*European Research Studies Journal*
*Volume XXVII, Issue Special 3, 2024*

*pp. 893-903*

# Smart Ports Process Maturity Model – Theoretical Framework

*Submitted 20/09/24, 1st revision 20/10/24, 2nd revision 11/11/24, accepted 30/11/24*

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***Abstract:***

***Purpose:*** *This paper proposes a theoretical process maturity model tailored specifically for smart ports, addressing unique operational, digital, and environmental requirements to support smart port development. The model aims to bridge existing gaps in the literature by providing a structured framework for assessing maturity across multiple dimensions essential to smart port functionality.*
***Design/Methodology/Approach:*** *A comprehensive literature review of smart port operations, process maturity models, and environmental sustainability frameworks was conducted to develop the model. The proposed framework comprises five progressive maturity stages—foundational, coordinated, integrated, sustainable, and collaborative network—each assessing a port's capabilities in digital infrastructure, operational efficiency, environmental sustainability, stakeholder engagement, and safety and security.*
***Findings:*** *The model provides a structured pathway for ports to incrementally enhance their digital, operational, and environmental practices. Each stage reflects an increasing level of integration, collaborative capability, and compliance with sustainability standards. The model also reveals critical insights into the phased development that can strengthen port competitiveness, resource management, and resilience against logistical disruptions.*
***Practical implications:*** *Port managers can apply this model as a practical tool for self-assessment, identifying targeted areas for improvement across the five defined dimensions. By advancing through the model's stages, ports can achieve optimized resource allocation, reduce environmental impact, and foster international collaboration, enhancing their strategic position in the global logistics network.*
***Originality:*** *This model fills a critical gap in the literature by offering a maturity assessment framework uniquely suited to smart ports, integrating digitalization and environmental management in a structured manner that aligns with industry-specific demands.*

***Keywords:*** *Smart ports, process maturity, digital infrastructure, sustainability, port management.*

***JEL classification:*** *L91, O32, Q56.*
***Paper type:*** *Research paper.*

***Acknowledgement:*** *This research is funded by the grants: WZNJ/2024/PI/03 and WZNJ/2024/PI/04.*

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## 1. Introduction

In the current global economy, smart ports have emerged as critical nodes within supply chains, playing a transformative role in advancing operational efficiencies, environmental sustainability, and competitive positioning. Defined by their integration of advanced digital systems and data-driven operations, smart ports enable real-time monitoring, process automation, and predictive analytics, fundamentally reshaping traditional port functions (Pham, 2023).

This digital transformation aligns with broader trends in global logistics, where the ability to adapt to technological advances and meet heightened sustainability standards is increasingly demanded by both regulatory bodies and market stakeholders (Charłampowicz and Mańkowski, 2024).

As noted by recent studies, the implementation of smart technologies in port operations not only optimizes traditional port activities, such as cargo handling and scheduling but also enables adaptive responses to environmental and logistical disruptions (Liu *et al.*, 2024), thereby enhancing resilience within maritime and inland logistics networks (Sawicki and Jaworek, 2017).

Despite the clear benefits of smart technologies in port environments, a significant gap exists in the literature regarding frameworks to assess the maturity of these transformative processes within smart ports. While general models for process maturity have been effectively applied across various sectors (Dewi and Mahendrawathi, 2019; Lee *et al.*, 2019; Röglinger *et al.*, 2012), the unique attributes of smart ports necessitate a specialized model that considers the complexity of digital integration and the cross-functional dynamics between environmental, operational, and stakeholder-focused processes (van Looy *et al.*, 2011).

Research on business process maturity within the transport and logistics sectors has underscored the importance of structured, phased development to achieve higher levels of operational effectiveness and adaptability (Charłampowicz *et al.*, 2024b). However, these models are typically designed for traditional logistics operations and do not comprehensively address the digital and environmental objectives that characterize modern smart port functions (Tarhan *et al.*, 2016).

The current study aims to address this research gap by proposing a theoretical model specifically tailored for assessing process maturity within smart ports. This model not only incorporates general principles from process maturity frameworks (Röglinger *et al.*, 2012) but also integrates criteria relevant to the advanced technological, environmental, and stakeholder management requirements unique to smart port operations (Paraskevas *et al.*, 2024).

