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(IJIREV)**www.gaexcellence.com/ijirev**SMART PORT DEVELOPMENT IN MALAYSIA:
A CONCEPTUAL REVIEW**

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Abstract:

The development of smart ports has become increasingly important in improving the efficiency and competitiveness of the maritime industry in Malaysia. As global trade continues to expand and digital technologies evolve rapidly, Malaysian ports are encouraged to adopt smart technologies and digital systems to enhance operational performance and sustainability. This conceptual paper reviews the concept of smart port development in Malaysia and discusses the potential opportunities and challenges associated with its implementation. The study examines existing literature related to smart technologies in port operations, including automation, Internet of Things (IoT), artificial intelligence (AI), blockchain systems, and digital communication technologies. In addition, the paper highlights the potential benefits of smart port development, such as improved operational efficiency, enhanced cargo handling processes, better supply chain visibility, reduced operational costs, and environmental sustainability. However, several challenges remain, including high implementation costs, cybersecurity concerns, lack of technological readiness, and workforce adaptation issues. This paper provides a conceptual understanding of smart port development and its significance within the Malaysian maritime industry. The study contributes to the growing body of knowledge on maritime digitalization and offers insights for port operators, policymakers, and future researchers. Future studies are recommended to further examine

the practical implementation and effectiveness of smart port technologies in Malaysia.

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Keyword:

Digitalization, Malaysia, Maritime Logistics, Maritime Technology, Port Efficiency, Smart Port.



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Introduction

The fast-paced digital transformation of global supply chains is driving the ports to transform into smart ports supported by digital technologies, automation and data-driven management that is at the heart of competitiveness and sustainability. Meanwhile, while Malaysian ports play a crucial role in the nation's trade and maritime logistics, there are clear signs that they are not performing optimally to the level of Industry 4.0 and are still not fully embracing the smart port ideas to the fullest. This paper, which targets the Malaysian context, can thus help to delineate the meaning of the term 'smart port development' and highlight strategic priorities with a conceptual review.

Smart ports deploy and use ICT, IoT, big data, artificial intelligence and automation to facilitate vessel and container management, increase energy efficiency, and lower greenhouse gas (GHG) emissions, thus bolstering the national economy's competitiveness and sustainability (Li et al., 2023; Min, 2022; Yang et al., 2018; Yau et al., 2020). Internationally, ports find themselves in a "Port 4.0" environment where they are embracing digital transformation and Industry 4.0 technologies in their operations and wider maritime value chain (Belmoukari et al., 2023; De La Peña Zarzulo et al., 2020; Heikkilä et al., 2022).

The seaports in Malaysia play a very important role and serve as the backbone of the country's logistics industry and trade and move the ever-increasing number of containers as well as support economic development (Jeevan et al., 2017; Othman et al., 2016; Salleh et al., 2021). However, recent research has revealed that Malaysian seaports are "still behind the global trend" in adapting to IR 4.0 and are just beginning to explore its concepts instead of being at the global benchmark (Othman et al., 2016; Salleh et al., 2021). Meanwhile, exclusive research conducted on Malaysian ports reveals that several challenges in Malaysian ports such as congestion, insufficient infrastructures, imbalance of hinterland connection and underutilization of inner terminal are still lingering such that it hampers Malaysian maritime logistics performance (Othman et al., 2016; Jeevan et al., 2017).

Recent bibliometric & review studies recognised that the research on Smart Ports has been ever growing, but overviews on the Smart Ports have been fragmented and incomplete, while the technologies and the management approach are considered as a technological necessity (Belmoukari et al., 2023; Guerrero-Molina et al., 2024; Hawari et al., 2024; Li et al., 2023).

Instead, empirical and conceptual studies have mostly concentrated on IR 4.0 readiness, seaport excellence and maritime logistical approach when it comes to smart port development, specifically for the Malaysian context (Abeng, 2022; Othman et al., 2016).

To review the concept of smart port development in Malaysia is opportune, especially in the context of Malaysia being an important strategic hub for oceanic activity, the global trend of smart port and Industry 4.0, and the limited amount of literature on smart port and research on Malaysia smart port. It can provide the synthesis of existing smart port concepts and technologies from around the world, connect with existing seaport and hinterland conditions in Malaysia and provide a coherent window for the actions of policy makers, port operators and industry stakeholders for sustainable and competitive smart port transformation.

