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THE INFLUENCE OF PORT INFRASTRUCTURE AND SUPRASTRUCTURE ON PORT CONCESSION REVENUE THROUGH PORT OPERATIONAL PERFORMANCE

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Abstract

Optimizing port infrastructure and superstructure is critical to improving operational performance and increasing concession revenue. This study investigates how such optimizations influence port operations and their subsequent impact on financial returns from concessions. A quantitative research method is applied, questionnaires, literature review, and port operational data analysis. Infrastructure optimization covering hinterland connectivity, infrastructure quantity, and quality is hypothesized to enhance service efficiency for vessels, cargo, and port equipment. Similarly, superstructure optimization measured by technology adoption, quantity, and quality is considered vital in boosting operational productivity and service effectiveness. Operational performance is examined as a mediating variable linking infrastructure and superstructure improvements to concession revenue, while port policy is evaluated as a moderating variable that may strengthen or weaken this relationship. The findings confirm that port infrastructure positively influences operational performance, enhancing efficiency through integrated transport networks and well-maintained facilities. Additionally, infrastructure directly increases concession revenue by attracting business partnerships. Operational performance significantly boosts concession revenue by improving service reliability and competitiveness. Port superstructure, including advanced technologies like IoT and automated logistics, also enhances operational performance and directly contributes to higher concession revenue. Furthermore, both infrastructure and superstructure indirectly increase concession revenue through improved operational performance. These results underscore the strategic importance of investing in port infrastructure and superstructure to optimize operational efficiency and financial sustainability.

Keywords: Infrastructure Optimization, Superstructure Optimization, Operational Performance, Concession Revenue, Port Management.

INTRODUCTION

Indonesia, as an archipelagic country, relies heavily on ports as the primary means to support trade and logistics distribution. These ports play a crucial role as gateways for both domestic and international goods. However, despite their significant potential, port management in Indonesia continues to face various challenges, including operational inefficiencies, limited international competitiveness, and infrastructure constraints (Pranata & Utama, 2021).

These limitations include inadequate facilities, such as insufficient port depth to accommodate large vessels, and underdeveloped supporting infrastructure. Additionally, the lack of efficient routes and supporting infrastructure also hinders the distribution of fisheries and other commodities (Gunawan et al., 2019). To overcome these barriers, large-scale development and modernization of port infrastructure are essential to enhance regional accessibility, reduce high logistics costs, and promote more equitable economic growth across the country.

Optimizing both port infrastructure and suprastructure is a key factor in improving operational efficiency and global competitiveness. Inadequate infrastructure can lead to delays in logistics, higher operational costs, and reduced service quality for users (Heilig, Voß, & Lalla-Ruiz, 2017). Therefore, investing in modern infrastructure and suprastructure, along with the implementation of digital technologies, is a vital strategy to ensure the smooth flow of goods and vessels within ports (Zhou & Zhou, 2022).

In the context of logistics and supply chains, hinterland connectivity also plays a crucial role in supporting port optimization. Efficient hinterland infrastructure allows for faster distribution of goods and reduced logistics costs, ultimately enhancing national economic competitiveness (Rodrigue, 2020). Other studies have shown that strategies aimed at optimizing hinterland infrastructure can significantly improve port efficiency and capacity, while also contributing to the economic development of surrounding regions (Setyawan, 2019).

In terms of concession fee schemes, there is a notable difference between the model applied at the Port of Antwerp in Belgium and those in Indonesia. At the Port of Antwerp, a tiered system is used, where concession fees vary based on the level of investment, the area of land utilized, and the duration of terminal use. The higher the amount paid by private operators, the longer the duration of their terminal usage rights.

