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## A Conceptual Model of Smart Port Performance and Smart Port Indicators in Thailand



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Received June 17, 2021

Revised July 20, 2021

Accepted August 12, 2021

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**Abstract** Autonomous ports and digital ports are a modern trend of global commercial ports that are established to develop toward smart ports in many ports. Smart port indicators (SPIs) are used as important tools for measuring, encouraging, and indicating smart port performance. These are the main indicators to operate smart port management as the practical direction and port development planning are enclosed. This research aims to identify the SPIs and to develop a conceptual model of smart port performance in a case study of The Eastern Economic Corridor (EEC) in Thailand. Triangulation data are used in the data collection with three sources: the reviewed literature of five international databases in 2016–2021, participant observations, and in-depth interviews. Content analysis is utilized to analyze these data to develop a conceptual model approach. The findings of this research are shown in three main domains classified as smart port operation, smart port environment/energy, and smart port safety/security. These indicators represent 29 SPIs for developing smart port performance, which can be explained with a conceptual model. This information will exist as the foundation framework guiding Thai smart ports towards international standards of smart port efficiency.

**Keywords** Smart port, Smart port indicators, Autonomous port, Digital port, Conceptual model

### 1. Introduction

Maritime transport is the main and most important transport mode for over 90% of global trade (Kong and Liu 2021; Puig and Darbra 2019; Rodrigues et al. 2021; Xu et al. 2021a), and is also the main transport mode for imports and exports in Thailand. Almost 60% of the ships calling in Thailand are calling at the Eastern ports and this number is expected to be higher in the future (Thai Marine Department 2020). The Royal Thai Government has laid out a 20-year strategy for Thailand to achieve high-income status by 2036. The strategy includes a wide range of top-down initiatives, infrastructure, and human resources development. The Eastern Economic Corridor (EEC) project lies under the national 20-year strategy and initially focused on the eastern provinces of Rayong, Chonburi, and Chachoengsao (EEC 2021). The EEC development plan envisages a significant transformation of both physical and social development, and the infrastructure development of seaports in the EEC area is also included in the plan. Not only infrastructure development is laid out in the port development plan but also superstructure. Smart ports are therefore introduced into the maritime industry in Thailand, especially commercial ports under the EEC project which are under transformation to become smart ports starting from the port operation management via truck queuing technology solutions to reduce traffic congestion in the port and in the surrounding area.

The global shipping industry is becoming more digitalized and automated (UNCTAD 2019; Yang et al. 2018). Smart shipping is the next step and a big challenge of global shipping development. It involves systems that apply new technologies for connecting ports and ships. Smart shipping will encourage stakeholders via decision making with efficiency, minimized costs, and smaller ecological footprints (Xiao et al. 2021) and will make global shipping and supply chains safer, more sustainable, more efficient, and more competitive (Kapkaeva 2021). Smart ships and smart ports are key pillars of smart shipping and both are brought into one global system by the Internet of Things (IoTs) and big data technology (Alop 2019).

Since the smart port is a new trend and has attracted attention from researchers from over the world, there are several researches regarding conceptual framework of smart port and smart port indicators (SPIs) have been issued. Botti et al. (2017)

used qualitative approach for the re-conceptualization of smart port service system of Salerno port. Douaioui et al. (2018) presented the modeling concept of smart port and context. Chen et al. (2019) analyzed the concept of the smart port and created a set of smart port evaluation indicator systems. Rodrigo González et al. (2020) conducted a research of a SPI and calculated a ranking for the Spanish port by applying smart port index. And recently D'Amico et al. (2021) created a multidimensional framework for comprehending factors, domains and goals of smart and sustainable logistics of port cities using systematic literature review. Not only the conceptual framework and the indicators of smart port were researched but also the technologies for smart port. The sample of the researches regarding smart port technology are as follows; Hanschke et al. (2016) has implemented Wifi-enabled and solar-powered sensors for smart ports at Hamburg. Carlan et al. (2017) studied the Information Communication Technology (ICT) innovations in the port sector and the degree of the success achieved in each ICT innovation. Rajabi et al. (2018) presented the applications of the automatic identification system (AIS) for data source in smart port. In another research, Irannezhad et al. (2020) has presented the prototype of an intelligent decision support system for a value-added service of port community system.

For academic manner, it seems only few researches have been developed the conceptual framework and indicators of smart port while the global industry has been driven under 4<sup>th</sup> innovation industry. These contributions need to identify a smart port conceptual framework and indicators knowledge for understanding the smart port overview. Also, smart port evaluating is the concept to apply for port performance measurement field.