Hence, the objective of this paper is to review the vision of smart ports developmental concept in Malaysia by looking at key smart port technologies, benefits, challenges and considerations for future smart ports implementation. This review aims to present the current panorama of the development of smart ports and to highlight this to decision makers, port operators and stakeholders.

This study adopts a narrative literature review approach to examine and synthesize the existing literature on smart port development. A narrative literature review is appropriate for conceptual research because it facilitates the critical interpretation and integration of knowledge from diverse scholarly sources to develop theoretical insights and identify research gaps. The synthesized literature provides the foundation for the conceptual framework proposed in this study. This study contributes to SDG 9 by examining smart port development in Malaysia through the lens of technological innovation, digital transformation, and resilient port infrastructure. The conceptual review highlights key technologies and strategic enablers that support sustainable and competitive port operations.

Literature Review

Smart Port Concept

In the literature a smart port is presented as the industry 4.0 version of ports (Smart Ports on Industry 4.0), providing the added value of digital technologies to increase dimensions of efficiency, sustainability and collaboration. Ports are considered to be in a 5th phase of their evolution representing digital transformation and alignment to Industry 4.0 practices. (De La Peña Zarzuelo et al., 2020)

Smart ports can be thought of as automated, collaborative, and 'green' ports, where maritime operations are automated, real-time monitored and optimized in a manner that promotes coordination between actors and environmental performance. (Heikkilä et al., 2022; Min, 2022) In line with the results of systematic review, there are various areas and aspects of business (infrastructure, operations, environment, safety, management and human capital) identified but a lack of definitions and concepts are highlighted. (Belmoukari et al., 2023; Heikkilä et al., 2022; Li et al., 2023)

Smart ports are not a radical new idea but are rather the latest development in the long evolution of port systems. With the increasing complexity and technology in maritime commerce, ports have evolved into something far more than just providers of cargo-handling facilities and have now become hubs of logistics and information. With the advent of the industry 4.0, this transformation has been fast-tracked, allowing ports to observe digital tools, automation, and real-time data to streamline operations and enhance coordination among their stakeholders. For this reason, the smart port idea has become a focus of attention as a strategic action for improving competitiveness and sustainability of contemporary maritime supply chains.

Over the years, ports have developed from a basic loading and unloading station into a large logistics center with which to facilitate trade, transportation, and supply chain functions. Port advocates of a port evolution theory have identified several developmental stages of ports. The Port 1.0 concentrated mainly on the facilitation of loading and unloading of cargo. Port 2.0 developed into industrial and commercial uses and Port 3.0 focused on logistics integration and value-added services. Today, following the appearance of the concepts of Industry 4.0, ports are going through a transformation, moving towards a Port 4.0 defined by digitalisation, automation and connectivity. In recent years a new vision of Port 5.0 has emerged, emphasising the pseudo-sustainable thinking together with the integration of new technologies, resilience and people-oriented development.

The definition of a smart port generally refers to a port that leverages cutting-edge digital technologies, data analytics, and automated systems to optimize its operations, minimize environmental impacts, and enhance stakeholder collaboration. The Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, block chain and cyber-physical systems have the potential to enable real-time monitoring, predictive decision making and seamless information sharing throughout port operations. Smart ports can utilize these technologies to improve traffic control of ships, loading and unloading operations, resource management, and logistics coordination.

The literature outlines some of the main attributes of smart ports. They encompass among others digitization, automation in operational processes, real-time data sharing, integrated logistics networks, environmental stewardship, safety and security management and cooperation with stakeholders. Smart Ports are envisioned to develop a connected environment, where the interchange of information is efficient among port authorities, shipping companies, logistics providers, government authorities, and customers to make well-informed decisions. Moreover, smart ports are a key enabler of sustainable development, with the ability to deliver energy-efficient operations, emission reduction initiatives, and optimized resource utilization. There are several challenges and opportunities that are present in the world and that have supported the development of the smart ports. Substantial increase in trade volumes combined with rising customer expectations, supply chain complexities, environmental issues and rapid technological developments have been sources of pressure for ports to be faster and more competitive. Moreover, with the entering of Industry 4.0 technologies, ports have been moving in the direction of Intelligent Ports that are quite data driven. Consequently, smart port development is a key strategic interest for many countries to improve maritime competitiveness, logistics performance and contribute to sustainable economic growth.

Smart Port Technologies

The use of Industry 4.0 technologies that support greater automation, connectivity and data-driven decision making across port operations are a major factor driving smart port development. The IoT applications and smart sensing systems stand out as some of the most crucial technologies, enabling real-time tracking of port assets, traffic, equipment efficiency, and environmental conditions. Ports and distributed sensor networks can enable automated operations and enhance operational visibility and responsiveness considering the activities of cranes, automated guided vehicles (AGV) and yard equipment (Salleh et al., 2021; Yang et al., 2018).

