Sustainability of Ship Operational Management Through Digital Servitisation: a Study of the Development of the Maritime Shipping Industry in Indonesia

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Abstract: In ship operations, spare parts management plays an important role in ensuring the availability of components required for ship maintenance, directly impacting downtime and improving operational efficiency. This research also analyses how digital servitization - a digital transformation that integrates technologies such as IoT and data analytics can strengthen spare parts management and improve the sustainability of ship operations. Data was collected through a questionnaire distributed to 36 respondents from shipping companies in Indonesia and analyzed using SmartPLS 4.0. The results showed that spare parts management significantly influences ship operations, both directly and through digital servitization as a mediating variable. Digital servitization is proven to strengthen the impact of spare parts management by improving the prediction of spare parts needs, accelerating replacement, and reducing ship operating costs.

Keywords: spare parts management, digital servitization, ship operations, efficiency, IoT

1. INTRODUCTION

The maritime industry is vital in supporting global trade with around 80% of the world's trade volume transported by sea. The sector provides efficient transport routes for essential commodities, fuelling economic growth and strengthening international connectivity. In addition, for island nations, the maritime industry plays a vital role in regional integration, logistics distribution, and national defense.

Ships are one of the high-value assets in the maritime industry, so to enhance their durability, continuous support for spare parts is essential for maintenance operations.

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The support will guarantee the accessibility and dependability of spare parts for their lifetime. In the maritime industry, ships play a crucial role in various transport service businesses, including passenger transport, cargo shipping, oil and gas activities, dredging, fishing, geophysical surveys, and military operations (González Chávez et al., 2024).

Spare parts logistics management plays an important role in the maritime industry to ensure optimal asset availability and reliability and keep operational costs under control at a reasonable level. Delays in the delivery of spare parts cause vessel operations to stop, resulting in a significant drop in revenue for the maritime industry. The turnover of ship spare parts is complex and costly, as ships are under sail, supply and demand points are spread across the globe, and timescales are tight, as well as multi-sectoral arrangements.

In the maritime industry, some regulations govern the specifications, technical guidelines, and operations of ships such as those set by the International Maritime Organisation (IMO) including SOLAS and MARPOL (Mouschoutzi & Ponis, 2022). Docking and ship surveys are mandatory for commercial vessels. Comprehensive ship maintenance and repairs are carried out during the period of dry-docking (Eruguz, Tan, & van Houtum, 2017). Then, maintenance activities, such as periodic surveys, docking surveys, intermediate surveys, and emergency surveys are the responsibility of the ship owner (Kian, Bekta, & Ouelhadj, 2018).

Furthermore, the technical condition of a ship directly affects its performance and financial results, as well as its resale value for its commercial aspects. Thus, the care and maintenance of ships is indispensable to ensure that ships meet international standards for safe and efficient transport services, provide a harmonized framework for global maritime trade, enhance trust between nations, and ensure fair competition in the shipping industry. Achieving these goals requires huge costs that range from 25-35% of the overall operational expenses of the maritime industries (Turan, 2009).

Typically, shipowners obtain spare parts for their vessels from international suppliers and store them in regional warehouses. These parts are transported to the port through different methods, including air, sea, or road freight. When the ship arrives at its designated port, the parts are delivered and utilized for maintenance on the vessel. For repairable parts of the ship's machinery, the parts are offloaded from the ship, repaired, and then sent back to the ship. Efficiently managing this logistics process is a significant challenge, which requires professional planning and distribution of spare parts for time and cost efficiency. Thus, delays in spare parts changeover cause considerable losses to the ship financially and operationally.

Following the COVID-19 pandemic, the maritime industry continues to evolve, aiming to enhance the adoption of advanced technologies and business models (Fruth and Teuteberg, 2017). This transformation is driven by factors such as heightened competition, rising customer expectations, the goal of reducing costs (Tijan et al., 2021), compliance with standards and regulations (Pinto et al., 2015), and the need for integration with interfacing systems (Ghaderi, 2019). Recent research highlights the importance of a servitization approach for improving the efficiency and sustainability of enterprises, particularly in transport services (Zhao et al., 2022). Thus, digital servitization is the right approach to improve the efficiency and effectiveness of the company because the approach is carried out by identifying the company's sustainability and designing comprehensively. It enables companies to remain competitive and improve service quality (Paschou et al., 2020). Many organizations are pursuing sustainability goals that can be achieved through servitization (Yang et al., 2017; Aiello et al., 2020).

