Developing Smart Port with Crucial Domains and Indicators in the Thai Port Case: A Confirmatory Factor Analysis

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The port is an important transportation hub of maritime transport, recently developing smart ship transport for the smart port. Therefore, smart port indicators (SPIs) are crucial for smart port development. Applying SPIs for port management improves the overall port performance, reduces environmental pollution, as well as promoting port safety and innovation. This research aims at confirming the smart port indicators and defining the primary strategies for smart port performance in Thailand. We have employed a questionnaire survey as a method of data collection. Descriptive statistical analysis of respondents' general information and confirmatory factor analysis (CFA) has been used to test the key domains and indicators for confirming the dominant and verify the relationship of these indicators to the domains to which the indicator belongs. The results obtained comprise three main domains: smart port operation, smart port environment/energy, and smart port safety/security, using primary nineteen SPIs measurements. Furthermore, this research results have succeeded in introducing port operation to performance management in smart ports, thereby ensuring and facilitating port practice planning.

KEY WORDS
~ Maritime transport
~ Smart port performance
~ Smart port indicators
~ Smart port environment
~ Smart port safety
~ Smart port operation

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1. INTRODUCTION

Maritime transport, being the primary transport mode, is extremely important to supporting global logistics and supply chains (Kong and Liu 2021; Puig and Darbra 2019; Rodrigues et al. 2021). However, according to UNTCAD (2020), maritime transport has decreased due to the coronavirus disease (COVID-19) pandemic, and is expected to recover and expand in 2021. COVID-19 has forced the global economy to become reduced to a contactless life, including the maritime industry, and the global logistics and supply chain pattern will probably begin to increase after the COVID-19 era (Othman, et al 2022; Keshta, et al 2020). A smart port is a solution to support a new trend, redesigning global logistics and supply chain, as well as contactless global trade. A smart port is a port that uses automation and integrates the 4th industry revolution (IR 4.0) technologies, including AI, Big Data, IoT, and Blockchain for port management (UNESCAP, 2021; Kosiek et al., 2021; Re, H and Vnl, O, 2016), with a view to improving port operational efficiency, safety, security, energy efficiency, and environmental impact.

A smart port indicator (SPI) is a tool for indicating, measuring, and encouraging smart port performance (Makkawan and Muangpan, 2021; T.H. Yen et al, 2022; Douaioui et al., 2018), and can be used for port management, transformation, and development. Therefore, SPIs must meet their purpose and be comparable, competitive, reliable, and manageable (De Monie, 1988; González et al., 2020). Since a smart port represents a new trend (González et al., 2020; Karaś A, 2020), only a few researchers, who have focused on and are involved in a smart port indicator, such as González et al. (2020), have studied and developed smart port indicators for measuring and applied them for ranking of Spanish smart ports. Zhao et al. (2020) proposed key performance indicators to evaluate and measure the functions of smart technologies in the coal part of Huanghua Port.

In Thailand, the smart port has recently been introduced in the maritime industry and is still in its early stages. The government is trying to develop and transform them into smart ports (DEPA. 2020). The developing infrastructure and advanced integrating technology for port transformation are to be adopted in some terminals. However, since the smart port transformation has begun, there is still a lack of suitable SPIs to assess building up a smart port in its beginning stage in Thailand.

Previously, a smart port conceptual model was developed, focusing on three domains to measure, encourage, and indicate the smart port performance academically in a case study of The Eastern Economic Corridor (EEC) in Thailand (Makkawan and Muangpan, 2021). The model has three domains: smart port operation, smart port environment/energy, and smart port safety/security, consisting of 29 indicators. Therefore this research aims at practically confirming a conceptual model and defining Thailand's primary strategies for smart port performance. Furthermore, SPIs support foundation knowledge, including guiding the ports and terminals in their development/transformation towards meeting the international standards and world regulations.