Moreover, big data analytics, cloud computing, and artificial intelligence (AI) play a pivotal role in enhancing intelligent port management. Through these technologies, these port-operator systems can process massive amounts of operational data, forecast machine failures, improve equipment utilisation and make better-informed decisions. The use of data-driven insights can lead to more efficient operations, fewer delays, and overall greater productivity for ports (Heikkilä et al., 2022; Li et al., 2023).

Additionally, the use of Information and Communication Technology (ICT) platforms and cyber-physical systems help to enable seamless communication and integration between various stakeholders, further contributing to the development of a smart port. These technologies enable real-time data sharing, automate processes, and facilitate coordination among different stages of port and logistics operations, improving the visibility and efficiency of the supply chain among all concerned in real time (Min, 2022; Yau et al., 2020).

With the ever-evolving digital port, cybersecurity and system integration have become key factors to take into account. Industry 4.0 technologies are based on systems connected to each other, which are characterised by secure data transmission, storage and processing. Ports, therefore, need to consider cyber security threats alongside managing the effective horizontal and vertical integration of operational, managerial and logistics activities. While these technologies provide many potential opportunities for change, previous research has shown that adoption and maturity rates of the various technologies vary widely across ports globally (De La Peña Zarzuelo et al., 2020).

Smart ports, overall, are technologically underpinned by IoT, AI, big data analytics, cloud computing, ICT platforms and cyber security, with them all contributing to more efficient, sustainable and resilient maritime operations.

Smart Port Development Benefits to Include the Following:

While various studies focus on different aspects, they have a common understanding that smart port technologies offer benefits in terms of operational performance. Digital platforms and automated systems facilitate quicker processing of cargo, precision in resource allocation, and improved visibility throughout logistics operations. Aside from securing operational benefits, some authors state that smart port initiatives could be crucial to boost the competitiveness of ports by facilitating interest from shipping lines and logistics service providers in reliable and technologically advanced services. Environmental improvements also have become a significant benefit as digital monitoring systems can contribute to lower energy usage, reduced

unnecessary movement, and aiding efforts to reduce emissions. All these advantages hint that the smart port development isn't just about technologies but also a medium of long-term economic and sustainability goals.

Smart ports can also boost competitiveness and economic growth, not just operations. With the adoption of ICT-based tools, ports are better able to easily manage and schedule vessel movement, containers and resource allocation, thus efficiently operating more ships with quality services in a constantly growing trade volume. Elevating operational performance increases ports' appeal for shipping companies, service providers, and global investors, thereby boosting national and regional economic competitiveness (Yau et al., 2020; Guerrero-Molina et al., 2024).

Smart port development also further contributes to environmental aspects by setting objectives for environmental sustainability. Through digital technologies, ports can keep track of and manage the usage of energy, optimize transportation flows, and minimize inefficiencies in their operations which lead to GHG emissions. As such, it is considered that the smart port will become an essential pillar of sustainable maritime development, thanks to a port's green operations and the balance of economic and environmental concerns (De La Peña Zarzuelo et al., 2020; Yau et al., 2020).

Further, literature indicates that smarter ports have the potential to improve the quality of services and experience for stakeholders. New methods of communication, the sharing of real-time information and integrated management platforms better enable port authorities, shipping lines, logistics providers and customers to work together and coordinate. These developments lead to increased stakeholder satisfaction, enhanced reliability in port services, and a more responsive port ecosystem (Hawari et al., 2024).

For Malaysia, these advantages are of great significance, especially with the rise in competition from regional ports and the urgency to adopt sustainable and efficient logistics. Thus, there is great potential in the implementation of smart port technologies to boost Malaysia's competitiveness in the maritime sector and help achieve their long-term economic and environmental goals.

Smart Port Problematic Environment

However, various challenges and threats become evident when considering the implementation of e-services.

High investment and affordability: Smart port infrastructure needs significant start-up investments that come with automation and sensor costs, IT and business intelligence, which can be a challenge because of the price point especially at less advanced ports (Belmoukari et al., 2023).

Organizational and labour impacts: Automation might make port work less valued, re-distribute skills from human operators to machines, and encounter resistance to automation (Hawari et al., 2024; Min, 2022).

