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The Effect of Environmental Management, Information Technology in the Implementation of Port Sustainability Operations in Ports

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ABSTRACT

This paper attempts to find the right concept to overcome the significant challenges related to environmental quality degradation due to development activities in the port area. Environmental damage, including the impact of port development, has become an increasingly pressing global issue. To face this challenge, countries are trying to integrate sustainability principles through the application of the Port Sustainability concept, with an emphasis on the digitalization of information technology. This approach aims to increase port operational efficiency, minimize excessive use of resources, and ensure environmental sustainability and port operations in the long term.
Methodology/approach - research method using Conceptual Framework Development. Where researchers try to analyze the literature on sustainable ports, environmental management, and information technology as key elements in sustainable port operations. The result is a conceptual framework that can be used as a basis for implementing further research. **Findings** – This research presents a theoretical framework and serves as a basis for further research that will analyze the influence of environmental management on sustainable port operations, the impact of environmental management on information technology development, the relationship between information technology development and the sustainability of port operations, as well as the mediating role of information technology in relation to environmental management and sustainability of port operations **The novelty/value** of this research concept includes the mediation of information technology in relation to environmental management and the sustainability of port operations, especially port operations, where little research has been carried out.

INTRODUCTION

Ports around the world are now facing serious challenges related to environmental degradation. In recent years, the issue of environmental damage has become a global concern, including the impact of port development on the environment. Environmental quality continues to decline every year, mainly due to the influence of various aspects, especially those related to operations and exploitation of natural resources. A worsening environment can cause failure in ecological management, which can ultimately lead to disaster (Drakel, 2022). To maintain maritime sustainability, especially in port services, a sustainable port concept (Port Sustainability) is needed which allows ports to adapt to global changes.

The phenomenon of decreasing environmental quality due to port operational activities and exploitation of natural resources drives the urgency of implementing the sustainable port concept. The trend of decreasing environmental quality continues to increase due to port operational activities and uncontrolled exploitation of natural resources, which has a significant impact on ecosystem damage and worsens the environmental crisis.

Sustainable innovation is a concept that is very relevant and urgent in the current era, especially when faced with environmental and social challenges, as well as demands that companies operate responsibly. In this context, ESG (Environmental, Social, and Governance) principles emerge as an important framework underlying innovation and sustainability. Continuous innovation is the key to ensuring a responsible and sustainable future.

Port activities can be seen as a complex system consisting of various entities with interrelated attributes. Entities that influence port operations include environment, supervision and inspection, planning, administration, research and development, workforce training, pollution, security, communications, regulations, operating methods, and politics (Hassan, 1993). These various port activities are challenges that must be faced by port managers throughout the world. Therefore, a green port concept is needed to ensure ports remain safe, comfortable and sustainable. A green port is a port that firmly and strictly applies environmentally friendly principles in its operations and is part of the port's global commitment to contribute to reducing carbon emissions. Countries around the world are in the process of developing ports with a green and smart port concept that focuses on the digitalization of information technology. The aim is to make all activities more efficient, increase state revenues, avoid or reduce corruption, and maintain sustainability.

Indonesian ports in several regions have adopted ESG principles, as reported by PT Pelabuhan Indonesia (Persero) in the 2022 Sustainability Report (Pelindo, 2023), but in-depth studies regarding the effectiveness of this implementation and its impact on environmental quality are still very limited. Objective of research to find the right concept to overcome the significant challenges related to environmental quality degradation due to development activities in the port area. Contribution of research presents a theoretical framework and serves as a basis for further research that will analyze the effect of environmental management on sustainable port operations.

LITERATURE REVIEW

a. Port Sustainability Operations

Sustainable development in accordance with the Sustainable Development Goals (SDGs) aims to ensure a balance between economic growth, social inclusion and environmental protection to meet the needs of the current generation without compromising the capabilities of future generations. This goal realizes the meaning of maximizing the use of natural resources and reducing environmental impacts order to improve the quality of human life in a sustainable manner.

At the United Nations Conference on Environment and Development (UNCED) in 1992, sustainability was defined as development that can meet current needs without compromising the ability of future generations to meet their needs, with an emphasis on a balance between environmental aspects, economic, and social. This definition emphasizes the need for balance between these three aspects. The World Business Council for Sustainable Development (WBCSD) also defines sustainability as development that meets the needs of the present without reducing the capabilities of future generations, by paying attention to environmental, social and economic aspects simultaneously. (Coni-Zimmer, 2023). This definition emphasizes that these three main aspects must be considered in making business decisions to achieve long-term sustainability.