2. LITERATURE REVIEW

The smart port can be a fully automated port that integrates innovative technologies and performs digital transformation (UNESCAP, 2021). Furthermore, the smart port will encourage improved productivity and efficiency by using IR4.0 technologies, including 5G, IoT, big data, and eco-friendly technology (Zhao et al., 2020; Jun et al., 2018; Ferretti and Schiavone, 2016). New technologies must be applied to transform a seaport to a smart port (González et al.,2020). The development of the port can be divided into four stages: Stage 1: port informatisation, Stage 2: automatic port, Stage 3: digital port, and Stage 4: smart port (UNESCAP,2021). Smart port indicators will be a tool to assess the level of port development, port transformation, and port performance. There are several research approaches to smart port indicators. González et al. (2020) analysed Spanish ports and defined smart port indicators using the Delphi method. They classified smart port indicators into four pillars, i.e., Operational economic (8 indicators), Social (7 indicators), Political & Institutional (8 indicators), and Environmental (9 indicators). Durán et al. (2019) proposed smart port domains to be classified into the following four groups: cyber, social, technological, and cognitive. In addition, Philipp (2020) studied the digital readiness index for seaports and classified it into five dimensions: management, human capital, functionality (IT), technology, and information.

Makkawan and Muangpan (2021) have developed smart port indicators (SPIs), classifying them into three key domains: smart port operation (11 SPIs), smart port environment/energy (11 SPIs), and smart port safety/security (7 SPIs).

The first domain, smart port operation, was developed using eleven leading indicators: port productivity and efficiency including terminal management efficiency (output/input, throughput) (OPR1), yard management efficiency (output/input, throughput) (OPR2), integrated smart technology in terminal management, such as IoT, Big Data, Cloud, Edge computing, Robotics, 5G, etc. (OPR3), availability of digital platforms for exchanging information among stakeholders in the port community (Cloud, Blockchain, etc.) (OPR4), capacity and smart technology for terrestrial connectivity (roads, railways) (OPR5), availability of automation in quayside cranes, yard gantry cranes, and equipment for internal cargo movement (AGV, ASC, QC, robots, etc.) (OPR6), availability of real time weather data analysis (OPR7), digitisation in customs processes (Customs single window) (OPR8), integrated technology in port traffic and roads control, such as RFID, WSN, OCR, real-time tracking systems, truck queue systems, etc. (OPR9), availability of information and technology for cargo tracking systems, such as IoT, RFID, real-time tracking, etc. (OPR10), and strategies and investment in digital and smart technologies (IoT, Big Data, Cloud, Edge computing, Robotics, Autonomous, AI, AR, VR, 5G, etc.) (OPR11).

The second domain, Smart port environment and energy, consists of eleven leading indicators: environment management certification and implementation (ENV1), water consumption management implementation (ENV2), implementation of technology for water quality measurement (ENV3), automation facilities for air quality assessment implementation (ENV4), sustainable waste management implementation (ENV5), automation facilities for air quality assessment implementation (ENV6), amount of GHG emissions by all terminal activities (ENV7), implementation of technology in noise pollution detection (ENV8), energy management plan certification and implementation (ENV9), implementation of clean and sustainable energy for port vehicles (ENV10), and implementation of renewable electricity production, such as solar power systems and wind energy (ENV11).

Finally, the smart port safety/security domain consists of seven leading indicators: availability of smart technology and systems for safety and security management (AI, AR, VR, Intelligent CCTV, etc.) (SAF1), safety and security certification (SAF2), rate of accidents in ports (SAF3), investment in safety, cybersecurity, and security (SAF4), security, cybersecurity and safety training conducted for port workers and implementation of smart technology for training systems (Digital Twin, AR, VR, etc.) (SAF5), cybersecurity measures implementation (SAF6), and digitisation of smart and access automation for security (SAF7). Consequently, Figure 1 shows the smart port management with the domains and these indicators responsible for confirming practically smart port management and defining the primary strategies of smart port management in this study.