Cyber-security and technological integration: IoT platforms add cyber security risks and challenge of integrating all types of technologies and data generation, transmission, storage and security. (Hawari et al., 2024; Min, 2022).

Conceptual fragmentation; limited maturity: Reviews point to fragmented definitions, immature technologies, and a still small, but fast-growing literature on the topic of smart ports. ((De La Peña Zarzuelo et al., 2020; Guerrero-Molina et al., 2024; Hawari et al., 2024)

Smart Port Development (ISPD) in Malaysia

The current status of IR4.0 and digitalisation.

Malaysian seaports have been seen as the hub in logistics and trade with the increase in containers but are behind in IR4.0 implementation. They are reportedly “still behind the global trend” as they started to explore IR4.0; many global ports are in adoption & expansion, while a few others are in the implementation phase.

Based on studies of seaports in Malaysia, there is a strong correlation between the quality of the seaports and the implementation of IR4.0, especially in the areas of effectiveness and reliability in the seaports and governance, which are highlighted as preparedness problems include IoT (Internet of Things) use and infrastructure problems (Othman et al., 2016).

Behind The Port Links And Dry Ports

Smart port development is not limited to seaports and requires effective hinterland connectivity in addition to intermodal transportation network. These days, ports are not so much transportation hubs, but integral parts of maritime logistics networks. Thus, seaports and inland logistics nodes, rail connections, road networks and dry ports become crucial for increasing the efficiency of cargo flows, decongesting the ports and other logistics infrastructure, and generally improve the logistics performance.

Dry ports and intermodal terminals are always emphasised in Malaysian literature on their strategic role in supporting the competitiveness of seaports and in facilitating maritime trade. But current research shows that many inland logistics facilities are not fully exploited and still has infrastructural, operating and planning deficits hindering their functionality in the national logistics chain (Jeevan et al., 2017; Othman et al., 2016). These restrictions can have a negative impact on the capability of seaports to efficiently manage the growing number of cargoes and on the potential gains of smart port initiatives.

Empirical evidence also found that a well-designed dry port enhances the performance of seaports through improved accessibility of services, increased port capacity for cargo handling, enhanced hinterland connectivity and trade development. Seaports are performing well in this regard and the effective link with inland logistics facilities will help to lessen bottlenecks, better use of resources, and increase the responsiveness of the chain (Jeevan et al., 2017). Accordingly, for Malaysia, smart port development should not be limited to only digitalization of seaport operations, it should also include modernisation of hinterland logistics. Seizing opportunities for sustainable improvements in maritime competitiveness and logistics

performances requires a two-in-one view that combines a smart seaport with effective inland transportation and logistics systems.

Maritime logistics and digitalisation in Malaysia

Digitalisation has now become a key enabler of competitiveness and performance in the maritime logistics industry in Malaysia. In an interconnected and increasingly, technology-driven world, a capability in leveraging digital technologies is crucial to achieve efficiency, resilience, and service excellence in maritime operations. Studies on Malaysian maritime logistics have found that in competitiveness and trade facilitation, customs clearance, infrastructure, and logistics performance, are important factors for national maritime competitiveness (Abeng, 2022). That's because they affect the efficiency of cargo handling, information sharing and supply chain coordination, which are vital aspects of a modern smart port environment.

Technological digitalisation is even more relevant during the COVID-19 pandemic, as it threw into sharp relief the importance of more flexible and robust logistics. Based on the study of the maritime logistic sector in Klang Valley, it can be seen that digital transformation can assist in the economic recovery and contribution to the industry sustainability. Digital platforms, technological innovation and long-term growth strategies were seen as key enablers of the maritime sector development and the importance of digitalisation in operational continuity and business resilience were highlighted (Norman & Othman, 2022).

Digitalisation is more than the uptake of single technologies from the smart port perspective and is the integration of information systems, logistics processes and stakeholder networks across the maritime supply chain. If digital solutions are implemented successfully, they can enhance visibility, coordination and decision making of port and logistics operations. Thus, the development of maritime digitalisation in Malaysia serves as a valuable starting point for achieving the smartport and becoming smart ports, in order ports to improve their operational efficiencies, connectivity in the port's supply chain and sustainable development towards the national maritime sector.

Implications for a Malaysian smart port agenda

Collectively, the literature suggests that Malaysia's smart port development sits at the intersection of:

- Catching up on IR4.0 and smart technologies in core port operations (Salleh et al., 2021).
- Upgrading hinterland connectivity and dry port performance as part of a smart port ecosystem (Othman et al., 2016).
- Embedding digitalisation and performance metrics within broader maritime logistics and economic resilience strategies (Abeng, 2022).

