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Intervening Role Use Modern Stevedoring Equipment In Relationship Green Smart Port Implementation And Performance Effectiveness

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Abstract: The implementation green and smart port concepts has rapidly developed worldwide, including in Indonesia, although still faces various challenges. This research analyzed the factors influence port performance, with focus on determining role the use modern stevedoring equipment as mediating variable in relationship between implementation green and smart ports and effectiveness of port performance. Research location at Pertamina Port and Logistics Jakarta, which has implemented green and smart ports. Research conducted quantitatively with saturated sample of 102 respondents who all employees handle green and smart ports, using 5 point Likert Scale. Data analyzed using SEM-PLS software and results showed that use of modern stevedoring equipment and implementation of green and smart ports had significant effect with p-value 0.000, 0.006, and 0.008, and increased effectiveness port performance by 97%. This emphasizes the importance of using modern stevedoring equipment and optimal implementation of green and smart ports for enhance effectiveness of port performance.

Keyword: Green and Smart Port, Modern Stevedoring Equipment, Port Performance Effectiveness, Implementation Green Smart Port, Economic Sustainability.

INTRODUCTION

Concept of green ports has evolved due to the growing global awareness of environmental issues. Lin et al (2022) argue that green ports are characterized by a healthy ecological environment, efficient resource utilization, low energy consumption, and minimal pollution. This development is essential to balance port operations with environmental protection, especially in the face of climate change. Ports are vital to economic development but pose significant environmental challenges. The green port concept addresses these issues by focusing on sustainable development, aiming to reduce pollution through energy conservation, environmental protection, and ecological management.

According to Chiu et al (2014) the key factors in achieving green port status include handling hazardous waste, controlling air and water pollution, and maintaining habitat quality. These priorities guide port authorities in implementing strategies that balance operational efficiency with environmental stewardship. According to Zu & Yan (2022) atomation and digitalization technologies are considered important elements in supporting green ports, as they allow for higher operational efficiency and waste reduction. So that automation and digitalization technology has an important role in the influence of intervention on green and smart ports and the effectiveness of port performance.

The implementation of green and smart ports in Indonesia is being actively promoted, yet research on this topic remains limited. A thorough and comprehensive study of their implementation and impact on port performance is crucial for the development of national ports. Urgent research is needed to identify the challenges and opportunities associated with green and smart port initiatives across various Indonesian ports and to develop effective strategies to overcome obstacles and maximize the benefits of efficient and environmentally friendly technologies (Purba, 2010).

Research on green and smart port implementation in Indonesia can focus on Pertamina Port and Logistics in Tanjung Priok, Jakarta, due to its relevant challenges. Despite adopting green and smart initiatives, their effectiveness requires thorough evaluation to ensure investments positively impact port performance. The implementation of Green and Smart Ports in Indonesia has become the main focus in improving port efficiency and reducing the environmental impact caused by port activities. However, in its implementation, there are a number of problems that must be faced. One of the main problems is the lack of adequate infrastructure and technology. Many ports in Indonesia still rely on technology and operational systems that do not fully support the green and smart port concept, which requires large investments for renewal and development (Safuan, 2024). Environmental issues are also a crucial issue in the implementation of green and smart port. Port activities, such as oil spills and greenhouse gas emissions, have a significant impact on the surrounding environment. Although there have been mitigation efforts, the existing approaches are still sporadic and not comprehensive (Tian et al., 2021). Human resources who have special skills and knowledge in operating and maintaining the technology are also an obstacle. Indonesia still faces a shortage of trained workers in the fields of information technology and industrial automation, especially those related to port operations. Without adequate experts, the implementation of green and smart ports can be hampered, because the technology adopted cannot be utilized optimally (Ritonga et al., 2022). The implementation of technologies such as warehouse management system (WMS) demonstrates the importance of digital integration in logistics management and port operations. This reflects how the use of modern, digitally connected stevedoring equipment can support the implementation of green smart ports by maximizing performance efficiency (Mardhiani et al., 2023). Green smart ports not only help reduce carbon footprints, but also improve port competitiveness in the global market. Investment in green technology and energy efficiency is critical to the future of the maritime industry (Alzate et al., 2024). This research is vital due to the challenges in implementing green and smart ports in Indonesia, a key player in global supply chains. Infrastructure deficiencies, limited adoption of green technologies, and fragmented mitigation efforts highlight gaps in prior research. Although Pertamina Port and Logistik Jakarta has adopted modern technology and sustainable practices, there is still room for improving facility management and energy distribution. Further research is needed to develop strategies for integrating green technology and digitalization, enhancing sustainability, global competitiveness, and reducing environmental impact in Indonesian ports.