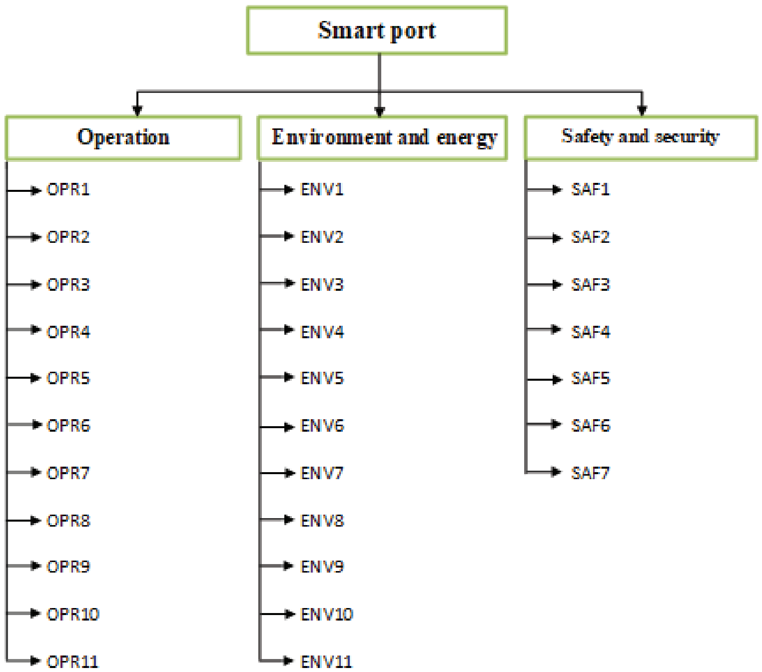

Figure 1.
Smart port domains and indicators.

3. METHODOLOGY

3.1. Data Population, Collection, and Questionnaire Design

The SPIs developed from the study of the previous article by Makkawan and Muangpan (2021), which used Triangulation data collection. Qualitative research with triangulation increased the validity and reliability of the results. In addition, there is the literature review used in the research, theories, critical evaluation, and discussion of this content. The participant observation studies a group by participating in its activities. The semi-structural interviews concerning data collection method rely on asking questions within a predetermined thematic framework to determine SPIs. In this research a quantitative approach is employed, using these SPIs to create a questionnaire survey with a view to examining this research tool. The questionnaire has three parts; part one is the general information of respondents, including the name of the port that the respondent is working, position, department, education background, and working experience. Part two is a rating scale of importance on which respondents can rate levels 1-5 (one is essential and five is critically important) of 29 SPIs in three main domains. Part three represents suggestions and recommendations. In addition, survey research contains data directly filed in the smart port operation to confirm the contribution of SPIs towards the smart port performance.

The population in this research was employed in the operation and safety/environment departments. Directly responsible for smart port management by 11 container terminals in the EEC Thailand, a total of 341 people. Probability sampling uses a simple random sampling method that determines the sample size from the calculation formula of Taro Yamane (Yamane, 1967) - 95% confidence level and 5% randomness error. Therefore, the total sample calculated, according to the Taro Yamane formula, was 184 samples for respondent acceptance.

3.2. Framework of Research Method and Statistics Analysis

The research method is presented in Figure 2. Descriptive statistics are employed to find general information of respondents, using frequency and percentage of qualitative variables. A quantitative approach using Factor analysis is Confirmatory factor analysis (CFA). These SPIs confirm the dominant structure of a set of indicators and the relationship of these indicators to the domains; moreover, to examine the existing model and the reliability measures (Wanichbuncha et al., 2018; Mishra, 2017; Sharif et al., 2011). Data analysis studied the fitting analysis according to the Pearson correlation coefficient and Kaiser-Meyer-Olkin test. Factor loadings would surpass the standard threshold of 0.5, thereby indicating the measure in which the data fits in this model (Pisharodi, 1992; Hidayat et al., 2014; De Araujo et al., 2013).