Industrial manner, smart port performance is the tool for developing the port operation to achieve smart port management that uses the SPIs for evaluating the performance measurement of smart port operation. The SPIs are developed in this research will enable us to measure the smart port performance in its three main domains: smart port operation, smart port environment/energy, and smart port safety/security (Rodrigo González et al. 2020; Molavi 2020b). Therefore, the purposes of this research are to study and find suitable SPIs for smart ports and develop the conceptual framework of smart port management using a case study of the container port of The EEC in Thailand.

## 2. Literature reviews

### 2.1 Port development and transformation

Maritime transport is the most important transport mode in global transport and shipping (Kong and Liu 2021; Puig and Darbra 2019; Rodrigues et al. 2021; UNCTAD 2020). The global maritime trade is growing but expanded at a slower pace in 2018 (UNCTAD 2019) then fell by 4.1% and had some negative impact to port throughput in 2020 due to the COVID-19 pandemic (Xu et al. 2021b). However, UNCTAD projections indicate that maritime trade will recover in 2021 and expand by 4.8% (UNCTAD 2020). The promotion of greater technology uptake and digitalization is one of the six policy actions that will assist in preparing for a post-pandemic world and the persistent challenges facing maritime transport and trade involving developing countries as recommended by UNCTAD (2020). This policy will support the digital transformation of maritime transport in its role to link global economies and supply chains. The smart port is an example of the adoption of this policy and should enable enhanced efficiency, including energy efficiency, and productivity.

The port development can be divided into four generations. The first generation until the 1960s is the loading and unloading port; the second until the 1980s is the industrial port; the third after the 1980s is the logistics and supply chain port, and the fourth following the 2010s is the smart port (Deloitte Port Services 2017). UNESCAP (2021) has introduced a port-level analytics maturity model (Table 1) and a stepwise strategy at the port level for smart ports for their state members (Figure 1). UNESCAP recommended that the state members check their current port level as shown in Table 1, then use the stepwise approach to develop smart ports.

### 2.2 Smart port operation

There is no internationally accepted standard definition for a smart port (Molavi et al. 2020a), but according to UNESCAP (2021), smart port means ports that autonomously process port operations and optimize logistics flows by applying new and advanced technologies. The research from Yang et al. (2018) defines a smart port as a fully automated port where all devices are connected via the IoTs network. Also it can be noted from Zhao et al. (2020) that the intelligent operation control system, service platform, and ecological control system are interrelated and interacting. Smart technology and big data analysis could contribute to the port achieving the integration of economic development, environmental protection, and social contribution. The reason why smart ports are necessary is because the volume of global trade is increasing, and as a consequence of growing

**Table 1. Port-level analytics maturity model based on the capability maturity model integration**

Phase	Port informatization	Automatic port	Digital port	Smart port
Definition	A port introducing informatization that reduces the use of paper document and manual processing	A semi-automated port that is applying to e-document and using information system	An automated port that provides an interoperability by information sharing, real-time service by RFID or etc.	A fully automated port that uses nascent, automation, and innovative technologies and performs digital transformation
Business	<ul style="list-style-type: none"> <li>- Less concerned to informatization</li> <li>- Less systematic business procedures</li> </ul>	<ul style="list-style-type: none"> <li>- More concerned to informatization and automation</li> <li>- Information and automation are applied to some port operation</li> <li>- More systematic business procedure</li> </ul>	<ul style="list-style-type: none"> <li>- High concerned to an automated port</li> <li>- Finding a national level collaboration model</li> <li>- Information sharing with related organizations or neighboring countries</li> </ul>	<ul style="list-style-type: none"> <li>- Encourage international standards compliance for global environment and technical barriers</li> <li>- Use 4IR Technologies in port operations</li> </ul>
Capability	<ul style="list-style-type: none"> <li>- Making an effort to transform to informatized port</li> </ul>	<ul style="list-style-type: none"> <li>- Datalization through information system construction</li> <li>- Upgrade port level by improving port facilities</li> </ul>	<ul style="list-style-type: none"> <li>- Prepare a national level masterplan (roadmap)</li> <li>- Transform toward to port automation</li> </ul>	<ul style="list-style-type: none"> <li>- Toward to the optimized port</li> <li>- Toward unmanned port</li> <li>- Encourage to adopt international regulation (Standard)</li> </ul>
Infrastructure	<ul style="list-style-type: none"> <li>- Parallel processing using paper document and information system</li> <li>- Manual processing by paper document</li> </ul>	<ul style="list-style-type: none"> <li>- e-Document (EDI, XML, etc)</li> <li>- TOS, Yard planning</li> <li>- Yard Crane, Gentry Crane, etc.</li> </ul>	<ul style="list-style-type: none"> <li>- Mobile application</li> <li>- RFID based real-time tracking service</li> <li>- National collaboration system such as Single Window, PCS, etc.</li> <li>- Global collaboration such as NEAL NET</li> </ul>	<ul style="list-style-type: none"> <li>- Digital transformation</li> <li>- Ultra-high speed 5G Network</li> <li>- Upgrading technologies such as AI Robot, big data, etc.</li> <li>- Upgrading infrastructure of private sector side</li> </ul>

Adapt from UNESCAP (2021) with permission of UNESCAP.