Literature review

1. Green and Smart Ports

Green ports are designed to minimize environmental impact through a variety of sustainability initiatives, including energy conservation, emission reduction, and waste management. The implementation of green ports is driven by global environmental policies and the need to mitigate the adverse impact of port operations on local ecosystems. According to Eide et al (2009) green ports focus on addressing climate change, effective dredging operations, noise management, and waste treatment. The European Sea Port Organization (2019) further emphasizes the importance of managing hazardous waste and reducing air and water pollution.

In their journal, Meyer et al (2024) stated that on the other hand, smart ports utilize advanced technologies such as automation and digitalization to improve operational efficiency. Smart ports integrate these technologies to streamline port operations, reduce logistics costs, and improve safety and security. Safuan (2022) highlights the importance of using advanced cargo handling equipment, automated monitoring systems, and digital integration to optimize port operations. The convergence of eco-friendly port concepts and smart ports aims to create a port that is not only environmentally friendly but also technologically advanced, thereby improving the overall performance of the port.

2. Modern Stevedoring Equipment

Modern stevedoring equipment plays a crucial role in the operational efficiency of ports. These technologies include automated cranes, remotely controlled machines, and digital monitoring systems that facilitate faster and safer cargo handling. The use of modern loading and unloading equipment is seen as a key component in achieving the destination of an environmentally friendly and smart port. Efficient cargo handling reduces ship turnaround times, minimizes energy consumption, and lowers emissions. Safuan (2022) argued that the integration of modern loading and unloading equipment can significantly increase port operational productivity. The use of modern technology, including advanced loading and unloading equipment, significantly improves the effectiveness of port performance. The implementation of information systems and digital technology, as applied to port operations, is proven to speed up loading and unloading activities and improve logistics efficiency (Ricardianto et al., 2023)

The efficiency of stevedoring equipment is measured by its ability to optimize loading and unloading processes, reduce loading and unloading times, and improve port resource utilization. Badurina et al (2017), explained that ports are one of the largest energy consumers and face challenges in adopting innovative solutions related to energy efficiency and environmental protection. Thus, the transformation of ports into green ports is an important step to reduce environmental impact while improving operational efficiency. His research also emphasizes that green ports can provide economic benefits for port authorities, in line with increasing economic activities and more environmentally friendly operations.

3. Port Performance Effectiveness

The effectiveness of port performance is an important measure of the success of port operations. Effective port performance is essential to maintain port competitiveness in the global logistics network (Wijaya & Nakamura, 2024). Bichou & Gray (2004) identified key indicators of port performance, including ship service efficiency, terminal operation effectiveness, and port traffic management. The implementation of environmentally friendly port practices and smart ports is expected to have a positive impact on port performance. Reduced energy consumption and emissions, coupled with improved operational efficiency, will improve the overall performance of ports (Bakhsh et al., 2024). According to Sadjiono et al (2018) discussed the relationship between green port initiatives and performance effectiveness, by highlighting the benefits of sustainable practices in improving port operations. The integration of modern loading and unloading equipment further reinforces these benefits by simplifying the cargo handling process and reducing operational costs.

4. The Role of Modern Stevedoring Equipment As An Intervening Variable

The relationship between the implementation of green ports and smart ports and the effectiveness of port performance is very complex and influenced by various factors. Modern loading and unloading equipment acts as an intermediary variable in this relationship, mediating the impact of green port and smart port practices on port performance. The effectiveness of green port and smart port initiatives depends on the successful integration of advanced cargo handling technologies. This integration ensures that the operational efficiencies gained from green port and smart port practices translate into tangible improvements in port performance (Alfian et al., 2022).

The use of modern loading and unloading equipment increases port operational capacity by reducing the time required for cargo handling, increasing the utilization of port facilities, and lowering operational costs. This improvement contributes to the overall effectiveness of port performance, thus becoming an important factor in the successful implementation of green port and smart port practices. Research by Eide et al (2009) supports this view, which shows that the adoption of advanced technologies is essential to achieve the sustainability goals of green ports.

5. Challenges In Implementing Green And Smart Ports

The implementation of green and smart ports faces challenges like technological readiness, high costs, and significant investments in technology and infrastructure. Financial constraints and compliance with complex international regulations add to the difficulty. Workforce adaptation is crucial, as modern equipment requires skilled workers. Training programs are essential to equip them with the necessary skills to operate advanced machines and systems. Research by Safuan (2022) highlights the importance of continuous training and capacity building in ensuring the successful adoption of modern technology in port operations.

METHOD

This study employs a quantitative approach to investigate the factors influencing port performance effectiveness and the role of modern cargo handling equipment as an intervening variable between green and smart port implementation and port performance. The research was conducted at Pertamina Port and Logistics Jakarta, focusing on the integration of green and smart port practices with modern cargo handling equipment to enhance operational efficiency and sustainability. A saturated sample approach was utilized, where the entire relevant population of 102 employees was included in the study. This approach was chosen due to the relatively small population size, allowing for comprehensive data collection and analysis (Sudarmanto., 2021).