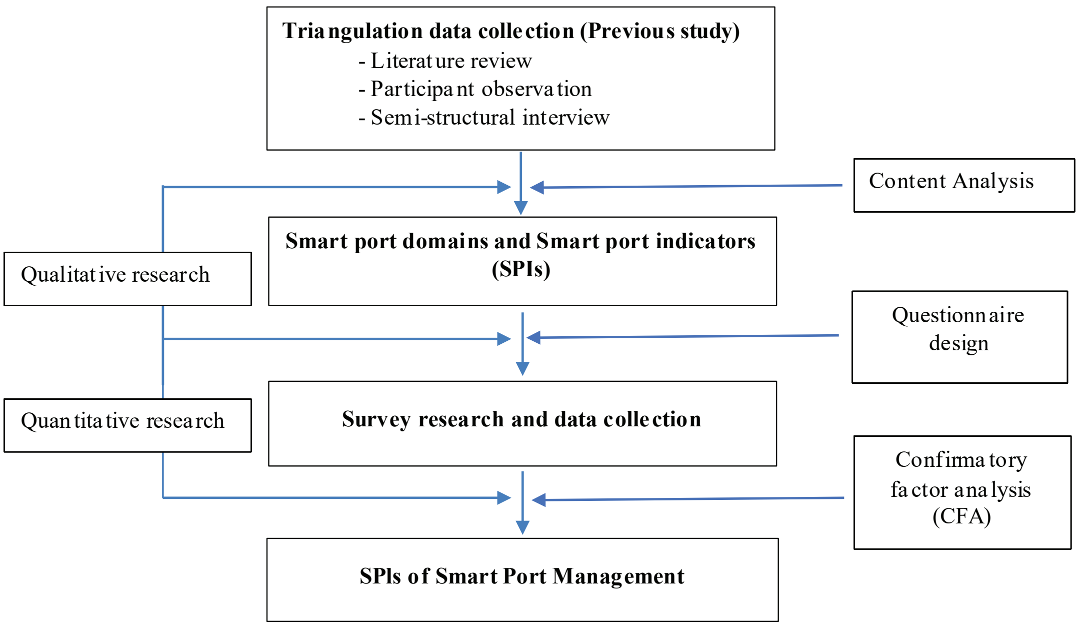

Figure 2.
A framework of research method.

4. RESULTS

4.1. Descriptive Statistics of the Research Sample

This part presents the personal information of the research sample. There have been 192 respondents from 11 container terminals in the Eastern Economic Corridor (EEC), and the sample size is the respondent acceptance. The summary of personal data is shown in Table 1. The samples included people directly responsible for smart port management in the operation and safety/environment departments. Of the respondents, 25.0% have worked in a management position, including manager, assistant manager, and supervisor, and 75% have worked in an officer position.

4.2. Correlation analysis

Factor analysis for this research: the indicators, domains, and relationships among them have tested the Pearson correlation coefficients of all pair-wise indicators in each smart port domain have proved significant ($p<0.05$). For example, the Kaiser-Meyer-Olkin measure statistic is 0.900 with a p-value is 0.000 (Table 2). Furthermore, the results have found that all indicators are significantly related. Therefore, a factor analysis should use the Principal Component Method to group the relevant indicators into domains. (Krzanowski, 1984; Camacho et al., 2017; Muangpan and Neamvonk, 2018)

Table 1.
Number and percentage of personal information.

Personal Information	Number	Percentage
Department of work		
Operation	28	14.6
Safety and environment	164	85.4
Position		
Manager, Assistant Manager, Supervisor	48	25.0
Officer	144	75.0
Education		
Below Bachelor Degree	12	6.3
Bachelor Degree	174	90.6
Master Degree	6	3.1
Doctor Degree	0	0.0
Working Experience		
0-5 Years	98	51.0
5-10 Years	50	26.0
More than 10 Years	44	23.0
Total	192	100.0

Table 2.
Kaiser-Meyer-Olkin statistic and p-value.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.900
p-value	0.000

4.3. Measurement Model for Smart Port

The research has tested the measurement model of smart port indicators using reliability and correlation analysis, followed by confirmatory factor analysis with principal component method extraction. The varimax rotation evaluates the error of indicators that compose the domains. The number of domains was fixed to three to confirm the framework of the three domains. Table 3 presents those indicator loadings representing the correlation of indicators to domains. The test indicates the strength of the relationship between domain and indicator by a value of the loading factor. The confirmatory factor analysis has classified that the three-domain model, supported and related to the sample data. The high-value loading factor is representative of the domain that indicators belong to (Hurley et al., 1997; Mueller and Hancock, 2001; Muangpan and Neamvonk, 2018)

The smart port operation domain has nine indicators; OPR3, OPR4, OPR5, OPR6, OPR7, OPR8, OPR9, OPR10, and OPR11 are significant correlative and relationship to this domain (loading factor values greater than 0.5). The smart port environment/energy domain has seven indicators: ENV4, ENV6, ENV7, ENV8, ENV9, ENV10, and ENV11 represent significant correlatives and have a relationship to this domain (loading In, In factor in values In greater than 0.5). Finally, the smart port safety/security domain has three indicators: SAF 2, SAF3, and SAF4, representing significant correlatives and having a relationship to this domain (loading factor values greater than 0.5).

Table 3.
Loading indicator of three domains.