Research on digital servitization in the maritime industry is still developing, including the exploration of digital capabilities required in the shipping sector (Pagoropoulos et al., 2017) and emerging digital technologies like blockchain (Zhao et al., 2022), autonomous solutions (Makkonen et al., 2022), and service-design methods for smart Product-Service Systems (PSS) (Solem et al., 2022). The maritime shipping sector is known for its complexity, involving numerous stakeholders who can leverage digital services to enhance value delivery, gain a competitive edge, and promote more sustainable practices. However, there remains a gap in understanding the key drivers and barriers influencing these business models. This research examines:

RQ_1: How does spare parts logistics management affect ship operational management?

RQ_2: How does digital servitization affect ship operational management?

RQ_3: How does spare parts logistics management influence digital servitization?

RQ_4: How does spare parts logistics management affect ship operational management with mediation using digital servitization?

To answer this question, the literature review section presents a theoretical framework for the concept of digital services and contextualizes it in the maritime transport industry, followed by spare part logistics management to be implemented in ship operational management. Then in the research method section, the stages of conducting research are explained along with the data processing techniques used in this study. In the discussion section, the results of the case study are reviewed, then the theoretical and empirical implications related to the research results. Finally, the conclusion of this study is presented.

2. LITERATURE REVIEW

DIGITAL SERVITIZATION

Servitisation and digitalisation are two keywords for industrial upgrading today (Tronvoll et al., 2020). Servitisation is described as the process of transformation from a product-focused business model to a service-oriented approach (Kowalkowski et al., 2017). In this study, digitalization is characterized as the application of digital technologies to reshape business models and create opportunities for generating new revenue and value (Bloomberg, 2018). Digitalization is viewed as a key enabler of servitization, as it is essential for defining the offering and facilitating a more comprehensive and detailed service portfolio (Pezzotta et al., 2022). In addition, digitization provides more complete data on the activity cycle through databases and analytics designed (Cenamor et al., 2017), to enable companies to be more efficient, adaptable, and effective in meeting customer needs appropriately (Xin and Ojanen, 2017). Typically, digitalization and service are studied separately (Paschou et al., 2020), creating a gap between digital transformation and adaptation processes (Luz Martín-Pena and others, 2018).

Several recent studies have shown that the commonly understood product-centric business model does not guarantee the success of the Company, thus the need for digitalization of services (Kindstrom, 2010). Digital services consist of a blend of new technologies, connectivity, and data analysis offered through a unified platform to generate new sustainable value by developing an integrated product-service-software system (Kohtamaki et al., 2019). Implementing digital servitization offers sustainability advantages for companies (Paiola et al., 2021), including facilitating the shift towards a circular economy through dematerialization and more efficient utilization of physical assets (Hojnik, 2018; Hallstedt et al., 2020).

The implementation of digital services necessitates the participation of shipping associations, governments, transport ministries, and port authorities, as most companies promptly comply with established regulations (Fasoulis and Kurt, 2019 a,b; Jović et al., 2020). Additionally, digital services can harmonize environmental and economic sustainability (Reim et al., 2015; Bocken et al., 2016), enhancing stakeholder loyalty, optimizing resource utilization, fostering transparent communication, boosting competitiveness, driving commoditization, and promoting collaboration (Rabetino et al., 2018).

The ongoing rise in digitalization is a key factor fueling the growth of digital services in the maritime sector. Furthermore, the implementation of relevant technologies in the shipping industry has become an obligation for the sustainability of companies, such as remote monitoring, cloud computing, cybersecurity, big data, real-time connectivity, and digital platforms, has become essential for sustaining companies (Toth et al., 2022). Another aspect behind the process of adopting digital services in maritime is the increasing focus on environmental issues. For instance, sulfur regulations and efforts to achieve zero emissions have been addressed through various agreements, creating mutual benefits, such as shared savings among stakeholders (Olaniyi and Gerlitz, 2019). Nonetheless, this business model poses challenges for long-established companies in the maritime sector, resulting in tensions, paradoxes, and contradictions (Sandvik et al., 2022). Innovation in shipping is driven by connectivity, digitalization, and traceability (Alcayaga et al., 2019). Despite the transformative potential of digital technologies in reshaping supply chains, the maritime sector still faces several limitations.

