data sharing. Stakeholders will not contribute data to a shared platform unless they trust that the data will not be used opportunistically by other stakeholders.

The maritime environment comprises constraints that distinguish PCO IT systems from land-based logistics IT systems. Intermittent connectivity, high latency, and variable bandwidth necessitate architectures designed for graceful degradation rather than continuous availability. A concern not fully captured in Table II but strongly surfaced in the interview is the primacy of vessel safety. Vessel safety always takes precedence over any potential optimization. Every requirement in the table must be interpreted in light of this overarching constraint: availability targets, QoS prioritization, and access control mechanisms all carry safety implications.

Finally, scalability and usability emerge as adoption-critical requirements that determine whether a technically sound ecosystem will actually be used. Solutions must function in small and under-resourced ports, and interfaces must accommodate operators with varying technical proficiency and language backgrounds — a finding that the interview grounded concretely in the challenges of radio communication quality and English proficiency.

Overall, the findings indicate that a PCO IT ecosystem must be architected as a federated, resilience-first, and governance-aware platform. The technical requirements are largely achievable with existing technologies; their realization depends critically on organizational alignment and trust-building mechanisms that software engineering alone cannot deliver.

V. Conclusion

Taken together, these findings offer a starting point for thinking more systematically about what a PCO IT ecosystem needs to do and how it might be structured. Rather than prescribing a definitive architecture, they point in a direction: toward federated rather than centralized designs, toward resilience as a baseline assumption rather than an afterthought, and toward explicit governance of data ownership and access as a condition for meaningful stakeholder participation. Whether this direction proves sufficient in practice remains to be tested, and the requirements presented here should be understood as a first synthesis rather than a final specification.

Much of the underlying technical capability already exists in adjacent domains, but translating it into a working maritime context will require further validation with a broader range of stakeholders and operational settings. In MISSION, standardized data exchange is being developed and tested with stakeholders such as shipping companies, port community systems, and service providers. Also, fine-grained access to data is being explored as part of the project. Further work includes a broader evaluation of the requirements with additional stakeholders from the field, refining them into measurable acceptance criteria, and evaluating them against real-world system designs in collaboration with port call optimization practitioners.

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