Taken together, these strands of literature provide a strong foundation for understanding smart port development in Malaysia, particularly in relation to technological readiness, logistics infrastructure, and national policy priorities.

Table 1: Proposed Dimensions and Indicators of Smart Port Development in Malaysia

Dimension	Components	Indicators from Literature	Malaysian Relevance
Technological Readiness	IoT, AI, Big Data Analytics, Cloud Computing, ICT Platforms, Cyber-Physical Systems	Real-time monitoring, automation, predictive analytics, data integration	Current IR4.0 adoption remains limited in Malaysian seaports
Operational Efficiency	Automated cargo handling, vessel traffic management, resource optimization	Turnaround time, cargo throughput, equipment utilization	Improves port productivity and service quality
Connectivity & Integration	Stakeholder information sharing, digital platforms, logistics integration	Supply chain visibility, information exchange, coordination	Supports integration between seaports, dry ports and logistics providers
Hinterland Connectivity	Dry ports, rail networks, road infrastructure, inland terminals	Cargo accessibility, intermodal efficiency, congestion reduction	Critical for strengthening national logistics performance
Sustainability	Green operations, energy efficiency, emission reduction	Carbon emissions, energy consumption, resource utilization	Supports Malaysia's sustainability agenda
Safety & Security	Cybersecurity, operational safety, risk management	System reliability, data security, incident reduction	Essential for increasing digitalisation
Economic Competitiveness	Trade facilitation, logistics performance, investment attractiveness	Trade growth, port competitiveness, economic resilience	Strengthens Malaysia's regional maritime position

Source: Developed by the authors based on the literature review (2026).

Theoretical Foundation

This study adopts the Technology–Organization–Environment (TOE) framework proposed by Tornatzky and Fleischer (1990) as the theoretical lens for understanding smart port development in Malaysia. The TOE framework explains how technological innovation is influenced by three contextual dimensions: technology, organization, and environment. Given that smart port development requires the integration of advanced digital technologies, organizational readiness, and supportive external conditions, the TOE framework provides a comprehensive basis for developing the proposed conceptual framework.

Conclusion

The concluding of a conceptual paper on the development of smart port in Malaysia should interweave the global agenda of Smart Port/Port 4.0 and its readiness, gaps and strategic direction relating to Malaysia.

All over the world, ports are experiencing fifth maturity stages characterized by a strong digital transformation and by the incorporation of Industry 4.0 technologies, such as IoT, sensing, big data, AI, cloud and cybersecurity (De La Peña Zarzulo et al., 2020; Li et al., 2023; Yang et al.,

2018). Based on the findings in this review, the direction of the development of a smart port in Malaysia should be seen as a multidimensional transformation from technological, organisational and infrastructural aspects. Though the global ports have advanced their application of Industry 4.0 technologies, the Malaysian ports are still at the early stage to implement these technologies. However, given its strategic location, existing port infrastructure, and continued efforts towards digitalisation, the country possesses a solid foundation for future smart port initiatives. The results reveal that 'good' smart port development involves investing (not only) in digital technologies, but also in governance, human capabilities, cyber-security and hinterland integration. Hence, a coordinated national effort of all concerned parties such as the Port Authorities, Government and Industry is needed to help facilitate Malaysia's evolution into a more competitive, resilient and sustainable maritime sector. Despite this, there is evidence that smart ports produce benefits such as greater efficiency, asset usage, visibility, communication and sustainability, turning smart ports into a 21st-century technological necessity (Guerrero-Molina et al., 2024; Li et al., 2023; Yau et al., 2020).

The literature reveals that seaports are of key importance in Malaysia's national logistics system and have not yet fully caught up with the trend of IR 4.0, and yet, congestion remains to be a serious issue, as well as limited infrastructure and underused intermodal terminals (Othman et al., 2016; Salleh et al., 2021). Meanwhile, empirical research shows that there is strong positive correlation between the implementation of IR4.0 and seaport service quality and dry port and hinterland connectivity contributes to seaport competitiveness (Jeevan, 2017; Othman et al., 2016).

In conceptual terms, the literature reviewed suggests a shift in thinking towards the development of smart ports in Malaysia – not just technological upgrades but systemic transformation – alignment of global Smart Port/Port 4.0 agendas with local IR4.0 readiness, alignment of governance and policy, and integration with broader maritime logistics strategies and aims to enhance resilience (Abeng, 2022; Norman & Othman, 2022; Yang & Hsieh, 2024). A customized Malaysia Port Conceptual Framework can hence fill the existing gaps in definitions and technologies, offer a roadmap in implementing digital, organizational, and physical adjustments and direct future empirical studies and policy development for the future competitive, smart, and sustainable Malaysia port system.