Ports, as global trade centers, are one of the industries that have a negative impact on the environment. This is due to its characteristics of producing large amounts of waste, harmful emissions and noise pollution (Özispa, 2021). Sustainability is related to how a company carries out its activities while considering the sustainability of resources in the future. This sustainability concept includes the Triple Bottom Line principle introduced by Elkington in 1997, which emphasizes the importance of three aspects: Profit, People and Planet. This concept emphasizes that companies must not only focus on profit (profit) but must also pay attention to the welfare of society (people) and play an active role in preserving the environment (planet) for the sustainability of resources (Elkington, 1997). A maintained environment and resources will ensure the continuity of the company's business in the long term, so that the company can achieve sustainable profits.

The three pillars of sustainability, namely economic, social and environmental, are the main foundations in the concept of port sustainability. Ports integrate the operation of services provided to users with an active role in sustainable development. The sustainable port concept aims to encourage all entities and communities to be more proactive in realizing a sustainable transportation system. In addition, this concept positions ports as

energy centers and digital nodes integrated in a sustainable transportation and logistics ecosystem (Haraldson et al., 2023).

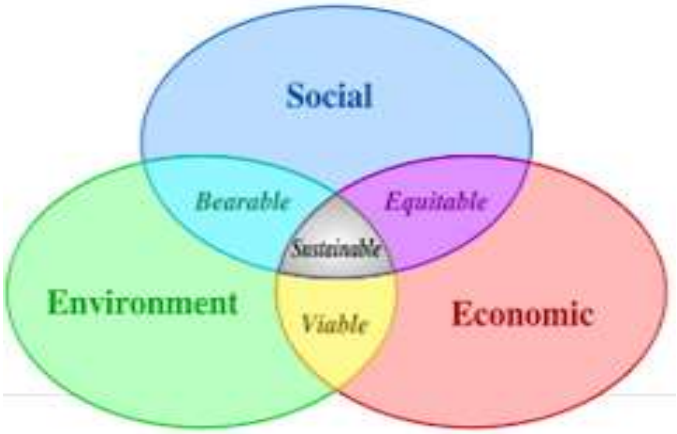

Figure 1 Sustainability Concept
Source: Jenkins (1997)

Prasetya and friends (2021) revealed that there are several important aspects that need to be considered in implementing the port sustainability concept. One of them is the impact on the atmosphere and efforts to reduce emissions produced by port activities, including maintaining the quality of the surrounding water. The main objective is to protect and maintain the flora and fauna around the port. Sustainability in port development and sea transportation contributes significantly to global trade, so ports are required to always operate optimally. However, excessive port operations without paying attention to sustainability aspects can cause environmental damage, so optimizing the green port concept is very important for the sustainability of port operations themselves. Port construction and development must not only meet environmental requirements, but also need to improve the economic welfare of communities around the port (Prasetya et al., 2021).

Elkington in the Triple Bottom Line (TBL) theory emphasizes the importance of balance between economic, environmental and social aspects in business sustainability, including port management (Elkington, 1997). Sustainable ports are an integral part of maritime economic development that cannot be separated from environmental economic valuation and ecosystem conservation. Achieving development and growth goals involving economic, social and natural resource aspects requires a holistic approach. Jenkins stated that sustainability provides solutions to maintain ecological balance in economic, environmental and social systems that are impacted by human activities and global environmental threats. This approach underscores the importance of ensuring resources are used responsibly to meet growing needs in the future (Jenkins, 2010).

The concept of green and sustainable ports does not only focus on improving environmental performance but must also be accompanied by good performance in the financial, economic and operational aspects of the port. This approach aims to realize the green port concept which leads to sustainable port development, by maintaining a balance between all these aspects to ensure the sustainability of port activities. If ports only focus on financial and economic performance, while ignoring operational and environmental aspects, then at some point the environmental carrying capacity and operational performance of the port will reach its maximum limit. This could lead to a financial slump, which could ultimately halt port development and defeat sustainability goals. Therefore, in determining indicators that influence port sustainability, it is necessary to consider operational and financial aspects in addition to environmental aspects.