Data Collection

This study took a sample of 102 (one hundred and two) respondents which included all employees who were directly involved with the green smart port system and port performance effectiveness, so that nothing was missed in data collection. The measuring tool used is a questionnaire using a 5-point Likert Scale. Data analysis in this study was carried out using Structural Equation Modeling Partial aLeast Squares (SEM-PLS) with the contribution of SmartPLS software version 4, which is designed to evaluate respondents' perception of the variables studied (Becker et al., 2020). The questionnaire data will be analyzed using path analysis to examine the mediating role of green smart port implementation, use modern stevedoring equipment, and port performance effectiveness. Instrument validity and reliability tests will ensure the questionnaire's quality. The analysis is expected to yield practical recommendations for Pertamina Port & Logistik Jakarta to enhance efficiency in port activities.

Data Analysis

The quantitative data collected through the questionnaire was processed using SmartPLS software, using the Structural Equation Modeling (SEM-PLS) method. This method was chosen because of its ability to handle complex relationships between various variables and to test the strength of the mediating effect of using modern stevedoring equipment loading and unloading equipment. This analysis also makes it possible to identify and measure the direct and indirect influence of independent variables on dependent variables in the research model.

Tabel 1 Measurement of Variables

Variable	Operational definition	Source
Implementation of Green and Smart Port	The implementation of a green smart port refers to a series of measures and initiatives taken by port authorities to improve the environmental performance of ports through the application of advanced technology and environmentally friendly practices.	(European Sea Port Organization, 2019)
Modern Stevedoring Equipment	The use of modern loading and unloading equipment allows the process of handling goods to be faster and safer, which contributes to reduced loading and unloading times and reduced operational costs. In addition, more advanced equipment also increases the port's handling capacity, allowing for the handling of larger volumes of goods in a shorter period of time, ultimately increasing the port's competitiveness at the global level.	(Safuan, 2022)
Port Performance Effectiveness	The effectiveness of the port is greatly influenced by the availability and quality of infrastructure, loading and unloading equipment, and competent human resources. An effective port can minimize ship waiting times, speed up the loading and unloading process, and ensure that supporting facilities such as docks and stacking yards are used optimally. In addition, port effectiveness is also related to the ability of ports to adapt to technological developments and market demands, so as to be able to increase operational capacity and competitiveness at the national and international levels.	(Sadjiono et al., 2018)

Conceptual Framework

The conceptual framework of this study is presented in the following diagram, which maps the relationship between the variables of implementation green smart port, modern stevedoring equipment, and port performance effectiveness. This model serves as a theoretical basis to comprehensively examine the relationship between these variables. In addition, this diagram plays a crucial role in identifying causal pathways that will be explored through empirical analysis in this study.

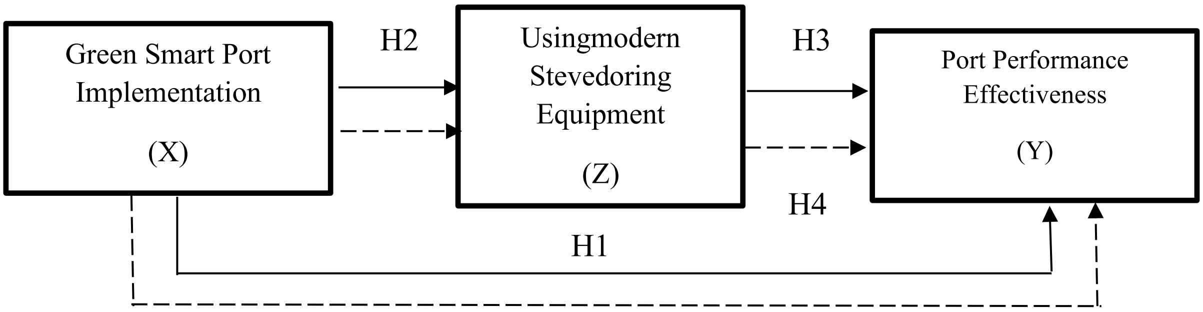

Figure. 1. Research Model

A hypothesis is a provisional answer to the formulation of a research problem, presented in the form of a statement, called provisional because the answer is only based on relevant theories and has not been supported by empirical evidence obtained from data collection. The hypothesis of this research is as follows:

H1: There is relationship between green smart ports and port performance effectiveness
H2: There is a relationship between the application of green smart port to modern stevedoring equipment
H3: There is a relationship between modern stevedoring equipment and port performance effectiveness
H4: There is application of green smart port and the use of modern stevedoring equipment simultaneously affect port performance effectiveness

RESULTS AND DISCUSSION

The Partial Least Squares (PLS) approach in Structural Equation Modeling (SEM) analysis is a statistical method used to model the relationship between latent variables (variables that cannot be measured directly) and observation variables (variables that can be directly measured). PLS-SEM is very useful when we want to predict latent variables using observation variables and when the model has high complexity or when the sample size used is relatively small (Sarstedt et al., 2022). The following are the results of research that has been carried out using the SEM approach method and using SmartPLS tools shown in Figure 2.