The introduction of a tailored process maturity model is anticipated to offer strategic value by providing smart port managers with a tool for self-assessment, enabling

them to systematically improve process capabilities in alignment with industry best practices and regulatory expectations. Therefore, the main purpose of this research is to establish a comprehensive theoretical framework for smart port process maturity assessment, laying a foundation for future empirical validation and application across diverse port environments.

## 2. Literature Review

The critical role of smart ports in global supply chain efficiency has driven extensive research, particularly in understanding the integration of digital technologies and sustainable practices within port operations (Min, 2022). The concept of the smart port encompasses a suite of advanced technologies, such as IoT, data analytics, and automated systems, which collectively enhance decision-making capabilities and operational responsiveness (Karaś, 2020).

Smart ports, by leveraging these technologies, can adapt dynamically to changes in demand and regulatory expectations, promoting a more streamlined, efficient, and environmentally sustainable approach to port management (Yang and Hsieh, 2024). Research emphasizes that this digital transformation enables ports to optimize throughput, reduce environmental impact, and support resilient supply chain performance (Testa *et al.*, 2014).

Despite these advancements, significant gaps persist in the literature, particularly regarding structured frameworks that assess and guide the maturity of smart port processes in this highly complex environment (Boullauazan *et al.*, 2023; Paraskevas *et al.*, 2024).

The concept of process maturity, well-established in management literature, serves as a framework to gauge the development stages of organizational processes and practices, enabling firms to progress systematically from initial to optimized levels of maturity (Lee *et al.*, 2019). Process maturity models have found widespread application in software engineering and general management contexts, where they guide organizations through successive stages of process control, measurement, and optimization (Tarhan *et al.*, 2016; van Looy *et al.*, 2011).

Such models are designed to advance process efficiency incrementally, often through a five-level structure that evaluates the consistency, repeatability, and adaptability of practices over time (Tarhan *et al.*, 2016). However, these general models, though effective in various industries, lack specificity for the port and logistics sector (Charłampowicz *et al.*, 2024b; Sawicki and Jaworek, 2017), particularly within smart port operations where technological integration and environmental considerations are central.

In the logistics and transport sectors, maturity models have been adapted to assess process effectiveness, yet their focus has primarily been on traditional operational

metrics, such as resource allocation, operational control, and workflow management. These frameworks have proven useful for transport logistics and intermodal management but are generally insufficient to address the unique needs of smart ports, which operate at the intersection of complex digital systems and stringent sustainability requirements (Behdani, 2023).

The adoption of business process maturity models within the inland transport sector has shown benefits for environmental compliance and quality control, yet these models lack a robust framework to evaluate and improve upon the integrated digital and environmental dimensions unique to smart ports (Zobel, 2016).

Consequently, while traditional models offer a degree of insight into process management within logistics, they do not capture the multi-faceted, high-stakes requirements that characterize smart port operations.

Research on environmental management in logistics and transport further underscores the limitations of traditional process maturity models. For instance, frameworks such as ISO 14001 and EMAS have facilitated improvements in environmental performance within logistics by establishing baseline standards for sustainable practices and compliance monitoring (Charłampowicz *et al.*, 2024a; Housni *et al.*, 2022; Testa *et al.*, 2014).

However, these frameworks are primarily compliance-focused and do not offer the comprehensive, multidimensional approach required by smart ports, where environmental management is closely integrated with digital and operational functions (Daddi *et al.*, 2016; Testa *et al.*, 2014).

The environmental demands of smart ports, which include real-time emission monitoring, energy optimization, and sustainable resource use, demand a more advanced maturity assessment model that aligns with the digital ecosystem within which these ports operate (Boullauazan *et al.*, 2023). Although these environmental management standards provide valuable insights into achieving compliance, they fall short of addressing the full scope of capabilities needed for process maturity in smart port settings.

The literature thus reveals a notable gap in maturity models tailored specifically to smart ports, as existing frameworks neither fully accommodate the technological integration requirements nor the evolving environmental standards in this sector. Despite the advancements of maturity models in related domains, a comprehensive model that evaluates maturity across dimensions such as digital infrastructure, stakeholder engagement, and process resilience in smart ports has yet to be developed.