Table 1. Concession Fees at Indonesian Ports

No	Para Pihak	*Fee* Konsesi (%)	Jangka Waktu (Tahun)
1	Otoritas Pelabuhan Belawan dan PT. Pelabuhan Indonesia I (November 2015)	2,5%	30
2	Otoritas Pelabuhan Tanjung Priok dan PT. Pelabuhan Indonesia II (November 2015)	2,5%	50
3	Otoritas Pelabuhan Tanjung Peraak dan PT. Pelabuhan Indonesia III (November 2015)	2,5%	30
4	Otoritas Pelabuhan Makassar dan PT. Pelabuhan Indonesia IV (November 2015)	2,5%	30

Source: Final Report on Concession Study, 2024

In contrast, Indonesia applies a flat concession fee rate of 2.5% for a 30-year period, regardless of variables such as the land area granted to private operators. This flat fee model has the potential to create a significant revenue gap when compared to the tiered scheme used at the Port of Antwerp. Without a mechanism that takes into account factors like investment levels and land usage, the revenue generated from port concessions in Indonesia becomes less optimal in supporting sustainable development of port infrastructure and suprastructure.

This study not only aims to provide solutions for improving the quality of port services in Indonesia, but also contributes to national economic growth and strengthens Indonesia's position in global trade (Maiti, 2023). Based on the research focus, this study formulates research questions related to the effectiveness of port services in supporting service quality improvements and their contribution to national economic development.

LITERATURE REVIEW

1. Optimization

In the context of ports, optimization refers to efforts to enhance operational efficiency and effectiveness in order to maximize service capacity and minimize vessel and cargo waiting times. This involves the use of digital technologies, improved operational management, and infrastructure upgrades to boost global competitiveness (Rodrigue, 2020). Port optimization often includes the integration of data-driven and technology-based systems to streamline supply chain processes, lower operational costs, and ensure a smoother logistics flow. These efforts are commonly realized through automation, digitalization, and game theory-based coordination models among stakeholders (Heilig, Voß, & Lalla-Ruiz, 2017).

2. Port Management

Port management is defined as a set of practices and policies aimed at enhancing port performance through improved operational efficiency, good governance, and collaboration between the public and private sectors (Brooks & Pallis, 2012). It encompasses planning, organizing, and overseeing port systems to support global supply chains and ensure seamless connectivity between sea and land transport modes (Rodrigue, 2020). With the integration of digital technologies, modern port management has evolved to include real-time data management, cargo flow optimization, and cost reduction strategies (Heilig et al., 2017). Furthermore, contemporary port management addresses not only operational efficiency but also the adoption of sustainable strategies to minimize environmental impact and improve global competitiveness (Barros et al., 2021).

3. Port Infrastructure

Port infrastructure is a strategic approach aimed at expanding capacity and enhancing operational efficiency to meet increasing logistics demands. This infrastructure includes physical facilities such as docks, cargo terminals, loading and unloading systems, and land-sea access that supports global supply chain connectivity (Rodrigue, 2020). Optimizing port infrastructure involves both the expansion of physical capacity and the implementation of technologies that improve service efficiency. Key elements include dock modernization, increasing port basin depth, and effective ship traffic management (Notteboom & Yang, 2017).

4. Port Suprastructure

Port suprastructure focuses on improving terminal capacity and productivity through the use of automation technologies and digital integration. These efforts aim to reduce vessel turnaround time and enhance the efficiency of maritime supply chains (Rodrigue, 2020). Digital transformation in port suprastructure including the application of Internet of Things (IoT) technologies and big data analytics helps optimize operational workflows and improve the accuracy of cargo and ship traffic management (Heilig, Voß, & Lalla-Ruiz, 2017). Suprastructure development also involves adopting environmentally friendly technologies such as automated cranes and cold ironing to reduce carbon emissions and support sustainable port practices (Chang, Lee, & Tongzon, 2021). Enhancing the quality of suprastructure, such as upgrading cargo handling equipment and AI-based logistics management systems, can help reduce operational bottlenecks and improve a port's competitiveness in international trade (Notteboom & Yang, 2022).