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References

- Abeng, M. Y. (2022). Maritime logistics development strategies and performance measurement: A case study. *Journal of Maritime Logistics*. <https://doi.org/10.46754/jml.2022.12.001>
- Belmoukari, B., Audy, J., & Forget, P. (2023). Smart port: A systematic literature review. *European Transport Research Review*, 15, 1–12. <https://doi.org/10.1186/s12544-023-00581-6>
- De La Peña Zarzuelo, I., Soeane, M. J. F., & Bermúdez, B. L. (2020). Industry 4.0 in the port and maritime industry: A literature review. *Journal of Industrial Information Integration*, 20, 100173. <https://doi.org/10.1016/j.jii.2020.100173>
- Guerrero-Molina, M.-I., Vásquez-Suárez, Y.-A., & Valdés-Mosquera, D.-M. (2024). Smart, green, and sustainable: Unveiling technological trajectories in maritime port operations. *IEEE Access*, 12, 47713–47723. <https://doi.org/10.1109/ACCESS.2024.3376431>
- Hawari, S. M., Hadiprawoto, T. R., Iriyanty, I., Alversia, Y., & Adiyono, S. (2024). Smart port management in digital transformation: A review for future research. *International Journal of Marine Engineering Innovation and Research*. <https://doi.org/10.12962/j25481479.v9i3.21475>
- Heikkilä, M., Saarni, J., & Saurama, A. (2022). Innovation in smart ports: Future directions of digitalization in container ports. *Journal of Marine Science and Engineering*, 10(12), 1925. <https://doi.org/10.3390/jmse10121925>
- Jeevan, J., Chen, S.-L., & Cahoon, S. (2018). The impact of dry port operations on container seaports competitiveness. *Maritime Policy & Management*, 46(1), 4–23. <https://doi.org/10.1080/03088839.2018.1505054>
- Jeevan, J., Salleh, N., Loke, K. B., & Saharuddin, A. (2017). Preparation of dry ports for a competitive environment in the container seaport system: A process benchmarking approach. *International Journal of e-Navigation and Maritime Economy*, 7, 19–33. <https://doi.org/10.1016/j.enavi.2017.06.003>
- Li, K. X., Li, M., Zhu, Y., Yuen, K. F., Tong, H., & Zhou, H. (2023). Smart port: A bibliometric review and future research directions. *Transportation Research Part E: Logistics and Transportation Review*, 178, 103098. <https://doi.org/10.1016/j.tre.2023.103098>
- Min, H. (2022). Developing a smart port architecture and essential elements in the era of Industry 4.0. *Maritime Economics & Logistics*, 24(2), 189–207. <https://doi.org/10.1057/s41278-022-00211-3>
- Norman, S. S., & Othman, M. R. (2022). Reviving the Klang Valley economy during pandemic through digitalisation of the maritime logistics industry. *Journal of Maritime Logistics*. <https://doi.org/10.46754/jml.2021.12.003>
- Othman, M. R., Jeevan, J., & Rizal, S. (2016). The Malaysian intermodal terminal system: The implication on the Malaysian maritime cluster. *International Journal of e-Navigation and Maritime Economy*, 4, 46–61. <https://doi.org/10.1016/j.enavi.2016.06.005>
- Salleh, N. M. H. M., Selvaduray, M., Jeevan, J., Ngah, A., & Zailani, S. (2021). Adaptation of Industrial Revolution 4.0 in a seaport system. *Sustainability*, 13(19), 10667. <https://doi.org/10.3390/su131910667>
- Yang, Y., Zhong, M., Yao, H., Yu, F., Fu, X., & Postolache, O. (2018). Internet of things for smart ports: Technologies and challenges. *IEEE Instrumentation & Measurement Magazine*, 21(6), 34–43. <https://doi.org/10.1109/MIM.2018.8278808>

- Yang, Y.-C., & Hsieh, Y.-H. (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>
- Yau, K., Peng, S., Qadir, J., Low, Y., & Ling, M. H. (2020). Towards smart port infrastructures: Enhancing port activities using information and communications technology. *IEEE Access*, 8, 83387–83404. <https://doi.org/10.1109/ACCESS.2020.2990961>