Therefore, a process maturity model for smart ports, integrating these diverse operational and environmental dimensions, is essential. Such a model would provide

a structured pathway for smart port managers to advance process capabilities progressively, bridging the current gaps in maturity assessment while fostering sustainable, adaptive, and resilient port operations.

## 3. Model of Process Maturity Assessment for Smart Ports

The proposed model for evaluating process maturity in smart ports aims to establish a structured approach that addresses the unique digital, operational, and environmental demands of modern port environments. Unlike traditional maturity models that emphasize generic stages, this model focuses on the advancement of smart port functions through new, distinct phases that reflect increasing levels of technological, environmental, and collaborative capabilities, while integrating unique requirements specific to the port industry.

The model distinct structure provides port authorities with a tailored framework for systematically developing digital infrastructure, enhancing environmental performance, and optimizing operational integration, thereby advancing the capabilities necessary for a fully realized smart port (Behdani, 2023).

The model comprises five maturity stages: foundational, coordinated, integrated, sustainable, and collaborative network. Each stage highlights a unique progression in digital and operational integration as well as environmental responsibility. In the foundational stage, port functions are characterized by initial digitization efforts where basic digital tools and isolated data management systems are implemented.

This stage often lacks comprehensive data integration, with various departments operating independently and relying on manual processes, resulting in limited data sharing and inefficient responses to operational challenges. As ports progress to the coordinated stage, initial connectivity and standardized digital practices across functions begin to take shape. Here, emphasis is placed on improving inter-departmental communication and implementing foundational digital platforms that enable basic data-sharing and cross-functional visibility, supporting early steps towards cohesive management and process integration within the port.

The integrated stage is marked by a shift toward comprehensive internal data networks that streamline operations, increase process visibility, control, and measurement, and enable more sophisticated analysis of operational data. This phase supports digital linkages across departments, allowing for efficient resource allocation and responsive adjustments to shifting operational demands.

Ports at this level are equipped to optimize core activities and coordinate processes effectively, establishing a reliable framework that facilitates higher efficiency and consistency (Charłampowicz and Mańkowski, 2024). The sustainable stage advances beyond integration, emphasizing both digital optimization and a commitment to sustainability goals.

At this stage, ports adopt technology that supports the management of processes connected with environmental monitoring, energy conservation, and emissions tracking, meeting regulatory expectations and positioning themselves as environmentally responsible nodes within the supply chain (Daddi *et al.*, 2016; Testa *et al.*, 2014). Ports within this stage not only utilize technology for active process management concerning operational efficiency but also engage in sustainable practices that address broader environmental impact.

At the highest level, the collaborative network stage, ports operate as fully developed smart hubs that engage in seamless digital interactions with other ports, stakeholders, and supply chain partners on a global scale, including process integration and continuous development. This stage emphasizes inter-port and supply chain connectivity, allowing for coordinated and continuous improvement of processes regarding data exchange, real-time adjustments, and collaborative environmental strategies.

The collaborative network stage represents a mature level of technological integration where ports contribute to regional and global logistics optimization while maintaining high standards for environmental performance. This level of integration requires advanced digital systems capable of secure, interoperable data sharing across global networks, ensuring operational continuity, resilience, and alignment with international logistics practices (Cheung *et al.*, 2021).

Implementing this model involves port-specific assessments across several critical dimensions (Table 1) digital infrastructure, operational efficiency, environmental sustainability, stakeholder engagement, and security. Each domain evaluates the extent of maturity within specific functions, allowing ports to identify priority areas for development.

***Table 1.*** *Process maturity model for smart ports*

| **Level 1: Foundational** | **Level 2: coordinated** | **Level 3: integrated** | **Level 4: sustainable** | **Level 5: collaborative network** |
|---|---|---|---|---|
| Digital infrastructure | | | | |
| Operational efficiency | | | | |
| Environmental sustainability | | | | |
| Stakeholder engagement | | | | |
| Safety and security | | | | |

***Source:*** *Own elaboration.*

Digital infrastructure assesses the sophistication and connectivity of data systems, while operational efficiency examines resource allocation, cargo flow optimization, and real-time management capabilities. Environmental sustainability focuses on the adoption of practices that align with regulatory frameworks for emissions reduction

and sustainable resource use, ensuring the port's impact is aligned with broader environmental goals (Housni *et al.*, 2022).