5. Operational Performance

Operational performance refers to measurable achievements in providing services to ships, cargo, and the use of port facilities and equipment within a specific time frame and unit (Sari, 2023). It includes the quality of activities related to the flow and movement of goods from raw material supply to final product distribution to end consumers (Putra, 2023). Operational service performance encompasses the evaluation of progress toward strategic objectives in government organizations, involving the setting of goals, defining performance indicators, measuring outcomes, and assessing results (Atria, 2023). Operational performance also includes evaluating the efficiency and effectiveness of operations, such as assessing location suitability, public transport operations, and circulation within terminals (Yusuf, 2018).

6. Port Concession Revenue

Port concession revenue generally refers to all financial income generated from service and operational activities within the port area. This revenue comes from various key sources, such as docking and mooring services, cargo handling, land leasing, and other services provided by port operators (Notteboom & Winkelmans, 2015). Port revenue is typically categorized into *marine revenue*, which includes charges applied to ships and cargo operating within the port, and *non-marine revenue*, which is derived from commercial activities such as warehouse leasing, terminal rentals, and other property-based services (Rodrigue, 2020).

RESEARCH METHODS

This study adopts a quantitative method with a descriptive-analytical approach to examine in depth the level of port revenue generated through the concession scheme. A case study method is applied, as it provides a detailed picture of monitoring dynamics and enables thorough analysis of operational aspects influencing the effectiveness of concession management (Yin, 2018). This approach is considered relevant for understanding the specific context in Indonesia, given the diverse conditions of ports and the various challenges they face (Creswell & Poth, 2018). The population in this study includes Port Management, Terminal Operators, Port Service Users, and Regulators. The sampling technique used is non-probability sampling, a method that selects samples without randomization, thereby allowing the researcher to directly determine a total of 125 respondents. The sample size is based on Hair's theory, which considers the number of variables and indicators in the study to determine an appropriate sample size. Data collection was conducted using both primary and secondary sources. Primary data were obtained through the distribution of online questionnaires via Google Forms. Meanwhile, secondary data were gathered through literature reviews, including scientific journals, articles, reports, documents, books, and other academic sources. To test the hypotheses, this research employs Structural Equation Modeling (SEM) using SmartPLS software version 4.1.

This study investigates the influence of port infrastructure (X1) and port suprastructure (X2) on operational performance (Y1) and port concession revenue (Z), with operational performance serving as a mediating variable. Port infrastructure refers to physical facilities such as docks, transportation networks, and warehouses, while suprastructure includes supporting technologies such as IoT systems, automated handling equipment, and waste management systems. Operational performance is measured by service efficiency, including vessel waiting times and cargo handling speed, whereas concession revenue reflects income derived from facility rentals and business partnerships.

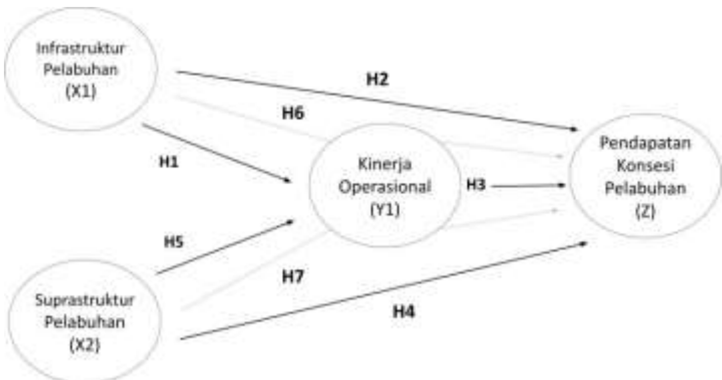

Figure 1. Research Framework

RESULTS AND DISCUSSION

Validity Testing

Based on the results of the validity test for each indicator (Port Infrastructure, Port Suprastructure, Operational Performance, and Port Concession Revenue), it was found that all loading factor values exceeded 0.50. Therefore, it can be concluded that all 18 indicators used to measure the respective variables (Port Infrastructure, Port Suprastructure, Operational Performance, and Port Concession Revenue) have met the criteria for convergent validity.