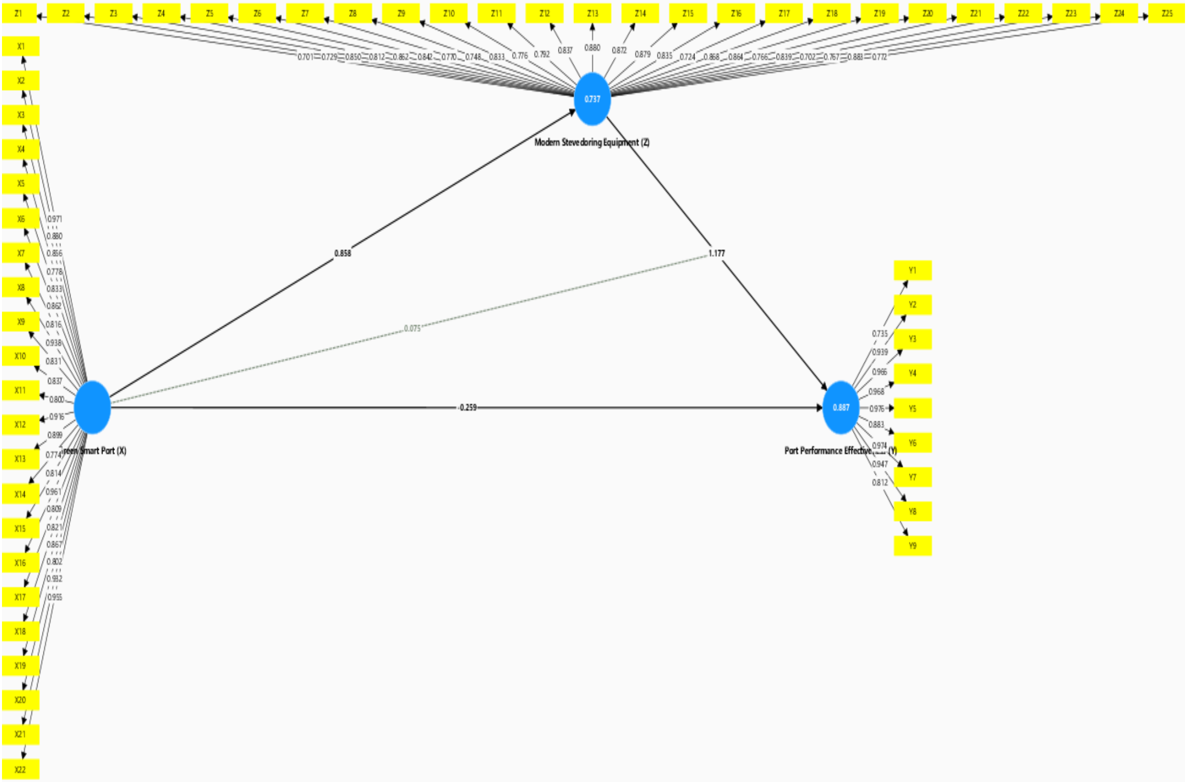

Figure 2. **Graphic output PLS-SEM**

The graph model of this study shows the relationship between the Implementation of green smart port (x), modern stevedoring equipment (z), and port performance effectiveness (y). The implementation of green smart port is measured by various indicators and has a direct effect on port performance effectiveness (path coefficient 0.259) and through modern stevedoring equipment (path coefficient 0.858), which is also measured by related indicators, affecting port performance effectiveness (path coefficient 1.177). Modern stevedoring equipment acts as a mediating variable, strengthening the influence of green smart port implementation on port performance effectiveness.

Convergent Validity

The external loading output, as assessed by SmartPLS 4 using the partial least squares (PLS). Method, reveals the relationship between each indicator and the construct it measures. This information allows for the evaluation of convergent validity in measurement models with reflective indicators, ensuring that the variables are accurately measured.