Stakeholder engagement addresses the extent of collaboration and information exchange with external partners, from supply chain stakeholders to community members, while safety and security focuses on the port capabilities to safeguard its digital and physical assets.

By evaluating the extent to which processes within each dimension are identified, defined, formalized, measured, managed, and continuously improved, a comprehensive maturity level for the port can be determined. This approach enables a structured analysis that accurately reflects the port's current stage of development within each critical area of its operations.

## 4. Discussion

The proposed model for assessing process maturity in smart ports builds upon key concepts from prior research in both the logistics and environmental management domains (Sawicki and Jaworek, 2017; Werner-Lewandowska and Golinska-Dawson, 2021), while adapting these frameworks to meet the unique operational requirements of smart ports (Pham, 2023). Existing process maturity models applied across various sectors have proven effective in enhancing structured development within organizations, often focusing on general operational improvements and strategic alignment (Lee *et al.*, 2019; Tarhan *et al.*, 2016).

However, the digital transformation and sustainability mandate specific to smart ports necessitate a model that can accommodate complex interdependencies among environmental, digital, and stakeholder considerations (Satta *et al.*, 2024; Testa *et al.*, 2014). This model extends the foundational maturity model structure, adding dimensions that reflect the advanced digital and environmental requirements of smart ports, thus addressing a gap observed in earlier maturity frameworks, which predominantly referred to general business or traditional logistics environments (Charłampowicz *et al.*, 2024b; Yang and Hsieh, 2024).

The five-stage progression of the model, from foundational to collaborative network maturity, provides a structured pathway that aligns with the phased approach common in maturity model research (Lee *et al.*, 2019; van Looy *et al.*, 2011). Each stage integrates the unique functional areas of digital infrastructure, operational efficiency, environmental sustainability, stakeholder engagement, and safety and security, allowing for a comprehensive assessment of a port maturity across multiple dimensions.

This cross-functional assessment enables ports to identify critical areas of improvement specific to the smart port context, which includes complex, technology-driven operational activities and stringent environmental requirements

(Mahmud *et al.*, 2023; Satta *et al.*, 2024). The model distinct emphasis on environmental sustainability within smart ports highlights the increasingly integral role of environmental compliance and resource optimization in port operations (Boullauazan *et al.*, 2023; Housni *et al.*, 2022).

By embedding sustainability as a core dimension, the model advances a balanced approach to maturity assessment, supporting ports in achieving environmental and operational goals simultaneously, a critical factor for modern port management.

## 5. Managerial Implications

Implementing this model within a port's management framework provides a structured, evidence-based method for assessing and enhancing operational maturity. Practically, port managers can use the five defined maturity levels as a roadmap for targeted improvement efforts. Beginning with an initial self-assessment across the dimensions of digital infrastructure, operational efficiency, environmental sustainability, stakeholder engagement, and safety and security, port managers can identify specific maturity levels for each dimension.

This focused assessment enables management to allocate resources strategically and set realistic, phase-based targets for advancing digital infrastructure, operational efficiency, and environmental compliance (Charłampowicz *et al.*, 2024b; Testa *et al.*, 2014). By systematically progressing through each stage, managers can ensure incremental improvements, from establishing foundational digital practices to achieving a fully collaborative, sustainable network that integrates with external supply chain partners and regulatory bodies.

Beyond guiding operational improvements, the model offers substantial long-term benefits by enhancing competitive positioning, cost-effectiveness, and resilience. Ports that advance through higher maturity levels can expect to reduce operational inefficiencies and environmental impact, as optimized digital and environmental practices enable more precise control over resource use, emissions, and energy consumption (Raschke and Ingraham, 2010; Tarhan *et al.*, 2015).