Indicator	Loading factor		
	Domain1	Domain2	Domain3
1. Smart port operation domain (OPR)			
1.1 OPR3		**0.587**	
1.2 OPR4		**0.782**	
1.3 OPR5		**0.823**	
1.4 OPR6		**0.533**	
1.5 OPR7		**0.601**	
1.6 OPR8		**0.635**	
1.7 OPR9		**0.644**	
1.8 OPR10		**0.713**	
1.9 OPR11		**0.684**	
2. Smart port environment and energy domain (ENV)			
2.1 ENV4	**0.569**		
2.2 ENV6	**0.667**		
2.3 ENV7	**0.826**		
2.4 ENV8	**0.751**		
2.5 ENV9	**0.686**		
2.6 ENV10	**0.839**		
2.7 ENV11	**0.843**		
3. Smart port safety and security domain (SAF)			
3.1 SAF2			**0.588**
3.2 SAF3			**0.736**
3.3 SAF4			**0.577**

5. DISCUSSION

The research results have shown that the 19 SPIs are the key attributes of smart ports' three total efficacy domains. As illustrated in Figure 3, the three-domain model shows the applicable model, which fits in 19 SPIs examined. The operation domain has a significant correlation to the smart port. Other operation domains and smart ports have a strong relationship. This domain is most important and consists of 9 SPIs (OPR3, OPR4, OPR5, OPR 6, OPR 7, OPR 8, OPR 9, OPR 10, and OPR 11) to encourage port productivity and efficiency. These are measured using an automation system for cargo movement and integrating the IR4.0 in infrastructure and the superstructure for terminal management (Molavi et al., 2019; Makkawan and Muangpan, 2021).

The environment/energy domain has a significant correlation to the smart port. The environment/energy domain and smart port have a strong relationship. The environment/energy domain is the second significant domain. It can consider applying all of this domain's 7 SPIs (ENV4, ENV6, ENV7, ENV8, ENV9, ENV10, and ENV11) by a terminal to decrease its consumption of water, fuel, and energy, and to use clean and sustainable energy/electricity. Moreover, it reduce the emission of greenhouse gas and environmental pollution in the air, water, waste, and noise (Taljaard et al., 2021; Makkawan and Muangpan, 2021).

The last domain, safety/security, correlates significantly to smart port. Other safety/security domains and smart ports have a relationship. This domain consists of 3 SPIs (SAF 2, SAF3, and SAF4). It is related to improving safety and security for all activities in port operation, including cybersecurity, which is necessary for a smart port driven by smart/advanced technologies. (Molavi et al., 2019; Alvin et al., 2020; Makkawan and Muangpan, 2021).

Therefore, container terminals wishing to improve their practice planning need to monitor their indicators continually

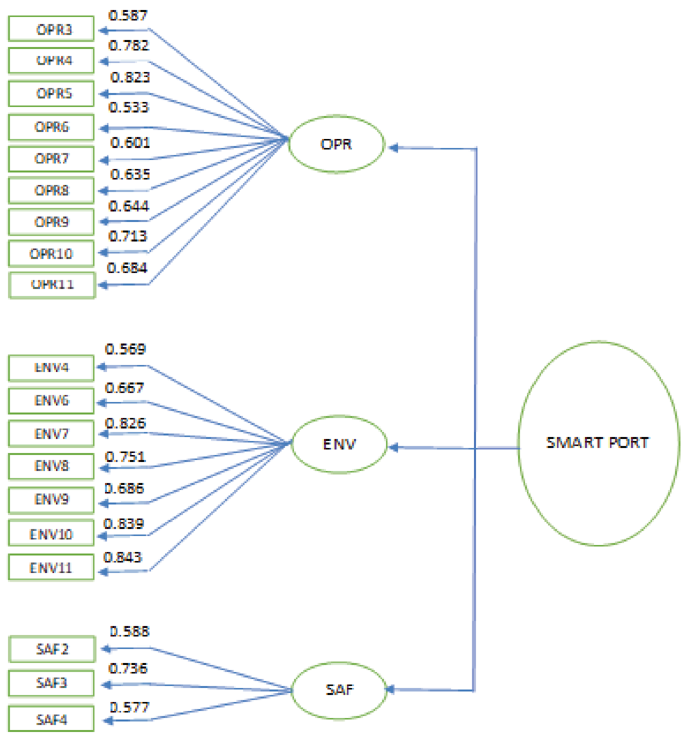

Figure 3.
The measurement model of critical smart port indicators.