Tabel 2. Output Of Research External Loading Analysis Results (2024)

No	Variable	Indicator	Outer loading
1	Implementation green smart port	X1	0.971
		X2	0.880
		X3	0.856
		X4	0.778
		X5	0.833
		X6	0.862
		X7	0.816
		X8	0.938
		X9	0.831
		X10	0.837
		X11	0.800
		X12	0.916

No	Variable	Indicator	Outer loading
		X13	0.899
		X14	0.774
		X15	0.814
		X16	0.961
		X17	0.809
		X18	0.821
		X19	0.867
		X20	0.802
		X21	0.932
		X22	0.955
2	Modern Stevedoring Equipment	Z1	0.701
		Z2	0.729
		Z3	0.850
		Z4	0.812
		Z5	0.862
		Z6	0.842
		Z7	0.770
		Z8	0.748
		Z9	0.833
		Z10	0.776
		Z11	0.792
		Z12	0.837
		Z13	0.880
		Z14	0.872
		Z15	0.879
		Z16	0.835
		Z17	0.724
		Z18	0.868
		Z19	0.864
		Z20	0.766
		Z21	0.839
		Z22	0.702
		Z23	0.767
		Z24	0.883
		Z25	0.772
3	Port performance Effectiveness	Y1	0.735
		Y2	0.939
		Y3	0.966
		Y4	0.968
		Y5	0.976
		Y6	0.883
		Y7	0.974
		Y8	0.947
		Y9	0.812

Achieving a composite reliability value above 0.7 is a crucial factor in confirming the consistency and reliability of the construct in modeling structural equations using the partial least squares approach (PLS-SEM). The outer loadings of the construct indicate that each indicator makes a significant contribution to the latent variable it represents. All of these outer loading values exceed the recommended threshold of 0.7, which confirms the validity of the construct measurements in this mode (Hair et al 2021).

Implementation Of Green And Smart Port (X):

Outer loadings for green and smart port implementations range from 0.701 to 0.971. These high values indicate that the indicators X1 to X22 (Table 2) are reliable measures for this construct. In particular, indicators such as X1 (0.971), X16 (0.961), and X22 (0.955) show a very strong contribution, which strengthens the robustness of this construct.

Modern Stevedoring Equipment (Z):

The outside load for using modern stevedoring equipment ranges from 0.785 to 0.883. The Z1 to Z25 indicators all show a charge above 0.7, with some indicators such as the Z15 (0.879), Z13 (0.880), and Z24 (0.883) showing very high reliability. This indicates that this construct is well defined and measured consistently across all indicators.

Port Performance Effectiveness (Y):

Outer loadings for the port performance effectiveness construct ranges from 0.735 to 0.976. Although there are some indicators with payload values that are close to the minimum recommended threshold, such as Y1 with a value of 0.735 and Y5 which reaches 0.976, most indicators, including Y5 (0.976) and Y7 (0.974), show a very high level of reliability. This confirms that the construct has been measured consistently and accurately, and reflects the dimensions in question well.

Henseler et al (2015) argue that these results show that the model shows high composite reliability and convergent validity. The reliability of the composite is assessed through the outer loading of the indicator, and a value above 0.7 indicates that the construct is measured reliably and consistently. Furthermore, convergence validity is confirmed when the indicators are strongly correlated with their respective constructs, as evidenced by the outer loadings. Hair et al (2021) high outer loadings on all constructs in the model indicate that the data has met the recommended reliability and validity standards. This indicates that the implementation construction of green and smart ports, modern loading and unloading equipment, and the effectiveness of port performance have been accurately measured. Thus, the PLS-SEM analysis carried out can be considered reliable and valid.

Test Construct Realibility And Validity

The purpose of construct validity and reliability tests to assess how reliable or highly reliable a research instrument, how much one can rely on the instrument to collect data. In his journal, Hollis (2024) emphasized that when an instrument undergoes a reliability test, the instrument is considered reliable if the Cronbach alpha coefficient (α) for each instrument variable is greater than 0.6; if the value is less than 0.6, the instrument is considered unreliable. Composite Reliability (CR) is a measure used to assess the internal consistency of indicators that measure a construct (latent variable) in a measurement model, especially in Structural Equation Modeling (SEM) analysis such as PLS-SEM. These measurements give an idea of how well these indicators work together to illustrate the construct in question.

Table 3. Processing Value Composite Realibility

	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extarcted (AVE)
X	0.984	0.986	0.985	0.746
Y	0.975	0.987	0.979	0.837
Z	0.978	0.980	0.979	0.656

Source: Results Of Research Analysis On Processing Value Composite Realibility (2024)

Table 3 demonstrates that both the composite reliability and Cronbach's Alpha values for each variable exceed the 0.60 threshold, indicating sufficient data reliability. The composite reliability values are higher than Cronbach's Alpha, confirming that each variable meets the required reliability standards for using SmartPLS in SEM analysis. The evaluation results show that the measurement model's instruments are both valid and reliable.

Cronbach's Alpha and composite reliability (rho_a and rho_c) values significantly exceed 0.60, indicating high internal consistency, while the AVE value surpasses 0.50, confirming strong convergent validity. These findings affirm the adequacy data reliability and validity in this study.