RFID, radio frequency identification; 4IR, 4th industrial revolution; EDI, electronic data interchange; XML, extensible markup language; TOS, terminal operating system; NEAL NET, northeast Asia logistics information service network; AI, artificial intelligence.



**Figure 1. Stepwise approach to developing a smart port (depending on port level).** Adapt from UNESCAP (2021) with permission of UNESCAP.

vessel sizes and cargo volumes, ports have become interested in optimizing operations, promoting efficiency, reducing logistics costs, and shipping activities have become main energy consumers and pollution sources (Chen et al. 2019; UNESCAP 2021; Xu et al. 2021c). The research from Ki et al. (2018) found that the transformation to smart ports was able to positively influence the Korean economy by increasing production by 5.7%–12.3%, value added by 16.8%–36.5%, and the employment rate by 130.0%–205.9%. Building upon the findings from Molavi et al. (2020a), the smart port consists of four main activity domains and sub-domains as follows: Domain 1, operations, consisting of three sub-domains: productivity, automation, and intelligent infrastructure; Domain 2, environment, consisting of four sub-domains: environment management systems, emissions and pollution control, waste management, and water management; Domain 3, energy, consisting of three sub-domains: efficient energy consumption, production, and use of renewables and energy management, and Domain 4, safety and security, consisting of three sub-domains: safety management systems, security management systems, and integrated monitoring and optimization systems.

The 4th Industrial Revolution (4IR) technologies has been introduced for smart ports including artificial intelligence (AI), robotics, autonomous, digital twin, virtual reality (VR), augmented reality (AR), IoTs, big data, blockchain, cloud, edge computing, and 5G (UNESCAP 2021; Yang et al. 2018). These technologies can be applied to developing infrastructure, facilities, transport means, cargo handling, traffic management, ensuring safety, monitoring energy consumption and performance, and so forth. Based on Yau et al. (2020), smart ports can achieve five main objectives: reduced greenhouses gas emissions, lower energy consumption, lower delays, lower monetary cost, and higher accuracy of estimation.

### 2.3 Literature review on smart port indicators (SPIs)

SPIs are reviewed from the total of 40 articles from academic journals published in 2015–2021 with four search keywords: “smart port”, “autonomous port”, “digital port”, and “port 4.0”. These academic articles are obtained from five main databases including Emerald Insight (found 1 article), Springer Link (found 3 articles), Science Direct (found 16 articles), ProQuest (found 9 articles), IEEE (found 8 articles) and other databases (found 3 articles). These are summarized as shown in Figure 2. During the period of 2015 – May 2021, there are not so many articles featuring the above-mentioned keywords. Most articles are published in 2020 as shown in Figure 3.

### 3. Methodology

This qualitative study involved documentary research, participant observation, and semi-structured interviews using triangulation of the data to identify the appropriate SPIs using Thailand as a case study for the container port in the EEC. Triangulation data refers to use the multiple data sources in qualitative research for understanding the concept theory or conceptual framework approach. Through, this tool is to increase finding the reliability of information results from different sources.

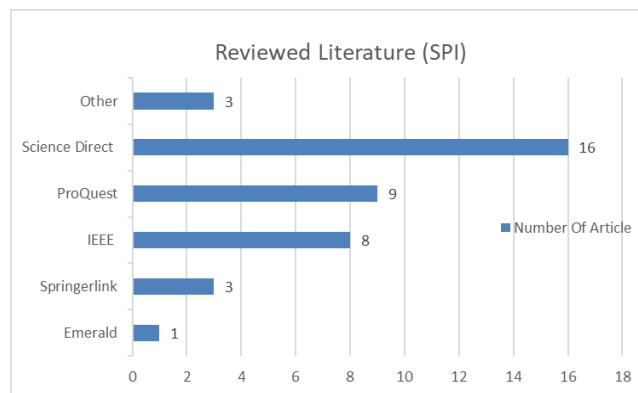


Figure 2. Number of article in each database.