Table 2.Discriminant Validity (Fornell-Larcker Criterion) Test Result

	Port Infrastructure (X1)	Operational Performance (Y)	Port Concession Revenue (Z)	Port Superstructure (X2)
Port Infrastructure (X1)				
Operational Performance (Y)	0,626			
Port Concession Revenue (Z)	0,647	0,801		
Port Superstructure (X2)	0,632	0,756	0,739	

Source: Processed by Author (2025)

Based on the validity test results presented in Table 1, the cross-loading values of each indicator in this study were found to be higher for the construct they are intended to measure than for other constructs. This indicates that each latent construct is better at estimating the indicators within its own block compared to indicators in other construct blocks. Therefore, it can be concluded that all indicators used in this study have met the criteria for discriminant validity.

Realibility Testing

Table 3. Realibility Test Result

	Cronbach's alpha	Composite reliability (rho_c)
Port Infrastructure (X1)	0,967	0,973
Operational Performance (Y)	0,875	0,924
Port Concession Revenue (Z)	0,855	0,912
Port Superstructure (X2)	0,942	0,954

Source: Processed by Author (2025)

Based on the reliability test results presented in Table 2, the Cronbach’s Alpha values obtained for all constructs in this study including Port Infrastructure, Port Suprastructure, Operational Performance, and Port Concession Revenue are equal to or greater than 0.70. This indicates that the instruments used in this research demonstrate a high level of reliability. In addition, a composite reliability test was also conducted, with the results presented as follows:

Table 4. Composite Realibility Test Result

	Cronbach's alpha	Composite reliability (rho_a)	Average variance extracted (AVE)
Port Infrastructure (X1)	0,967	0,969	0,859
Operational Performance (Y)	0,875	0,876	0,802
Port Concession Revenue (Z)	0,855	0,857	0,775
Port Superstructure (X2)	0,942	0,942	0,776

Source: Processed by Author (2025)

Based on the reliability test results presented in Table 3, the composite reliability values for all five variables (with a total of 18 indicators) used in this study are above 0.70. This finding indicates that the instruments employed in this research can be considered reliable.

Inner Model Testing

Following the outer model assessment, the next step is to perform the inner model evaluation. The inner model assessment involves determining the coefficient of determination, followed by hypothesis testing.

1. Coefficient of Determination

The coefficient of determination (R^2) is measured as a percentage and ranges from 0.0 to 1.0. The closer the value is to 1.0, the higher the predictive accuracy of the model being used.

Table 5. Coefficient of Determination Values (R2)

	R-square	R-square adjusted
Operational Performance (Y)	0,513	0,505
Port Concession Revenue (Z)	0,570	0,559

Source: Processed by Author (2025)

Based on Table 4, the model for Port Concession Revenue shows a coefficient of determination (R^2) value of 0.968 or 96.8%, which falls into the strong category. In addition, the adjusted R-Square value for the Port Concession Revenue variable is 0.570 (57%), and for the Operational Performance variable, it is 0.513 (51.3%), both of which are also categorized as strong. Therefore, it can be concluded that the model used in this study is robust and demonstrates a high level of predictive accuracy.

2. Goodness of Fit (GOF)

Table 6. GoF

	AVE	*R-square adjusted*
Port Infrastructure (X1)	0,859	

Operational Performance (Y)	0,802	0,505
Port Concession Revenue (Z)	0,775	0,559
Port Superstructure (X2)	0,776	
Avarage	0,803	0,532

Source: Processed by Author (2025)

$$GOF = \sqrt{AvarageAVE \times Avarage\ RSquare}$$

$$GOF = \sqrt{0{,}803 \times 0{,}532}$$

GOF = 0,47

Based on the calculation results, the Goodness of Fit (GoF) value obtained is 0.47, indicating that the combined performance of the outer model and inner model in this study falls into the high GoF category.