The transformation of digital services requires the involvement of many stakeholders (Kim et al., 2020) to identify technical needs on an ongoing basis to implement the company plan (Del Giudice et al., 2022). The implementation of digital services in the maritime sector has many challenges, such as the need for large networks (Simmons and McLean, 2020), handling the availability and management of significant volumes of data (Aiello et al., 2020), that can hinder innovation in digital business models, seafarers' knowledge and experience are difficult to access in digital information systems. Addressing these obstacles requires the development of managerial technologies (Simmons and McLean, 2020) that can leverage data services and technological expertise to promote innovative and sustainable solutions through informed decision-making (Koilo, 2021).

Sustainable business models in the maritime industry are well established, including transport services that adhere to new environmental regulations (Schiavone et al., 2022). The connection between the shipping industry and sustainability issues has become a significant area of research, particularly regarding technological innovation solutions that align economic growth with environmental protection (Del Giudice et al., 2022). So far, there have been few empirical studies examining the advancement of sustainability through digital services (Poulakidas, 2014; Wahab et al., 2018).

SPARE PARTS LOGISTICS MANAGEMENT

A crucial aspect of maintenance is having spare parts available. Spare parts refer to machine components kept on hand for repairing or replacing damaged machinery parts. Then, spare parts logistics is defined as the planning, design, realization, and control of the supply and distribution of spare parts, along with the information systems of a company and its network partners (Wagner, Jönke, & Eisingerich, 2021). Spare parts logistics aims to provide the necessary components for maintenance, ensuring an optimal level of tool availability while maintaining stable logistics costs through efficient operational activities.

Maritime resources can be viewed as a collection of technical systems organized in a multi-tiered structure (Eruguz et al., 2017). Ships, as part of maritime resources, can operate effectively and efficiently when regular maintenance and repairs are conducted. This results in certain damaged components being replaced with new, identical, and ready-for-use (RFU) parts. The strategy is part of 'repair-by-replacement' (van Houtum & Kranenburg, 2015). Currently, this treatment is not feasible. For example, when a ship suffers damage to the hull, it must stop operating for docking. Consequently, the company incurs losses when the vessel is not operational, making the availability of spare parts as crucial as the ship itself. Therefore, managing the supply chain and logistics of ship spare parts, ranging from procurement to delivery to the vessel, is a crucial element of an effective ship maintenance strategy.

Maintenance can be classified into two categories: corrective maintenance (CM) and preventive maintenance (PM). CM involves maintenance tasks conducted after a component has failed, while PM consists of activities performed to prevent damage and keep a component in a specific condition (Wang, 2002). PM can be further categorized into usage-based maintenance and condition-based maintenance. Usage-based maintenance is a conventional approach where equipment is repaired or replaced based on usage, with the assessment of usage determined by the time the equipment has been in operation.

Condition-based maintenance (CBM), in contrast, can be executed through either regular inspections or condition monitoring, often referred to as predictive maintenance. Additionally, CBM involving condition monitoring is a maintenance program that suggests actions based on data collected from sensors within a defined system (Ahmad & Kamaruddin, 2012). Traditional inspections involve checking equipment at set intervals, while condition-based monitoring permits ongoing observation of the equipment's status. Generally, the most suitable method for evaluating the condition of equipment depends on its specific characteristics. For instance, metal components can be visually inspected to assess the quantity and length of cracks (Pook, 2007). Therefore, a combination of corrective maintenance (CM) and preventive maintenance (PM) is more effective for maintenance and enhancing the availability of spare parts concerning operational time and maintenance expenses (Tomlinson, 2015).

RESEARCH METHODS

The type of research used in this study is quantitative research. This research design uses cross-sectional, namely research on independent, moderating, and dependent variables measured at the same time (John W. Creswell, 2010: 5). The variables used in this study are presented in the following figure.