For example, ports that reach the integrated and sustainable stages are better positioned to manage resources dynamically and meet regulatory requirements for emissions reduction, which can reduce compliance costs and mitigate operational risks (Housni *et al.*, 2022). Furthermore, the collaborative network stage enables ports to establish secure, interoperable data-sharing platforms, facilitating real-time communication and joint problem-solving across multiple ports. This high level of integration enhances a port resilience to disruptions and builds stronger, value-added relationships with global partners.

As ports progress through this maturity model, they also enhance their ability to attract investment, meet stakeholder expectations, and align with international

standards. Adopting a structured maturity assessment provides transparency in the port's development strategy, building stakeholder confidence and reinforcing the entity commitment to sustainable, adaptive growth. Ultimately, this model enables ports to evolve into intelligent, adaptive logistics hubs that are fully equipped to meet the demands of modern supply chains and international regulatory frameworks, providing a competitive advantage in a globalized market.

## 6. Conclusions

This study represents preliminary research in developing a theoretical framework for assessing the process maturity of smart ports. Future research should focus on creating a detailed questionnaire tailored to evaluate each dimension of process maturity—digital infrastructure, operational efficiency, environmental sustainability, stakeholder engagement, and safety and security. Such a tool would enable comprehensive assessment across these critical domains, ensuring that the model is both practical and relevant for port management.

After development, this questionnaire should undergo empirical validation and testing within diverse port environments, including both large and smaller, regional ports. Validating the tool in real-world settings would confirm its applicability and accuracy, allowing for any necessary adaptations based on port-specific variables, such as technological resources, regulatory contexts, and operational complexities. This step is essential for transforming the theoretical model into a practical resource that port authorities and stakeholders can confidently apply to guide strategic decision-making.

A validated maturity assessment tool would provide port authorities and stakeholders with valuable insights into areas for improvement, guiding resource allocation and strategic priorities. Furthermore, such a tool could facilitate industry-wide benchmarking, enabling ports to compare their process maturity with others in the sector. This comparative capability would foster a culture of continuous improvement and knowledge-sharing, contributing to the overall advancement of smart port practices.

However, it is worth noting that the main limitation of the research is the theoretical nature of the model, which requires further validation in practical operational conditions to confirm its adequacy for various types of ports.

## References:

Behdani, B. 2023. Port 4.0: a conceptual model for smart port digitalization. Transportation Research Procedia, 74(2022), 346-353. https://doi.org/10.1016/j.trpro.2023.11.154.

Boullauazan, Y., Sys, C., Vanelslander, T. 2023. Developing and demonstrating a maturity model for smart ports. Maritime Policy and Management, 50(4), 447-465. https://doi.org/10.1080/03088839.2022.2074161.

Charłampowicz, J., Mańkowski, C. 2024. Environmental Process Maturity of Logistics Operators: Theoretical Aspects. European Research Studies Journal, 27(3), 3-14.

Charłampowicz, J., Mańkowski, C., Saikouk, T. 2024a. Strategic integration of environmental sustainability in inland logistics: A multi-criteria decision-making approach. Business Strategy and the Environment, 33(7), 7544-7561. https://doi.org/10.1002/bse.3885.

Charłampowicz, J., Mańkowski, C., Weiland, D., Wierzbowski, P. 2024b. Inland Transport Enterprises Process Maturity Assessment – Theoretical Aspects. European Research Studies Journal, XXVII(1), 39-49.

Cheung, K., Bell, M.G.H., Bhattacharjya, J. 2021. Cybersecurity in logistics and supply chain management: An overview and future research directions. Transportation Research Part E: Logistics and Transportation Review, 146, 102217. https://doi.org/10.1016/j.tre.2020.102217.

Dewi, F., Mahendrawathi, E.R. 2019. Business process maturity level of MSMEs in East Java, Indonesia. Procedia Computer Science, 161, 1098-1105. https://doi.org/10.1016/j.procs.2019.11.221.

Housni, F., Boumane, A., Rasmussen, B.D., Britel, M.R., Barnes, P., Abdelfettah, S., lakhmas, K., Maurady, A. 2022. Environmental sustainability maturity system: An integrated system scale to assist maritime port managers in addressing environmental sustainability goals. Environmental Challenges, 7(February), 100481. https://doi.org/10.1016/j.envc.2022.100481.