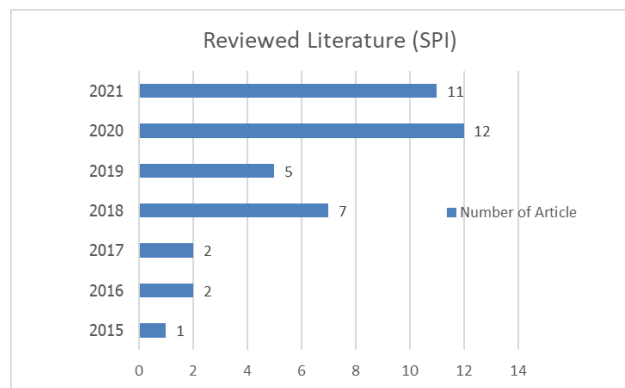
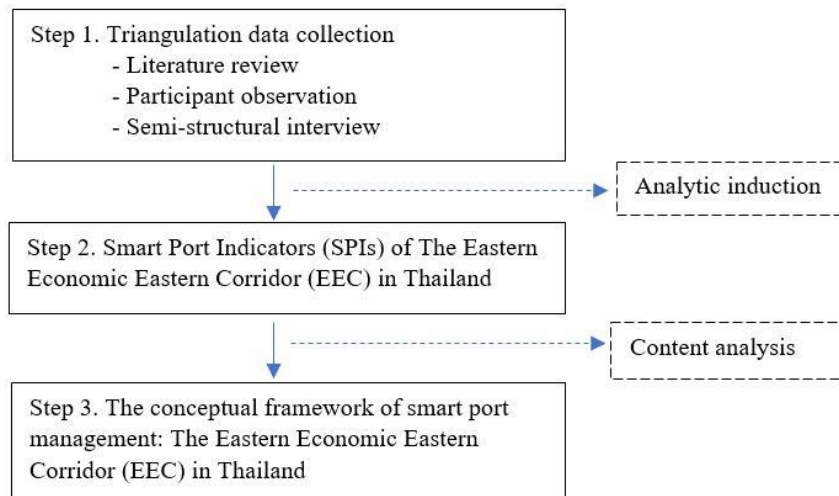


Figure 3. Number of article in each year.



**Figure 4. Framework of qualitative research approach. SPI, smart port indicators.**

Figure 4 shows the three steps of this research approach that used three data sources in finding SPIs and developing the conceptual framework. This research presents the main tools that were used to analyze the qualitative data. The process included analytic induction and content analysis, which were shown in the analysis in step 2 and step 3. Analytic induction was methodically developed to explain the types of content, building up explanations of classification, and used to collect data to find the causes under examination (Fontana 2015; Gilgun 2015). Content analysis was a research tool that defined the concepts within the qualitative data. This instrument was an understandable technique supporting the analysis of the idea meanings and the relationships of the content. Moreover, this was a technique which identified the key concepts that comprised the conceptual model (Bengtsson 2016; Erlingsson and Brysiewicz 2017).

Firstly, triangulation data collected through analytic induction was applied to identify the acceptable SPIs by reviewing academic journals published between 2015 to May 2021, which were sought using five databases including Emerald Insight, Springer Link, Science Direct, ProQuest, and IEEE. The searches of key words were “smart port management”, “autonomous port” and “digital port” and resulted in the discovery of 40 articles covering this field. Also examined were reviews of maritime transport by UNCTAD and smart port development policies in Asia and the Pacific by UNESCAP. Furthermore, the participant observations with top three terminal in EEC and semi-structured interviews were completed with smart port manager on port operation and safety/environment sections of the top three terminal in EEC that is directly smart port expert in to support the acceptance for SPIs.

Secondly, analytic induction was applied to determine preferable SPIs and classify them into main domains based on smart port activities. Analytic induction is used to research strategy in social science that aims to the collect data, analysis, and establish research findings. This instrument is described to knowledge and concept conclusion which are well right from a viewpoint and studied to better conclusions (Hammersley 2010; Larson et al. 2018; Robinson 1951).

Finally, the conceptual model of smart port management was developed through the framework explanation using content analysis in order to set the main domains and all SPIs of each domain, while the relationships among them were also explored. Content analysis is to identify the concepts statement and focus on complement qualitative data. Recompences of content analysis is directly examining statement that provides to understand the conceptual models and a reasonable research method. The bound of this technic is found the difficult systematize with automate, and the problematic relationships/impacts creation in study process. However, this study is not found that has these problems and increase the reliability of analysis results with the use of multiple data source for good research approach (Mayring, 2004; Prasad 2008; Stemler 2000; Stemler 2015).