Based on the results of analysis and research conducted by Ahmadi et al., the concept of sustainable port development in implementing green ports does not only focus on environmental aspects, but also considers operational and financial aspects (Ahmadi et al., 2016). Operational aspects include several things: first, port performance such as waiting time, berth occupancy rate (BOR), operational readiness of loading and unloading equipment (BM), speed of loading and unloading, port security (port security), as well as occupational Health and Safety. Second, the human resources (HR) aspect includes HR performance, HR competency, and improving the quality of HR. HR management plays a role in ensuring that the organization has a workforce

that is competent, motivated, and works in accordance with the organization's needs and goals (Zainal, 2015). Third, port development which is measured through indicators such as port information systems, additional facilities and docks, as well as port-related business development. Environmental aspects in port areas involve environmental quality, resource and energy utilization, waste management, spatial planning, and social impacts. Meanwhile, financial and economic aspects include the company's internal and external economy.

b. Environmental Management

Ports not only function as a link between sea and land transportation, but also play an important role in logistics processes and supply chains, both at the national and international levels. The port is now also being transformed into an industrial production area. In the context of the supply chain, ports act as a network that connects various companies that work together to create and distribute products until they reach the hands of end users (Rivai, 2023: 276). As ports develop as production areas, ports also become a major source of water pollution, solid waste, and significant noise and air pollution. This increase in activity has a direct impact on the surrounding environment. Most ports in the world have committed to developing proactive procedures to support sustainable development by adopting environmentally responsible approaches to preserve and protect ecosystems (Housni et al., 2021).

Environmental management (Environmental Management) generally refers to a system that manages organizational or company policies that have a connection or potential impact on the environment around the operational area. This system includes various stages starting from planning, research, implementation, responsibility, review, to evaluation and maintenance of established policies. Environmental management in ports aims to integrate high-quality port services with superior environmental performance, through the application of modern management strategies and effective implementation (Chlomoudis et al., 2024).

In managing port environmental management, the International Maritime Organization (IMO) plays an important role through the implementation of various conventions, such as the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (Marpol). MARPOL, which is an international regulation created by the IMO, focuses on preventing pollution caused by ships. Based on research conducted by Dwiyanto and his colleagues, there are five important aspects in port environmental management that have a significant impact, namely: waste production, labor absorption, water pollution, ship waste management, and management of liquids resulting from waste production (Dwiyanto et al., 2019).

The development of the port industry can have a significant environmental impact. Sustainability is measured along three main dimensions: economic, environmental, and social. The biggest impact is seen in environmental aspects, especially in the form of air pollution, greenhouse gas emissions, water pollution, and the impact on health. Port operations also contribute to air and water pollution. Currently, efforts are focused on reducing greenhouse gas (GHG) emissions and marine pollution. There are six performance indicators commonly used to assess environmentally friendly ports in maritime operations: reduction of ship speed after anchoring, engine cooling, use of electrically powered equipment at the berth, promotion of low-sulfur fuels, utilization of recyclable resources, and development of transportation modes general (Bentsos, 2021).

c. Information Technology

Smart ports are ports that use advanced technology to implement innovative operations and data-driven solutions to improve operational efficiency, safety and sustainability. One example of the application of technology in the port industry is the Port Management Integrated Digitization System (PMIDS) (Kusumawati et al., 2023). PMIDS includes various components such as Internet of Things (IoT), big data analytics, Artificial Intelligence (AI), and blockchain technology. The aim of the PMIDS concept is to optimize port operations through the integration of technological systems with digital systems, known as an integrated digitalization system. The benefits obtained from implementing this integrated digitalization system include increased efficiency, better accessibility, increased comfort and safety, and environmental conservation.

In general, the application of system technology in ports covers three main areas: sea, land (terminal), and supporting service systems. On the seaside, technology aims to improve ship service performance, so that ship waiting times and mooring processes can be accelerated with more efficient costs. On the land side, technology is implemented to optimize terminal operations. Meanwhile, the support service system is designed to simplify the administration and payment process. In Indonesia, various technologies are used to support port operations, including Inaportnet, Vessel Management System (VMS), Marine Operating System (MOS), Vessel Traffic Service (VTS), and Terminal Operating System (TOS). For goods operations, the applications used

include Non-Container Terminal Operating System (NPK-TOS), Car Terminal Operating System (CarTOS), Autogate System, Single Truck Identification Data (STID), Behandle Management System (BMS), E-Service, and i-Hub.