Karaś, A. 2020. Smart Port as a key to the future development of modern ports. TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation, 14(1), 27-31. https://doi.org/10.12716/1001.14.01.01.

Lee, D., Gu, J.W., Jung, H.W. 2019. Process maturity models: Classification by application sectors and validities studies. Journal of Software: Evolution and Process, 31(4), 1-30. https://doi.org/10.1002/smr.2161.

Liu, M., Christina, L., Xu, W.Y.W. 2024. Smart ports for sustainable shipping: concept and practices revisited through the case study of China's Tianjin port. Maritime Economics and Logistics, 1-46. https://doi.org/10.1057/s41278-024-00291-3.

Mahmud, K.K., Mojahid, M., Chowdhury, H. 2023. Green port management practices for sustainable port operations: a multi method study of Asian ports. Maritime Policy and Management, 1-36. https://doi.org/10.1080/03088839.2023.2258125.

Min, H. 2022. Developing a smart port architecture and essential elements in the era of Industry 4.0. Maritime Economics and Logistics, 24(2), 189-207. https://doi.org/10.1057/s41278-022-00211-3.

Paraskevas, A., Madas, M., Zeimpekis, V., Fouskas, K. 2024. Smart Ports in Industry 4.0: A Systematic Literature Review. Logistics, 8(1), 1-29. https://doi.org/https://doi.org/10.3390/logistics8010028.

Pham, T.Y. 2023. A smart port development - Systematic literature and bibliometric analysis. The Asian Journal of Shipping and Logistics, 39(3), 57-62. https://doi.org/10.1016/j.ajsl.2023.06.005.

Raschke, R.L., Ingraham, L.R. 2010. Business Process Maturity's effect on performance. 16th Americas Conference on Information Systems 2010, AMCIS 2010, 6, 4088-4095.

Röglinger, M., Pöppelbuß, J., Becker, J. 2012. Maturity models in business process management. Business Process Management Journal, 18(2), 328-346. https://doi.org/10.1108/14637151211225225.

Satta, G., Vitellaro, F., Ganir, A. 2024. Green strategies in ports : a stakeholder management

perspective. Maritime Economics and Logistics, 1-27. https://doi.org/10.1057/s41278-024-00294-0.

Sawicki, P., Jaworek, P. 2017. Business process maturity of the transport-forwarding-logistics sector in Poland. Research in Logistics and Production, 7(4), 337-350. https://doi.org/10.21008/j.2083-4950.2017.7.4.6.

Tarhan, A., Turetken, O., Reijers, H.A. 2015. Do mature business processes lead to improved performance? A review of literature for empirical evidence. 23rd European Conference on Information Systems, ECIS 2015, 2015-May.

Tarhan, A., Turetken, O., Reijers, H.A. 2016. Business process maturity models: A systematic literature review. Information and Software Technology, 75, 122-134. https://doi.org/10.1016/j.infsof.2016.01.010.

Testa, F., Rizzi, F., Daddi, T., Gusmerotti, N.M., Iraldo, F. 2014. EMAS and ISO 14001: the differences in effectively improving environmental performance. Journal of Cleaner Production, 68, 165-173. https://doi.org/10.1016/j.jclepro.2013.12.061.

van Looy, A., de Backer, M., Poels, G. 2011. Defining business process maturity. A journey towards excellence. Total Quality Management and Business Excellence, 22(11), 1119-1137. https://doi.org/10.1080/14783363.2011.624779.

Werner-Lewandowska, K., Golinska-Dawson, P. 2021. Sustainable logistics management maturity-the theoretical assessment framework and empirical results from Poland. Sustainability, 13(9). https://doi.org/10.3390/su13095102.

Yang, Y., Hsieh, Y. 2024. The critical success factors of smart port digitalization development in the post-COVID-19 era. Case Studies on Transport Policy, 17, 101231. https://doi.org/10.1016/j.cstp.2024.101231.

Zobel, T. 2016. The impact of ISO 14001 on corporate environmental performance: a study of Swedish manufacturing firms a study of Swedish manufacturing firms. Journal of Environmental Planning and Management, 59(4), 587-606. https://doi.org/10.1080/09640568.2015.1031882.