Test Determination

The feasibility testing of the model was measured by using R-square for each latent variable that was independent of the dependent variable. Based on Table 4, is the result of calculating the value of R square using SmartPLS.

Table 4. Value R Square

	R-Square	R-Square Adjusted
Modern Stevedoring Equipment (Z)	0.887	0.884
Port Performance Effectiveness_ (Y)	0.737	0.734

The R-square and adjusted R-square values in Table 4 show the effectiveness of the model in explaining the variability in the dependent variables. For using modern stevedoring equipment (Z), more than half of the variances are explained by the model, while for port performance effectiveness (Y), the model explains most of the significant variances. These values indicate that this model has good explanatory power and is suitable for predicting the outcome of interest in research.

Test Predictive Relevance /Q-Square

Q-Square is important measure in PLS-SEM that helps researchers and analysts understand the predictive power of their models. A high Q^2 value indicates that the model is capable of accurately predicting outcomes, making it a reliable tool for analysis and forecasting (Hair et al., 2021). Thus, Q^2 can also be used to assess models that have significant predictive relevance values, which ultimately increases the validity of predictions in quantitative research.

$$Q^2 = 1 - [(1 - 0.887) \times (1 - 0.737)]$$

The Q-Square value as we did before and getting a value of 0.970 that means that the model has very high predictive relevance, which indicates that the model is very good at predicting endogenous variables based on exogenous variables. Test Goodness of Fi Shows that the model has predictive relevance. The closer to 1, the better the predictive power of the model. A high Q-Square value (e.g., close to 1) indicates that the model has an excellent ability to predict endogenous variables. The Goodness of Fit is aimed at assessing the global fit of a model by combining the fit of measurements and structural models. This helps determine if the model's predictions are consistent with the observed data. The GoF considers the described variance of the endogenous construct and the quality of the measurement model.

Table 5 Output Model Fit

	Saturated Model	Estimated Model
SRMR	0.104	0.104
d_ULS	17.315	17.325
d_G	30.017	29.949
Chi-square	7581.464	7578.964
NFI	0.475	0.475

The model match table shows that both the saturated model and the estimated model have a similar match index across all metrics:

a) SRMR is below the threshold of 0.10, signaling a good model fit.
b) d_ULS and d_G do not have a specific threshold, but the consistency of values across models indicates stability.
c) chi-square is high, which usually indicates a poor fit, but this can also be due to sensitivity to sample size.
d) NFI below the desired threshold (generally above 0.90), indicates that the model fit can still be improved.

While some metrics indicate an acceptable fit (SRMR), others indicate that there is still room for improvement (Chi-square, NFI). The same values for saturated models and estimated models show consistency in model assessment, but improvements in model specifications or data may needed for an overall better fit.

Hypothesis Testing

One technique to clarify the relationship between research variables is structural model testing. We can look at the statistical significance of the t-value and the p-value to see if the hypothesis proposed is valid. The hypothesis is accepted if the p-value is less than 0.05. The output results or values contained in the output, including the path coefficient and indirect influence, are the basis used in the context of the evaluation of this hypothesis.

Table 6. Path Coefficients (Mean, STDEV, T-Statistic)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STCEV)	T Statistics (|O/STDEV|)	P Values
Implementation of Green and Smart Port -> Modern Stevedoring Equipment	0.858	0.861	0.023	38.076	0.000
Implementation of Green and Smart Port -> Port Performance Effectiveness	-0.259	-0.265	0.098	2.647	0.008
Modern Stevedoring Equipment -> Port Performance Effectiveness	1.177	1.185	0.079	14.915	0.000
Implementation of Green and Smart Port x Modern Stevedoring Equipment -> Port Performance Effectiveness	0.075	0.075	0.027	2.743	0.006

P-value: The p-value used to assess significance is < 0.05. In this table, all p-values are below 0.05, which indicates that the result is statistically significant (Zhou et al., 2024)

T-statistics are used to assess the significance of an effect. In most cases, t-statistics must be greater than 1.96 to be significant at the 5% (two-sided) level (Konietschke & Pauly, 2014). From the table 6 :

a) X -> Y : T-Statistic = 2.647 (Significant)
b) X -> Z : T-Statistic = 38.076 (Very Significant)
c) Z -> Y : T-Statistic = 14.915 (Very Significant)
d) X x Z -> Y: T-Statistic = 2,743 (Significant)

Original Sample vs. Sample Mean: The difference between the original sample and the sample mean should be small, indicating the stability of the model estimate. From the table, the difference between O and M is quite small, indicating a stable model.