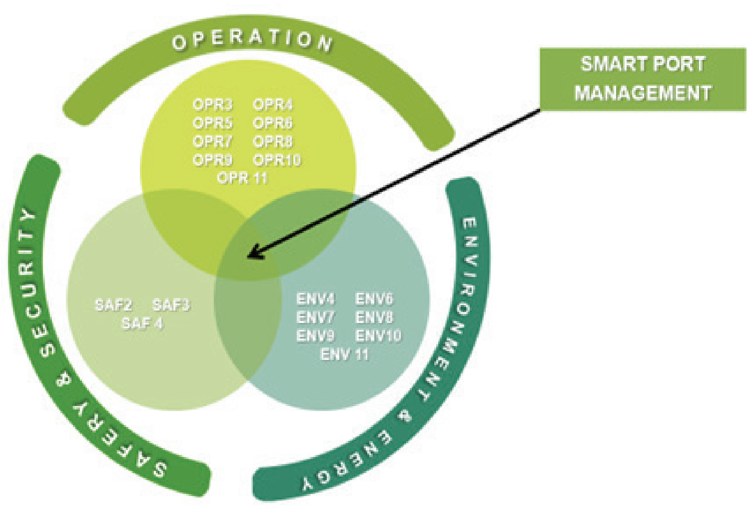

Figure 4.
Smart port management.

and compare them to these indicators. In addition, the critical domains of the smart port, for which we have developed the basis on the container terminal, can be applied identically to non-container and multi-purpose terminals. Therefore, these main domains/indicators can be used for any other port/smart port in the very introduction, confirming that these are the key domains/indicators required to develop the smart port and improve smart port management.

Figure 4 smart port management model explains the three critical smart port domains which constitute the primary practice of smart port development. These SPIs represent the application policy, mission, and strategy, including the operation practice, for achieving smart port performance and upgrading primary elements in smart port management, especially in the initial stage of the smart port.

Since Thailand is still developing and is in the foundation stage of smart port, there are still many steps to be taken in order to create a world-class smart port. Therefore the authors have proposed a strategic plan for developing a smart port, as presented in figure 5. The goal is the smart port management model (Figure 4). Secondary data literature has been reviewed regarding smart port development policies in Asia and the Pacific (UNESCAP, 2021), as well as six policy actions in order to prepare for a post-pandemic world (UNCTAD, 2020). The plan aims at developing and upgrading the port infrastructure and related components to transform it into a world-class smart port. In addition, the programme aims at increasing performance and efficiency, creating customer value, making the port safe and secure, and achieving the global standard. The authors have projected strategies according to smart port domains to complete this goal. The strategies to apply in each smart port domain are as follows:

Of strategic importance for the smart port operation domain is infrastructure development. This strategy consists of four main strategies: strategy 1- Increase terminal and management efficiency by using automation equipment for internal cargo movement (AGV, ASC, QC, robots, etc.); strategy 2 - Using smart platforms for exchanging information in the port community (Blockchain, Cloud), strategy 3 - Using technology for port traffic and cargo tracking system (IoT, RFID, etc.), and strategy 4 - Development of terrestrial connectivity for road and railway.

Strategic consideration for the smart pot environment/energy domain is the accelerator of sustainability. This strategy