Hypothesis Testing

Hypothesis testing was conducted to determine whether the independent variables namely Port Infrastructure and Port Suprastructure as well as the mediating variable, Port Operational Performance, have a direct or indirect effect on Port Concession Revenue. This analysis was carried out using Partial Least Squares (PLS) through the SmartPLS software version 4.1.0.0. Figure 2 below presents the path diagram generated from the hypothesis testing output based on Partial Least Squares (PLS) analysis using SmartPLS version 4.1.0.0.

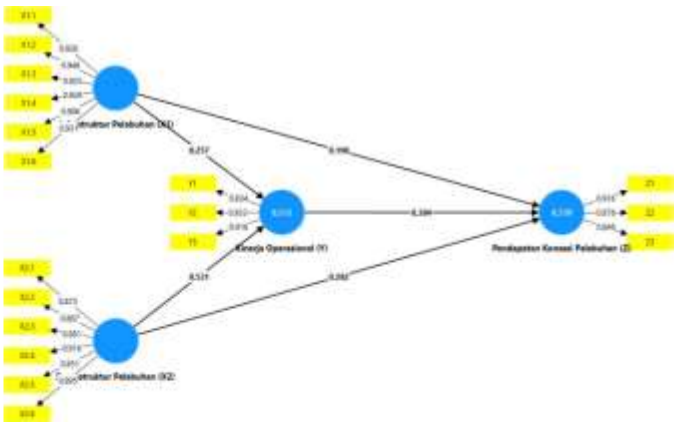

Figure 2. Path Diagram Output Results of Hypothesis Testing

Based on the data processed using SmartPLS version 4.1.0.0, as shown in the bootstrapping output in Figure 2 above, and presented in Table 7 displaying the direct effect test results, as well as Table 8 presenting the indirect effect test results, a more detailed explanation is provided as follows :

Table 7.Testing the Influence of Direct Output from Partial Least Square

	Original Sample	*Standard Deviation*	*T Statistics*	*Pvalues (1 Tail)*	Conclusion
Port Infrastructure (X1) -> Operational Performance (Y)	0,257	0,074	3,482	0,001	H1 accepted/supported

Port Infrastructure (X1) -> Port Concession Revenue (Z)	0,198	0,08	2,463	0,014	H2 accepted/supported
Operational Performance (Y) -> Port Concession Revenue (Z)	0,384	0,093	4,111	0,000	H3 accepted/supported
Port Superstructure (X2) -> Operational Performance (Y)	0,531	0,065	8,231	0,000	H4 accepted/supported
Port Superstructure (X2) -> Port Concession Revenue (Z)	0,282	0,094	3,02	0,003	H5 accepted/supported

Source: Processed by Author (2025)

1. Hypothesis 1

The test results show a p-value of 0.001, which is less than 0.05 (5% significance level), thus H1 is accepted. This statistical finding, with 95% confidence, confirms a positive effect of Port Infrastructure on Operational Performance. Based on this, it can be stated that Port Infrastructure plays a significant role in enhancing Operational Performance.

The results of Hypothesis 1 testing indicate that port infrastructure has a significant influence on operational performance. This suggests that the better the quality and availability of port infrastructure, the more optimal the operational performance achieved. The presence of well-integrated land transportation networks (such as roads, railways, and sea access), along with efficient hinterland support, has been proven to facilitate the smooth flow of goods into and out of the port. This leads to reduced vessel waiting times and faster loading and unloading processes. Additionally, adequate dock length and depth enable efficient servicing of vessels of various sizes, while optimal utilization of terminal and warehouse facilities further enhances overall logistics service efficiency. Regular infrastructure maintenance ensures long-term, sustainable service life, and the use of renewable energy supports operational reliability. Overall, these findings reinforce that well-developed port infrastructure is a crucial element in improving operational performance.