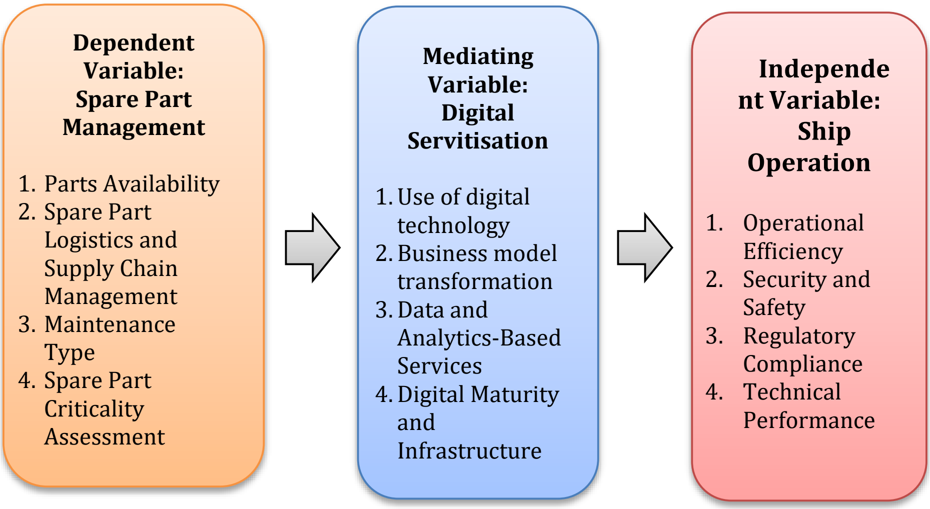

Figure 1: Research Variables

To obtain relevant, complete, and accurate data, two kinds of data sources are used, namely primary data and secondary data. Primary data is in the form of questionnaires directly filled out by shipping companies in Indonesia, then secondary data is in the form of documents and regulations relating to the variables studied. The sample used was 36 shipping company employees. The questionnaire used refers to the instrument grid presented in the table below.

Table 1. Instrument of research

No.	Variable	Dimension	Indicator	Symbol
1.	Spare Part Management	Parts Availability	Stock Level	AV1
			Fulfilment Time (Lead Time)	AV2
			Minimum inventory quantity optimization (Safety Stock)	AV3
		Spare Part Logistics and Supply Chain Management	Distribution Efficiency	SCM1
			Demand Forecast Accuracy	SCM2

		Maintenance Type	Maintenance Schedule Compliance Level:	MT1
			Spare Parts Replacement Quality	MT2
		Spare Part Criticality Assessment	Classification of spare parts by operational criticality	SCA1
			Determination of spare parts that impact ship downtime	SCA2
			Frequency of use of spare parts in a given period	SCA3
2.	Digital Servitisation	Use of digital technology	Digital Platform Utilisation	DT1
			System Connectivity and Integration	DT2
			Cloud deployment for data storage and processing.	DT3
		Transformation of business models	Customer Satisfaction with Digital Services:	BT1
			Business Model Innovation Rate	BT2
			Digital Service Development	BT3
		Data-based services	Real-time Operational Data Collection	DAT1
			Predictive Analytics for Maintenance	DAT2
			Service Personalisation through Data	DAT3
		Digital Maturity and Infrastructure	Digital Maturity Level	DM1
			The scale of Digital Infrastructure Investment	DM2
			Adoption of Modern Digital Platforms	DM3
3.	Ship Operation	Operational Efficiency	Efficient Use of Energy	OE1
			Operational Time Efficiency	OE2
		Security and Safety	Safety Protocol Compliance	SS1
			Crew Training and Preparedness	SS2
		Regulatory Compliance	Compliance with International and National Law	CR1
			Fulfillment of Maritime Certification and Standards	CR2
		Technical Performance	Ship Technical Readiness	TP1
			Routine Maintenance Sustainability	TP2

The data analysis technique uses path analysis with SmartPLS software version 4.0. The equation model used is Structural Equation Modeling (SEM) with a variance-based approach or component-based structural equation modeling. Mathematical analysis is needed to describe and forecast an existing phenomenon (Fahcruddin, 2023). PLS-SEM analysis consists of two sub-models, namely the outer model and the inner model. Outer model evaluation is carried out with validity tests including convergent validity and discriminant validity. Convergent validity is determined using the loading factor parameter and the AVE (Average Variance Extracted) value. Discriminant validity is determined by looking at the cross-loading of each variable and is categorized as having discriminant validity if it has a cross-loading value of more than 0.7 and/or an AVE value of more than 0.5. The AVE value is determined using the formula:

$$AVE = \frac{\left(\sum \quad \alpha_i^2\right) var\ F}{\left(\sum \quad \alpha_i^2\right) var\ F + \sum \quad \delta_{ii}}$$

with α_i as factor loading, F is factor variance, δ_{ii} is error variance. Furthermore, the outer model evaluation criteria are presented in the following table (Ghozali, 2021).