Contribution To Knowledge

This research significantly contributes to knowledge in port operations, technology implementation, and environmental sustainability. It reveals how using modern stevedoring equipment acts as an intervening variable that strengthens the relationship between green smart port implementation and port performance effectiveness. The study highlights the role of technology in enhancing stevedoring efficiency and port operations, while also supporting sustainability goals by implementing green smart port. By providing empirical evidence on the role of modern equipment in mediating the green smart port and port performanc effectiveness relationship, this research fills a literature gap and advances understanding of technological innovation's impact on operational performance.

CONCLUSION

The four hypotheses (H1, H2, H3, and H4) were accepted, as the path coefficients were positive and statistically significant. The Implementation of green and smart port positively affects the use of modern loading and unloading equipment and port performance effectiveness. Specifically, the implementation of green and smart ports (X) significantly influences modern equipment use (Z) with a path coefficient of 0.736 and T statistic of 14.857 (H2), and also improves port performance (Y) with a path coefficient of 0.766 and T statistic of 9.974 (H1), highlighting the impact of sustainable practices. In addition, the use of modern loading and unloading equipment (Z) itself has been shown to have a positive and statistically significant impact on the effectiveness of port performance (Y), with a line coefficient of 0.204 and a T statistic of 2.378, indicating that equipment advancement contributes to better performance metrics (H3). Finally, the combined effect of the implementation of eco-friendly ports and smart ports (X) and the use of modern loading and unloading equipment (Z) on the performance effectiveness of ports (Y) is also significant, highlighting the synergistic benefits of integrating sustainable practices with modern technologies in port operations (H4). These findings collectively emphasize the critical role of innovative and environmentally sound strategies in improving the efficiency and effectiveness of port operations, thereby supporting the broader goals of sustainability and operational excellence in the maritime industry.

REFERENCES

Alfian, H. A. S., Zakaria, A., & Md.Arof, A. (2022). *Green Port Performance Indicators for Dry Bulk Terminals: A Review BT - Advanced Maritime Technologies and Applications* (A. Ismail, W. M. Dahalan, & A. Öchsner (eds.); pp. 61–77). Springer International Publishing.

Alzate, P., Isaza, G. A., Toro, E. M., Jaramillo-Garzón, J. A., Hernandez, S., Jurado, I., & Hernandez, D. (2024). Operational efficiency and sustainability in smart ports: a comprehensive review. *Marine Systems & Ocean Technology*, *19*(1), 120–131. https://doi.org/10.1007/s40868-024-00142-z

Badurina, P., Cukrov, M., & Dundović, Č. (2017). Contribution to the implementation of "Green Port" concept in Croatian seaports. *Pomorstvo*, *31*(1), 10–17. https://doi.org/10.31217/p.31.1.3

Bakhsh, W., Fiori, C., & de Luca, S. (2024). *Literature Review on the Smart Port: Evolution, Technological Development, Performance Indicators of Smart Ports BT - Computational Science and Its Applications – ICCSA 2024 Workshops* (O. Gervasi, B. Murgante, C. Garau, D. Taniar, A. M. A. C. Rocha, & M. N. Faginas Lago (eds.); pp. 340–357). Springer Nature Switzerland.

Becker, Klein, & Wetzels. (2020). A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). *International Journal of Market Research*, *62*(3), 284–315.

Bichou, K., & Gray, R. (2004). A logistics and supply chain management approach to port performance measurement. *Maritime Policy and Management*, *31*(1), 47–67. https://doi.org/10.1080/0308883032000174454

Chiu, R. H., Lin, L. H., & Ting, S. C. (2014). Evaluation of green port factors and performance: A fuzzy AHP analysis. *Mathematical Problems in Engineering*, *2014*. https://doi.org/10.1155/2014/802976

Eide, M. S., Endresen, Ø., Skjong, R., Longva, T., & Alvik, S. (2009). Cost-effectiveness assessment of CO2 reducing measures in shipping. *Maritime Policy and Management*, *36*(4), 367–384. https://doi.org/10.1080/03088830903057031

European Sea Port Organization (ESPO). (2019). ESPO Environmnetal Report 2019. *Espo*, 1–23. https://www.espo.be/media/Environmental Report-2019 FINAL.pdf

Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2021a). *Evaluation of Formative Measurement Models*. https://doi.org/10.1007/978-3-030-80519-7_5

Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2021b). *Evaluation of the Structural Model BT - Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook* (J. F. Hair Jr., G. T. M. Hult, C. M. Ringle, M. Sarstedt, N. P. Danks, & S. Ray (eds.); pp. 115–138). Springer International Publishing. https://doi.org/10.1007/978-3-030-80519-7_6

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, *43*(1), 115–135. https://doi.org/10.1007/s11747-014-0403-8

Hollis, L. P. (2024). *Graduated Validity: Cronbach Alpha Calculations for Graduate Student Workplace Bullying Instrument (2017) BT - Instrumental Social Justice in Higher Education: Eight Surveys for Workplace Bullying and Social Justice Research* (L. P. Hollis (ed.); pp. 63–73). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-49289-1_5