2. Hypothesis 2

The test results indicate a p-value of 0.014, which is less than 0.05 (5% significance level), therefore H2 is accepted. This statistical evidence, with 95% confidence, confirms a positive effect of Port Infrastructure on Port Concession Revenue. Consequently, it can be concluded that Port Infrastructure contributes to increasing Port Concession Revenue.

Hypothesis 2 results demonstrate that port infrastructure significantly impacts the increase in port concession revenue. This finding indicates that investments in well-connected land transportation networks and efficient hinterland infrastructure directly affect the port's attractiveness as a strategic business partner for terminal operators and service users. Physical infrastructure such as sufficient dock length and depth to accommodate vessels of various sizes, along with optimal utilization of port facilities like container terminals and warehouses, contribute to increased operational activities. This, in turn, boosts revenue potential through land leasing, warehouse rentals, and terminal concessions. Furthermore, maintaining infrastructure quality through routine care and integrating renewable energy sources add value to the port by establishing a reliable, efficient, and sustainable service system. Therefore, infrastructure optimization not only supports daily operations but also serves as a strategic tool for sustainably increasing port concession revenue.

3. Hypothesis 3

The test results reveal a p-value of 0.000, which is below 0.05 (5% significance level), so H3 is accepted. This statistical finding, with 95% confidence, confirms a positive effect of Operational

Performance on Port Concession Revenue. Hence, it can be concluded that Operational Performance contributes to increasing Port Concession Revenue.

The results of Hypothesis 3 confirm that port operational performance significantly affects the increase in port concession revenue. The findings show that ports capable of delivering efficient operational services reflected by shorter vessel waiting times, faster cargo handling, and optimal use of container stacking yards tend to earn higher trust and satisfaction from terminal operators and port service users. Such efficiency not only smooths the logistics flow but also enhances the port's competitiveness in attracting more commercial activities and concession partnerships. Superior operational performance creates added value for the port as a strategic logistics hub, thereby driving higher rental values for land, terminals, and warehouse facilities, as well as expanding revenue opportunities from various concession partners.

4. Hypothesis 4

The test results indicate a p-value of 0.000, which is less than 0.05 (5% significance level), thus H4 is accepted. This statistical evidence, with 95% confidence, confirms a positive effect of Port Suprastructure on Operational Performance. Accordingly, it can be concluded that Port Suprastructure improves Operational Performance.

Hypothesis 4 testing shows that port suprastructure has a significant influence on operational performance. The implementation of information systems supported by Internet of Things (IoT) technology and big data for real-time monitoring, along with automation in loading and unloading activities, effectively increases service efficiency and reduces vessel waiting times. The efficiency of handling equipment such as cranes and reach stackers, as well as the integration of logistics facilities with distribution centers, also accelerates cargo movement. Meanwhile, effective waste management and the adoption of green port concepts contribute to sustainable and environmentally friendly operations. Supported by a modern, sophisticated, and integrated suprastructure, ports are able to consistently maintain smooth and reliable operational performance.

5. Hypothesis 5

The test results show a p-value of 0.003, which is less than 0.05 (5% significance level), so H5 is accepted. This statistical finding, with 95% confidence, confirms a positive effect of Port Suprastructure on Port Concession Revenue. Thus, it can be concluded that Port Suprastructure increases Port Concession Revenue.

Hypothesis 5 results indicate that port suprastructure significantly affects the increase in port concession revenue. This suggests that the implementation of technologies such as IoT-based information systems, automated logistics processes, and the use of efficient cargo handling equipment can significantly improve port service productivity and reliability. These improvements increase the port's attractiveness to terminal operators and business partners. Additionally, integrating logistics facilities with distribution centers, along with applying sustainability principles such as green port initiatives and effective environmental management, helps position the port as more competitive and valuable in the eyes of investors and service users. This conducive environment ultimately drives increased demand for port services and opens wider opportunities for collaboration through terminal concession schemes, land leasing, and other logistics facility partnerships.