Table 2. Summary of Outer Model Testing

Validity and Reliability	Parameters	Description
Convergent Validity	Loading Factor	Loading Factor > 0.70
	AVE	AVE > 0.50
Discriminant Validity	Cross Loading	Cross Loading > 0.70 for each variable
Reliability	Cronbach's Alpha	Cronbach's Alpha > 0.70
	Composite Reliability (CR)	Composite Reliability > 0.70

Then to show the relationship or estimation strength between latent variables or constructs based on substantive theory, outer model testing is used which fulfils the following criteria.

Table 3. Summary of Inner Model Testing

Parameters	Description
R-Square	R-Square values of 0.75, 0.50, and 0.25 can be concluded that the model is strong, moderate, and weak.
Effect Size f^2	The f-square values of 0.02, 0.15, and 0.35 can be interpreted as whether the latent variable predictors have a weak, medium, or large influence at the structural level.
Q^2 predictive relevance	If the value of $Q^2 > 0$ indicates the model has predictive relevance, while if $Q^2 < 0$ indicates the model does not have predictive relevance.
Goodness of Fit (GoF)	$GoF = \sqrt{\underline{AVE} \times \underline{R^2}}$ with $\underline{AVE}$ is the average AVE and R^2 is the average R-Square. The criteria used are 0.1 (low GoF), 0.25 (medium GoF), and 0.36 (high GoF).

3. DISCUSSION

DATA DESCRIPTION

Data collection was carried out by distributing questionnaires to respondents who worked in shipping companies in Indonesia. The total of 36 respondents with the following description of the respondents.

Table 4. Characteristics of Respondents

Respondent Characteristics	Total	(%)
Position		
Chief Mate	18	50
KKM	18	50
Gender		
Male	32	89
Women	4	11

Table 4 shows that the respondents' positions have the same percentage, namely chief mate and KKM (50%) so that the respondents' daily activities are closely related to the statements in this study. Furthermore, the male gender dominates respondents (89%) so that respondents have free time and are more focused on answering the questionnaire.

INNER AND OUTER MODEL MEASUREMENTS

From the SmartPLS 4.0 output, the results show that there are 2 statements whose outer loading value is less than or equal to 0.7, namely DT1 and BT3 so these indicators in the digital servitization variable are excluded from the study and then retested for convergent validity so that the outer loading value in the study is greater than 0.7. Then, all indicators that make up each variable in the study meet discriminant validity, namely the cross-loading value exceeds the value of 0.7. Then, all indicators that make up each variable in the study fulfill discriminant validity, namely, the cross-loading value exceeds the value of 0.7. Furthermore, the results of the inner model and outer model measurements are presented in the following table.

Table 5. Inner Model and Outer Model Measurements

Variable	AVE	CR	Cronbach's Alpha	R^2
Spare Part Management	0,611	0,932	0,928	
Digital Servitisation	0,440	0,899	0,877	0,734
Ship Operation	0,565	0,893	0,888	0,829

Table 5 shows that the composite reliability value is more than 0.7, then the Cronbach's Alpha value above shows a value above 0.6 so the measurements in this study are reliable. Furthermore, the R-square value for the digital servitisation variable is 0.734. This means that the percentage of the influence of digital servitization is 73.4% while the remaining 25.1% is influenced by other factors. Then, the percentage of the influence of ship operations is 82.9% while the remaining 17.1% is influenced by other factors. Furthermore, the inner model built in this model falls into the strong category. Then the f-square in this article is presented in the following table.

Table 6. f-square value

Variable	Ship Operation
Spare Part Management	0,279
Digital Servitisation	0,681

Because the f-square value of spare parts management> 0.15, the spare parts management variable has a medium effect in the model, then the f-square value of digital servitization> 0.35, the digital servitization variable has a large effect (Ghozali, 2021). From the results of testing Q^2 predictive relevance in smartPLS, the Q^2 value is more than zero, so the model has predictive relevance. The results of testing Q^2 predictive relevance in smartPLS are obtained as follows.