Konietschke, F., & Pauly, M. (2014). Bootstrapping and permuting paired t-test type statistics. *Statistics and Computing*, *24*(3), 283–296. https://doi.org/10.1007/s11222-012-9370-4

Lin, C. Y., Dai, G. L., Wang, S., & Fu, X. M. (2022). The Evolution of Green Port Research: A Knowledge Mapping Analysis. *Sustainability (Switzerland)*, *14*(19). https://doi.org/10.3390/su141911857

Mardhiani, S., Puspita, R., Tatiana, Y., Gabriella, N., Hayam, D., Chamsudi, M., Bijaksana, G., & Simatupang, V. S. (2023). *Intervening Role of Cargo Control in Relation with Warehouse Management System Influence Freight Stations Efficiency*. *5778*, 95–114.

Meyer, C., Gerlitz, L., & Prause, G. (2024). *Smart City and Smart Port Concepts: A Conceptualisation for Digital Small and Medium-Sized Port-City Innovation Ecosystems BT - Reliability and Statistics in Transportation and Communication* (I. Kabashkin, I. Yatskiv, & O. Prentkovskis (eds.); pp. 41–53). Springer Nature Switzerland.

Purba, A. (2010). Green Port, Keharusan Bagi Pelabuhan Internasional Menuju Hub Port. *Jurnal Rekayasa*, *14*(2), 79–86.

Ricardianto, P., Fonataba, Y., Veronica, Marzuki, S., Priyohadi, N. D., Wijonarko, G., Haryani, E. B. S., Kamsariaty, Sitorus, P. P., & Endri, E. (2023). Determinants of logistics effectiveness on port operational performance: Empirical evidence from Indonesia. *Uncertain Supply Chain Management*, *11*(2), 799–810. https://doi.org/10.5267/j.uscm.2022.12.010

Ritonga, R. A., Ahmadi, N., Kusumastanto, T., Suwandi, R., Suwito, S. R., Hasriningtyas, S., Arafat, H., & Soleh, A. (2022). Kesiapan Implementasi Smart Port Di Indonesia. *Coastal and Ocean Journal (COJ)*, *6*(1), 8–23. https://doi.org/10.29244/coj.6.1.8-23

Sadjiono, I., Istijab, B., & Malisan, J. (2018). *Jurnal Penelitian Transportasi Laut A Potential Freight Consolidation Center for Asia Pacific Regional Hub : An Importance Performance Analysis*. *20*, 98–108.

Safuan, S. (2022). Penerapan Teknologi Digital di Pelabuhan Indonesia untuk Menurunkan Biaya Logistik Nasional Application of Digital Technology in Indonesian Ports and Contribute to Lowering National Logistics Costs. *Jurnal Manajemen Transportasi & Logistik (JMTRANSLOG)*, *09*(03). https://journal.itltrisakti.ac.id/index.php/jmtranslog

Safuan. (2024). Opportunities and Challenges of Implementing Green and Smart Port Concepts in Indonesia. *Journal of Maritime Research*, *21*(1), 168–173.

Sarstedt, M., Ringle, C. M., & Hair, J. F. (2022). *Partial Least Squares Structural Equation Modeling BT - Handbook of Market Research* (C. Homburg, M. Klarmann, & A. Vomberg (eds.); pp. 587–632). Springer International Publishing. https://doi.org/10.1007/978-3-319-57413-4_15

Sudarmanto, E., Kurniullah, A. Z., Revida, E., & Ferinia, R. (2021). *Desain Penelitian Bisnis Pendekatan Kuantitatif (R. Watrianthos & J. Simarmata (eds.))*. http://eprints.binadarma.ac.id

Tian, J., Wang, Y., & Chen, Z. (2021). An improved single particle model for lithium-ion batteries based on main stress factor compensation. *Journal of Cleaner Production*, *278*, 123456. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123456

Wijaya, W. M., & Nakamura, Y. (2024). Port performance indicators construction based on the AIS-generated trajectory segmentation and classification. *International Journal of Data Science and Analytics*. https://doi.org/10.1007/s41060-024-00614-w

Zhou, Y., Kumar, S., & Furuoka, F. (2024). Enhancing customer value co-creation and stickiness in social commerce: integrating PLS-SEM and NCA for deeper insights into customer-to-customer dynamics. *Humanities and Social Sciences Communications*, *11*(1), 46. https://doi.org/10.1057/s41599-023-02586-x

Zu, Q., & Yan, J. (2022). *Innovation Framework for Green Ports BT - Human Centered Computing* (Q. Zu, Y. Tang, V. Mladenovic, A. Naseer, & J. Wan (eds.); pp. 295–304). Springer Nature Switzerland.