Table 8. Testing the Influence of indirect Output from Partial Least Square

	Original Sample	Standard Deviation	T Statistics	Pvalues (1 Tail)	Conclusion
Port Infrastructure (X1) -> Operational Performance (Y) -> Port Concession Revenue (Z)	0,099	0,037	2,667	0,008	H6 accepted/supported
Port Superstructure (X2) -> Operational Performance (Y) -> Port Concession Revenue (Z)	0,204	0,055	3,717	0,000	H7 accepted/supported

Source: Processed by Author (2025)

6. Hypothesis 6

The test results show a p-value of 0.008, which is less than 0.05 (5% significance level), thus H6 is accepted. This statistical finding, with 95% confidence, indicates a significant positive indirect effect of Port Infrastructure on Port Concession Revenue through Operational Performance. Based on this, it can be concluded that Port Infrastructure enhances Port Concession Revenue via Operational Performance.

The results of Hypothesis 6 confirm that port infrastructure has an indirect impact on increasing concession revenue through operational performance as a mediating variable. This means that well-developed infrastructure such as efficient hinterland connectivity, docks capable of accommodating vessels of various sizes, and well-maintained, sustainable port facilities positively contributes to improved operational performance. For example, these factors reduce vessel turnaround times, accelerate loading and unloading processes, and optimize terminal facility utilization. The improvement in operational performance then acts as a catalyst for attracting more economic activities, expanding concession partnerships, and increasing revenue from land leasing, terminal operations, and logistics services. Therefore, infrastructure plays not only a direct role but also serves as a strategic driver by enhancing operational efficiency.

7. Hypothesis 7

The test results show a p-value of 0.008, which is less than 0.05 (5% significance level), hence H7 is accepted. This statistical finding, with 95% confidence, indicates a significant positive indirect effect of Port Suprastructure on Port Concession Revenue through Operational Performance. Consequently, it can be concluded that Port Suprastructure increases Port Concession Revenue through Operational Performance.

Hypothesis 7 results indicate that port suprastructure has an indirect effect on increasing concession revenue through operational performance as a mediating variable. This suggests that the implementation of advanced technologies such as IoT-based information systems, automated cargo handling, and efficient use of operational equipment plays a vital role in enhancing port service quality. These technologies help reduce vessel waiting times, speed up container processing, and maximize port facility utilization. As operational performance efficiency improves, trust and confidence from terminal operators and service users grow. This increased trust fosters greater interest in concession partnerships and contributes to higher port revenue from various sources, including terminal leases and other logistics service

CONCLUSION

This study confirms that the low operational efficiency and concession revenue in Indonesian ports are significantly influenced by limitations in infrastructure and suprastructure, which constitute the root causes as identified in the background. Key findings reveal that inadequate infrastructure (such as short docks and limited transportation networks) and less modern suprastructure (such as minimal automation) directly hinder operational performance, resulting in high logistics costs and reduced competitiveness of Indonesian ports. The inflexible concession policy (a flat fee of 2.5%) also contributes to suboptimal revenue, whereas investment-based concession schemes like those in the Port of Antwerp could serve as sustainable funding sources for modernization.

The availability of adequate port infrastructure and suprastructure significantly impacts the increase in concession revenue. In port management, physical infrastructure elements such as docks, access roads, and efficient cargo handling facilities, along with suprastructure components like cranes, terminal management systems, and advanced information technology, are crucial in supporting smooth operational and logistics processes. These facilities not only enhance service efficiency but also strengthen the port's competitiveness in attracting terminal operators, service users, and business partners to invest through concession schemes (Bichou & Gray, 2005). Consequently, this directly improves overall port performance and indirectly increases concession revenue through increased cargo flows, optimized land use, and expanded supporting service offerings (Notteboom & Rodrigue, 2005).

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