Table 7. Q-testing² predictive relevance

Variable	SSO	SSE	$Q^2(= 1 - SSE/SSO)$
Spare Part Management	360,000	360,000	0,000
Digital Servitisation	432,000	302,191	0,300
Ship Operation	288,000	156,311	0,457

The goodness of fit assessment can be known through the GoF value using the formula:

$$GoF = \sqrt{\underline{AVE} \times \underline{R^2}} = \sqrt{0{,}539 \times 0{,}521} = 0{,}56$$

Because the value of GoF is 0.56 in the high category, it can be concluded that the model has a large GoF and the greater the GoF value, the more suitable it is in describing the research sample. So, the structural model in the study has good goodness of fit. Further evaluation of the inner model by looking at the path diagram which shows how much influence the independent variable has on the dependent variable.

In Figure 2, it can be seen that the direct effect of the spare part management variable on ship operation is quite small, namely 0.376. Meanwhile, the direct effect of spare part management on digital servitization is quite large at 0.857. Then the direct effect of the digital servitization variable on ship operation is positive at 0.588. Therefore, the implementation of digital servitization has a considerable indirect effect on improving spare part management on ship operations.

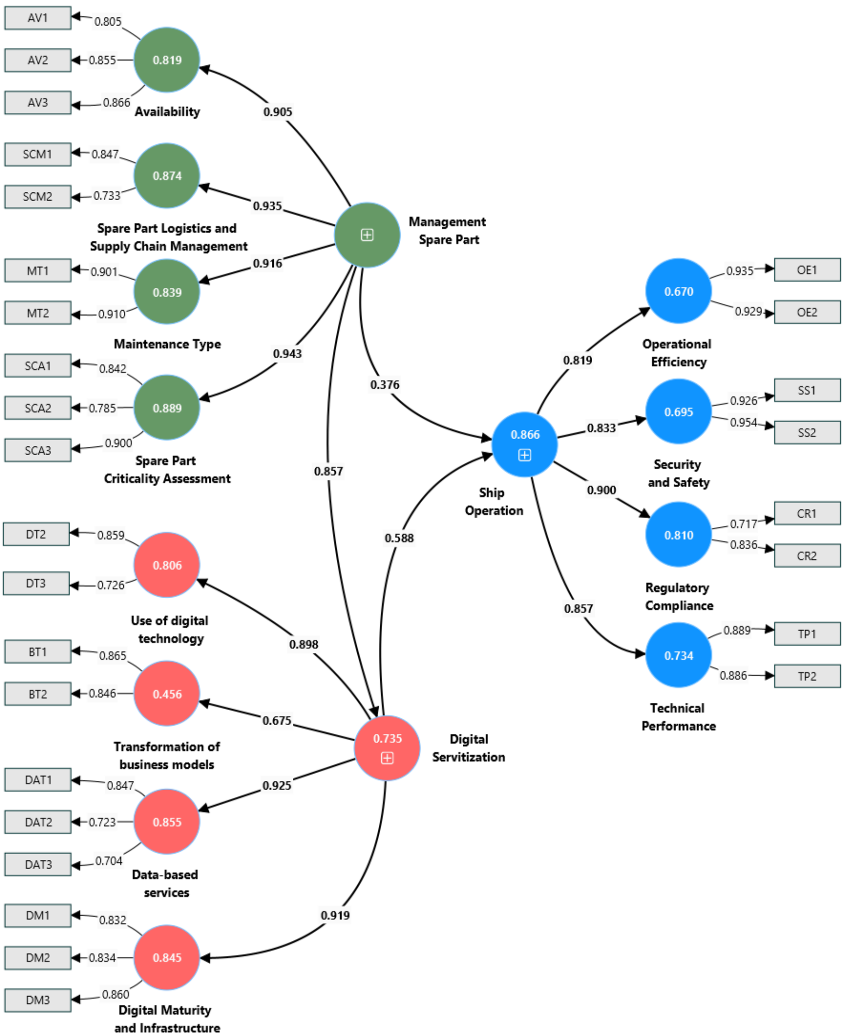

Figure 2. Path diagram in the model

In the model analysis, the spare part critical assessment dimension in spare parts management shows the highest factor loading of 0.943, so this aspect is considered very important by respondents. Indicator MT2 under the maintenance type dimension has the highest factor loading of 0.910, indicating that spare parts replacement quality is a factor that must be maintained. Conversely, the transformation of the business model dimension has the lowest factor loading of 0.675 so it needs to be improved. The DAT3 indicator in the data-based services dimension also has the lowest factor loading of 0.704, indicating that the personalization of services through data must be improved to increase digital servitization. Then testing the influence and significance of each variable is presented in the following table.