On the seaside, the implementation of the Marine Operating System (MOS) is an application designed to increase the efficiency and effectiveness of ship piloting and towing services at ports. This system includes time-based vessel scheduling and planning, so that services can be carried out more quickly and precisely, according to resource availability and traffic conditions at the port (Rahmiyana et al., 2022). This information technology helps reduce port operational costs, allows services to be carried out optimally, and increases competitiveness.

The benefits of implementing a Marine Operating System (MOS) include: 1) reducing paper use (paperless); 2) provide services in real time; 3) allows tracking (tracing); 4) save operational costs, especially fuel; 5) reduce operational time; and 6) provide certainty in service (Rifadli et al., 2019). Research conducted by Rifadli shows that the use of MOS or pilotage systems in ports in Indonesia has a positive and significant influence on reducing ship waiting times. By implementing MOS, the waiting time for ships to be serviced is shorter, so costs and time can be minimized.

RELATIONSHIP BETWEEN VARIABLES AND HYPOTHESES

a. Environmental Management (EM) and Port Sustainability Operations (PSO)

Environmental management has a significant impact on the sustainability of port operations. Lam and Notteboom's (2014) research show that ports are very focused and serious in implementing environmental standards through strict regulations and law enforcement approaches. Most operational activities focused on shipping traffic in ports are guided by the International Maritime Organization (IMO). Port authorities have a big influence in implementing environmentally friendly port policies. Although port stakeholders have diverse interests and needs, they need to collaborate to achieve sustainable port development (Lam & Notteboom, 2014).

With the development of ports as production centers, they have become a major source of water pollution, solid waste, and significant noise and air pollution. Considering this increasing environmental impact, many ports around the world have committed to developing proactive procedures for sustainable development by adopting an environmentally responsible approach, to preserve and protect ecosystems (Housni et al., 2021). Research conducted by Housni and his colleagues evaluates various activities and environmental aspects related to the shipping industry and identifies key indicators for assessing and developing Environmental Management Systems (EMS) to achieve sustainable development.

Environmental management in ports, through strict standards and stakeholder collaboration, plays an important role in the sustainability of port operations, with many global ports committing to environmentally friendly procedures to reduce the impact of pollution and protect ecosystems.

H1: There is a positive relationship between Environmental Management (EM) and Port Sustainability Operations (PSO)

b. Environmental Management (EM) and Information Technology (IT)

The environmental management system (EMS) is an effort to increase the company's competitiveness while ensuring environmental responsibility. Providing IT infrastructure as a high-cost component allows environmental management to be more structured and integrated with other systems. Companies are increasingly interested in adopting systems-based environmental management to strengthen their overall competitiveness and environmental responsibility (Watson et al., 2004). However, from a financial perspective, the use of EMS is not completely effective in reducing costs.

Environmental Management Information Systems (EMIS) are defined as technical systems designed to systematically collect, process and provide relevant environmental information for companies. The development of these systems is driven by the increasing need to manage environmental information, in response to internal and external pressures, such as government regulations, consumer demands, shareholders, and changes in the business environment (El-Gayar & Fritz, 2006). Environmental management utilizes a variety of information technologies, ranging from data spreadsheets and database systems to simulation systems, mathematical programming tools, knowledge-based expert systems, as well as computational intelligence tools such as neural networks, fuzzy systems, genetic optimization, and other artificial intelligence techniques such

as based reasoning. cases, intelligent agents, and visualization software (Chabanyuk and Obvintsev, 2000). These systems do not operate separately, but rather require integration because the output of one system often becomes input for other systems.

Environmental management systems and environmental management information systems help companies increase competitiveness and environmental responsibility by utilizing integrated information technology. Environmental needs make IT development more rapid, especially regarding data integration with other systems, so Hypothesis:

H2: There is a positive relationship between Environmental Management (EM) and Information Technology (IT)

c. Relationship between Information Technology (IT) and Port Sustainability Operations (PSO)

Ports today face intense competition in the global supply chain. Smart ports, known as high-performance ports, utilize information and communications technology to implement various intelligent applications. This has resulted in significant improvements in ship management and loading and unloading operations, ultimately increasing competitiveness and sustainability (Yau et al., 2020).