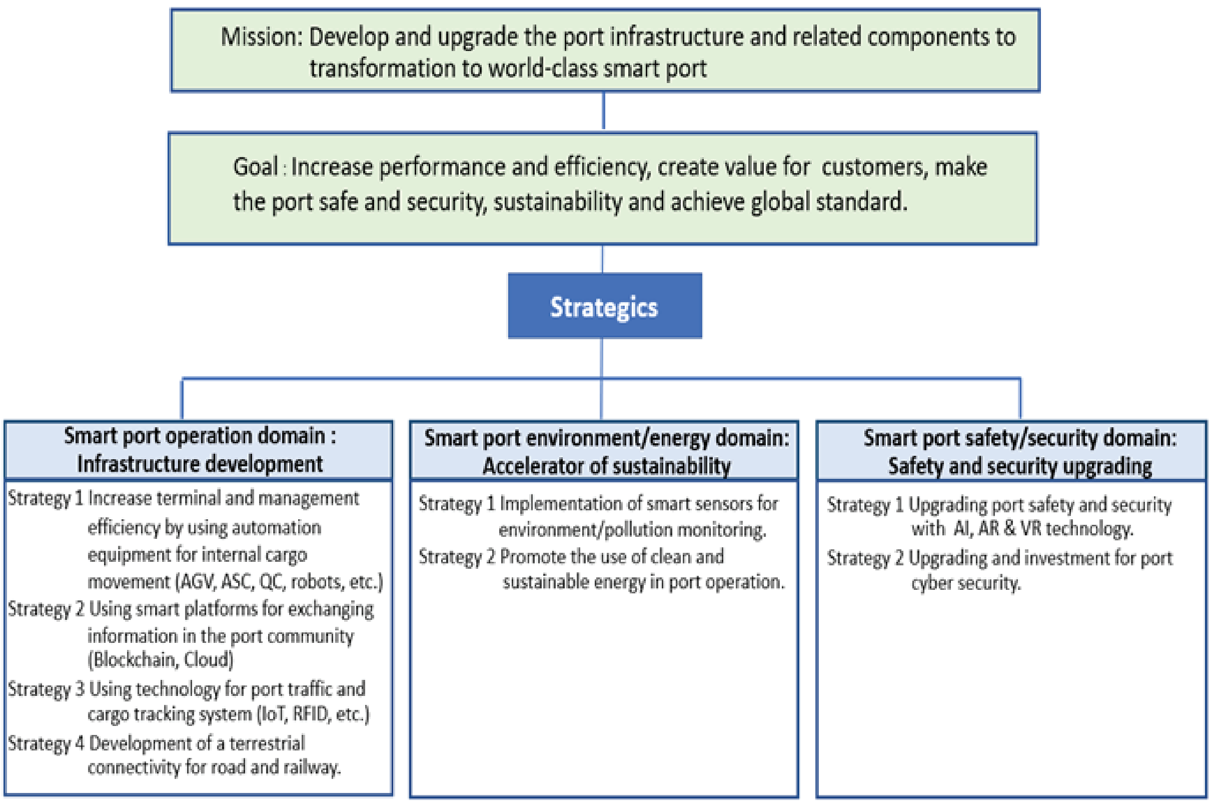

Figure 5.
Smart port strategic plan.

consists of two main strategies: strategy 1- Implementation of smart sensors for environment/pollution monitoring, and strategy 2- Promotion of the use of clean and sustainable energy in port operation.

Strategic for the safety/security domain is safety and security upgrading. This strategy consists of two main approaches: 1) upgrading port safety and security with AI, AR & VR technology, and 2) upgrading and investing in port cybersecurity.

According to the final 19 key attributes of SPIs, it can be concluded that the IR4.0 technologies are essential and contribute towards all smart port domains. The IR4.0 technologies can be applied to the operation domain and increase port productivity and efficiency, such as big data, IoT & prediction analysis, cloud, Robotics, and 5G. For example, in the terminal management system and IoT, RFID, real-time tracking for real-time cargo tracking, including using automated AGV, ASC, QC, and Robot for cargo movement in port/terminal. For the environment/energy domain smart pollution sensors can be applied to control and reduce pollution emissions from port activities.

Finally, the safety/security domain can improve its performance by using AR/ VR / Digital twin for safety and security training. Through simulation, RFID/ Intelligent CCTV in safety measurement, AI/Intelligent Biometric access control/Automatic license reading systems, and RFID in access automation for security come to be used.

6. CONCLUSION

Smart port management is the solution for the post-COVID-19 pandemic era that expects the global trade and supply chain to redesign and become contactless trade—IR4.0 technologies to be applied to all primary activity domains in smart ports. However, smart port management and development still lack suitable SPIs for measuring and encouraging smart port performance, especially in Thailand, which is still in the early stages of the smart port. The measurement model of this smart port indicator for the case study of the container terminal in Thailand's Eastern Economic Corridor (EEC) has been developed using confirmatory factor analysis to analyse the factors influencing the efficiency and effectiveness of the terminal's operations. This research aims at establishing the dominant structure and the indicators' relationship. The results have found 19 SPIs in three key domains; OPR: smart port operation (9 SPIs). ENV: smart port environment/energy (7 SPIs), and SAF: smart port safety/security (3 SPIs) correlate significantly to smart port and can be vital to smart port development.

Furthermore, the performance model of smart port management and the smart port strategic plan is to represent management guidelines. This critical information sets port development strategies and their applications to port operation practice aspects. Future research can use these SPIs for performance benchmarking to compare smart port performance in Thailand with other smart ports worldwide. Furthermore, sustainability factors should be considered and added to smart port indicators to ensure covering of all domains of smart port management.

CONFLICT OF INTEREST:

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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