Table 8. Hypothesis Test

Path	T Statistics	P Values	Description
Spare Part Management → Digital Servitisation	18,966	0,000	Significant
Spare Part Management → Ship Operation	2,152	0,031	Significant
Digital Servitisation→ Ship Operation	3,394	0,001	Significant
Spare Part Management → Digital Servitisation → Ship Operation	3,597	0,000	Significant

After analyzing the data using SmartPLS 4.0, the following discussion results were obtained.

THE INFLUENCE OF SPARE PART MANAGEMENT ON DIGITAL SERVITISATION

From the results of hypothesis testing, it is concluded that there is a positive and significant influence between spare parts management on digital servitization of 0.857. Spare parts management can run effectively and efficiently if supported by the implementation of Digital Servitization. Well-managed spare parts, from procurement to maintenance, require the implementation of digital transformation so that real-time data and comprehensive monitoring of spare parts conditions are obtained through technologies such as the Internet of Things (IoT) and Big Data Analytics (Paschou, 2020). Digital servitization, which combines digital technology-based services with service business models, relies heavily on data availability, predictive maintenance, and operational optimization supported by efficient spare parts management (Rabetino, 2018).

Digital servitization requires companies to shift from a product-focused business model to one that focuses on technology-based services (Cenamor, 2017). In this context, spare parts management facilitates that transformation process by providing the necessary components and information for predictive maintenance and more efficient equipment management. Quickly and timely available spare parts are helpful in the maintenance process, which directly contributes to the success of digital servitisation.

INFLUENCE OF SPARE PART MANAGEMENT ON SHIP OPERATION

From the results of hypothesis testing, it is concluded that there is a positive and significant influence between spare parts management on ship operation of 0.376.

Proper spare parts management is essential to ensure ship operations run smoothly and efficiently. In the maritime industry, spare parts that are not available on time or are poorly managed can cause significant ship downtime, hinder operations, and increase operating costs. Spare parts management ensures ships have the necessary components for corrective maintenance (CM) and preventive maintenance (PM), ultimately minimizing disruptions in a ship's daily operations. Efficient management enables quick replacement of spare parts to reduce vessel downtime (Wagner, 2018). Good spare parts management plays an important role in maintaining a ship's operational efficiency. With the availability of spare parts always maintained, repairs can be made more quickly when damage occurs or during routine maintenance. This reduces downtime and allows the vessel to return to service as quickly as possible.

One of the main effects of good spares management on ship operations is a reduction in operating costs. Poor spare parts management can lead to urgent spare parts needs having to be met through more expensive means, such as emergency deliveries or unplanned purchases from suppliers. On the other hand, efficient spare parts management helps in planning purchases and inventories well, thus avoiding unnecessary costs.

The operational reliability of a vessel is highly dependent on the technical readiness of the spare parts used in maintenance. Good spare parts management ensures that parts that are critical to ship operations, such as engine components or navigation equipment, are always available when needed. This increases the operational reliability of the vessel and reduces the risk of technical failures during the voyage. Poor spare parts management increases a vessel's operational risks, including potential damage leading to accidents, technical failures, or delays. With proper spare parts management, ships can minimize operational risks through good maintenance and timely replacement of spare parts (Tomlinson, 2014).

THE INFLUENCE OF DIGITAL SERVITISATION ON SHIP OPERATIONS

From the results of hypothesis testing, it is concluded that there is a positive and significant influence between digital servitization on ship operation of 0.588. Digital servitization changes ship operations through the application of digital technology that allows companies to manage and monitor ship activities more efficiently. Ship Operations benefit from digital servitization which includes the use of technologies such as IoT, Big Data, cloud computing, and real-time connectivity (Cenamor, 2017). With digital servitization, ship operations can be monitored in real-time, including engine condition, cargo performance, as well as predictive maintenance that prevents major damage while the ship is sailing. Data collected from digital systems allows ship captains and management teams to make faster, data-driven decisions, improving operational efficiency as well as vessel safety (Tronvoll, 2020).