Research by Moura and his colleagues analyzed the application of Industry 4.0 technologies in container handling operations at ports, showing that these technologies have a major impact on environmental management and sustainability. Information technology used in port terminals to handle container processing and management has been proven to contribute to a more sustainable environment (Moura, 2022). In Indonesia, especially in Karimun Regency, Riau Islands Province, studies on the implementation of information technology policies have shown a significant positive impact on the transformation of port management. Research conducted by Sambuardi shows that managing ship traffic efficiently not only increases operational efficiency but also contributes to environmental sustainability efforts (Sambuardi, 2024).

Smart ports that utilize information technology and Industry 4.0 are proven to increase operational efficiency and environmental sustainability, as well as strengthen port competitiveness amidst global supply chain competition.

H3: There is a positive relationship between Information Technology (IT) and Port Sustainability Operations (PSO)

d. The Mediating Influence of Information Technology (IT) on Environmental Management (EM) on Port Sustainable Operations (PSO)

With the rapid development of new technologies such as automation, Internet of Things (IoT), big data analytics, Artificial Intelligence (AI), and blockchain technology, there are still many ports that have not yet fully utilized these technologies to significantly improve operational efficiency and strengthen their economic competitiveness. Integrated technology management in the development of smart or intelligent ports is an important concern in the context of global sustainable development, especially when humanity faces increasing risks due to climate change, sea level rise and supply chain disruption. Empirical findings show that technology and innovation management issues are the basis for aligning digital transformation among stakeholders through integrated solutions such as IoT, Industry 4.0, 5G, and Big Data (Lim et al., 2019). This research identifies four key areas in port sustainability performance and assessment: 1) current trends, 2) implementation of measures and mechanisms, 3) gap assessment, and 4) challenges. For current trends, efforts to evaluate the applicability and practicality of green operations have increased awareness of government green policies. Implementation steps involve utilizing techniques that identify optimal practices for sustainable operations, while implementation mechanisms are concerned with establishing indicators that help better understand performance.

Research in global ports has identified the results of implementing the smart port and Port 4.0 concepts which focus on three main areas: automation, sustainability and collaboration (Heikkilä et al., 2022). Based on scenario building theory, this article develops four alternative scenarios for the future of smart ports and shows how these scenarios will lead to different digital innovation priorities, particularly regarding automation, sustainable development and cooperation. These scenarios will have a major influence on the direction of port digitalization in the future (Bouhlal et al., 2022).

If all potential threats can be overcome, the aspects mentioned above can have a significant impact on Port performance, especially in terms of the efficiency of its main operations, namely container activities. This development should be encouraged by all stakeholders. Ports can become the most attractive ports if they succeed in encouraging the adoption of Internet of Things technology.

With technological developments such as IoT and automation not yet fully utilized by ports, research shows the importance of integrated technology management and digital innovation to improve operational environmental management efficiency, sustainability, as well as collaboration, which will shape the future of smart ports through different innovation priority scenarios.

H4: Information Technology (IT) mediates Environmental Management (EM) towards Port Sustainability Operations (PSO).

METHODOLOGY

The research method uses a conceptual framework development approach. This framework will be an important part of further research, especially for studies that aim to explain the relationship between environmental management variables, information technology and sustainable port operations. The relationship between variables in the context of this research can be explained as follows. Environmental management has a direct relationship to sustainable port operations, both theoretically and empirically. Theoretically, effective environmental management can increase operational efficiency while reducing negative impacts on the environment. Empirically, research shows that ports that implement strict environmental standards tend to be more globally competitive.

Information technology contributes significantly to sustainable port operations. Theoretically the technology enables automation, real-time monitoring, and reduced inefficiencies in various port processes. Empirically, the use of technology such as blockchain or the Internet of Things (IoT) has been proven to increase operational efficiency and transparency at ports. Combined with environmental management and information technology, this relationship further strengthens its impact on sustainable port operations. Theoretically, information technology can support the effectiveness of environmental management by providing accurate data and technology-based solutions to manage environmental impacts. Empirically, ports that use digital technology for monitoring emissions are more successful in achieving sustainability targets than ports that do not use this technology.

The combination of environmental management and information technology is an important key in encouraging the creation of sustainable port operations. With this methodology it is possible to ensure that the conceptual framework built has a strong theoretical basis, practical relevance, and clarity of relationships between variables.

RESULT AND DISCUSSION

a. Result Model Framework

The research results obtained a concept as shown in the picture below with the relationship between the independent variables Environmental Management, Information Technology, and the dependent variable Port Sustainability Operations as well as the mediating variable Information Technology in Environmental Management.

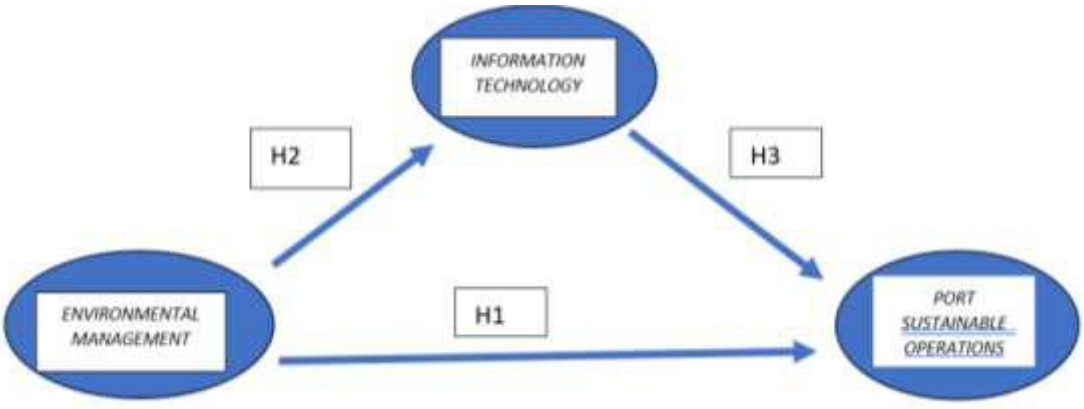

Figure 2 Conceptual Framework of the Port Sustainability Operations Model

Source: Researcher (2024).

Discussion

The results of this conceptual framework research identified a significant relationship between the independent variables, namely Environmental Management and Information Technology, and the dependent variable, namely Port Sustainability Operations. The research found that Information Technology acts as a mediating variable that strengthens the influence of Environmental Management on Port Sustainability Operations. This relationship illustrates how these three elements contribute to each other in creating a more sustainable port, both from environmental, economic and social aspects.

Environmental Management has a significant direct relationship to the sustainability of port operations. Practices that include waste management, carbon emission reduction and efficient use of natural resources have a positive impact on the ecosystem around the port while increasing its operational efficiency. Effective environmental management not only reduces negative impacts on the environment but is also able to increase the competitiveness of ports globally.

Information Technology is a key factor that directly influences the sustainability of port operations. Technology enables automation of processes, real-time data-driven monitoring, and reduction of operational inefficiencies. Application of Information Technology includes the use of IoT-based systems to monitor logistics activities and blockchain to increase transparency of logistics data. This innovation not only increases time efficiency and reduces operational costs, but also ensures that ports comply with applicable environmental regulations.

This research framework highlights the mediating role of Information Technology in the relationship between Environmental Management and Port Sustainability Operations. Information Technology acts as an enabler that strengthens the effectiveness of environmental management by providing tools for more accurate monitoring, transparent environmental data reporting, and more integrated environmental risk management. Technology-based emissions monitoring systems enable ports to meet international environmental standards while simultaneously improving operational efficiency.

This conceptual framework shows that the relationship between Environmental Management, Information Technology and Port Sustainability Operations is synergistic. The combination of planned environmental management with the support of information technology can create a greater impact in achieving port sustainability goals. In the context of modern ports, the integration of technology in environmental management is a crucial element for responding to global challenges such as climate change, regulatory pressures and demands for economic sustainability.

CONCLUSION

Company compliance and awareness of sustainability principles is a must for all business actors, including entities in the port sector. By adopting appropriate and environmentally friendly technology, ports can be optimized through the application of appropriate information technology. The correct use of information technology not only brings efficiency and profit, but also plays a role in facilitating human life and maintaining the sustainability of the environment (planet).

Development Suggestions. It is hoped that several limitations in this research can be corrected or produce better findings in subsequent research. First, this research is still at the conceptual framework stage and has not been validated with empirical data from the field. Hypotheses based on theory focus more on port operations on the seaside, which opens up opportunities for research development on the land side, such as terminal areas or port support systems. In addition, in determining the parameters and criteria for assessment indicators, this research uses several information technology standards that are commonly used in ports in Indonesia. This can be expanded to include dimensional parameters and port information technology indicators that are more comprehensive and cover ports throughout the world.

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