Digital servitisation is changing the approach to ship maintenance from reactive maintenance to predictive maintenance. Through data-driven monitoring and predictive analysis, shipping companies can predict when ship parts or components need to be replaced before damage occurs. This reduces ship downtime, allowing vessels to operate longer without interruption.

The use of digital technology in servitisation enables shipping companies to optimise fuel usage. IoT technology connected to a ship's fuel system can provide real-time data on fuel consumption, which helps ship management to set optimal cruise lines, ship speed, and load. Digital servitisation also plays a role in improving the safety and security of ship operations. Digitally connected systems enable continuous monitoring of vessel conditions, including safety systems such as leak sensors, fire alarms, and navigation systems. This information can be sent to the control center ashore, allowing the management team to take swift action when risks are detected.

THE INFLUENCE OF SPARE PART MANAGEMENT ON SHIP OPERATION MEDIATED BY DIGITAL SERVITISATION

From the results of hypothesis testing, it is concluded that there is a positive and significant influence between spare parts management on ship operations mediated by digital servitization. Digital servitization, which integrates digital technology in business services (Paiola, 2021), acts as a link between spare parts management and ship operational performance. This process amplifies the impact of spare parts management by optimizing the use of digital technologies to support more efficient, safe, and sustainable operations.

Effective Spare Part Management ensures that spare parts are available on time for maintenance. When digital servitisation is the mediator, this process is optimised as ship maintenance is supported by real-time data and predictive analytics obtained from digital systems such as the Internet of Things (IoT) and big data analytics. These systems enable more precise spare parts management, predict spare parts requirements, and facilitate spare parts replacement before major damage occurs (Cenamor, 2017). In a system supported by digital servitization, spare parts management can be done more efficiently through automation and data integration. Digital servitization enables centralized and automated management of spare parts inventory. The process of ordering, shipping, and distributing of spare parts is integrated with the digital system, which ensures that spare parts needed for maintenance are available on time and without delay.

One of the advantages of digital servitisation in supporting spare parts management is predictive maintenance. Real-time data collected from sensors on ships can be processed and analyzed to predict when certain components or parts will require replacement. This allows shipping companies to make replacements before the component breaks down, which reduces the risk of operational failure and improves the operational reliability of the ship (Kohtamäki, 2019).

Spare parts management coupled with digital servitisation enables shipping companies to proactively manage spare parts stocks. The digital system assists in planning spare parts requirements based on historical usage data and analysis of vessel operational trends. This ensures that the necessary spares are always available, which reduces the risk of downtime due to spares shortages. Digital servitization enables data-driven decision-making to improve ship operational efficiency. Data obtained from digital systems connected to ship parts and maintenance provide important insights for ship management to make more informed and faster decisions. This includes decisions related to maintenance, cruise routes, energy usage, and parts replacement (Eruguz, 2017).

The effect of spare parts management on ship operations mediated by digital servitisation is also evident in the improvement of operational efficiency and cost reduction. When spare parts are available on time through an integrated digital system, ship operations become more efficient. This implies a reduction in emergency repair costs, fuel savings through route optimization, and a reduction in costly vessel downtime.

4. Conclusion

This research shows that spare part management has a positive influence on ship operation, both directly and through the mediation of digital servitization. Effective spare part management improves ship operational efficiency, reduces downtime, and minimizes unexpected repair costs. In addition, digital servitization acts as an important link that amplifies the impact of spare part management by leveraging digital technologies such as IoT and big data analytics. Through this integration, predictive maintenance, real-time condition monitoring, and automated stock management enable vessel operations to run more efficiently, safely, and in compliance with maritime regulations.

Shipping companies should more widely adopt digital technology to enhance ship operations, particularly in predictive maintenance and data-driven spare parts management. Then, spare parts management should be enhanced through automation and improved data integration to ensure optimal availability of spare parts during ship operations. Furthermore, the implementation of digital servitization requires the involvement of various parties, including the government and port authorities, to ensure that the regulations and technology implemented are in line with international maritime standards.

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