#### 4. Finding and discussion

The findings of this study are divided into two parts. The first part covers the result of the analytic induction of SPIs, while the second part is the conceptual framework of smart port management using content Analysis.

## 4.1 Smart port indicators (SPIs)

This study applied the analytic induction to analyze all information revealed in the review of the literature of five international databases in 2015–2021, participant observations confirm by reviewed literature and semi-structured interviews with top three terminal experts acceptance SPIs as summarized the results in Tables 2 and 3.

Table 2 presents smart port domains and 29 indicators. There are three domains of smart ports. The first domain, smart port operation, has 11 indicators. The second domain, smart port environment/energy, has 11 indicators. Finally, the third domain, smart port safety/security, has 7 indicators. The references for each indicator are also presented in the table. These main SPIs are achieved to operational planning of port management that can be upgrade of port operation towards smart port improvement.

Table 3 presents the three domains of smart ports and the 29 SPIs together with measurement variables for each indicator which were determined by measurement variable. These variables provide guidance for measuring each indicator in the smart port practical aspect. When the port achievement with these SPIs that can be applied the measurement variable to create the SPIs checklist and performance measurement planning is to design for evaluating the port operation. While performance report is shown the SPIs measurement which this report is to present the points of SPIs improvement toward advance SPIs planning as improving the SPIs operation and well smart port management.

## 4.2 Conceptual framework of smart port management

This conceptual framework presents the main domains, indicators, and relationships among smart ports. The operational aspect has three domains including the smart port operation domain (OPR), smart port environment/energy domain (ENV), and smart port safety/security domain (SAF) as presented in Figure 5.

### 4.2.1 Smart port operation (OPR)

The smart port operation domain refers to the port operation and activities. This domain involves cargo operations including loading, unloading, and shifting cargo in the terminal and yard areas. Productivity, automation systems, and smart technologies in infrastructure are considered in this domain (Molavi et al. 2020a). The smart port operation domain is developed by the main indicators of increasing 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), digitization 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 technology (IoT, big data, cloud, edge computing, robotics, autonomous, AI, AR, VR, 5G, etc.) (OPR11).

### 4.2.2 Environment and energy (ENV)

The smart port environment and energy domain refers to the environmental impact from smart port activities (Taljaard et al. 2021): GHG and air pollution, noise pollution, water pollution, waste pollution, and water consumption, including electricity and energy consumption. This domain focuses on reducing pollution from port activities by controlling emissions and implementing the use of a management system. There is also a clear focus on efficient energy and electricity consumption and the use of clean and renewable energy sources. The smart environment/pollution sensor system is the main technology that is introduced into this domain. The smart port environment and energy domain is developed by the main indicators of 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).

**Table 2. Smart port indicators**

Domain/smart port indicators	Reference																				
	ADB (2020)	UNESCAP (2021)	Rodrigo González et al. (2020)	Molavi et al. (2020b)	Molavi et al. (2020a)	Buiza et al. (2015)	Tan et al. (2018)	Douaioui et al. (2018)	Rajabi et al. (2018)	Jović et al. (2019)	Yau et al. (2020)	Philipp (2020)	Zhao et al. (2020)	Durán et al. (2019)	Heilig and Voß (2017)	Chen et al. (2019)	Yang et al. (2018)	Sakty (2016)	Karri et al. (2021)	D'Amico et al. (2021)	
<b>1. SMART PORT OPERATION</b>																					
1.1 Terminal management efficiency (output/input, throughput)			x	x	x	x	x										x	x	x		
1.2 Yard management efficiency (output/input, throughput)			x	x		x															
1.3 Integrated smart technology in terminal management such as IoT, big data, cloud, edge computing, robotics, 5G, etc.	x	x	x	x										x	x	x	x	x	x	x	
1.4 Availability of digital platforms for exchanging information among stakeholders in the port community (cloud, blockchain, etc.)	x	x	x	x	x				x		x			x	x				x	x	
1.5 Capacity and smart technology for terrestrial connectivity (roads, railways).			x	x	x	x				x								x	x	x	
1.6 Availability of automation in quay side cranes, yard gantry cranes and equipment for internal cargo movement (AGV, ASC, QC, robots, etc.)	x	x	x	x	x	x	x	x			x	x	x		x	x	x	x	x	x	
1.7 Availability of real-time weather data analysis	x	x															x			x	
1.8 Digitization in custom processes (customs single window)	x	x	x								x				x					x	
1.9 Integrated technology in port traffic and roads control such as RFID, WSN, OCR, real-time tracking systems, truck queue systems, etc.	x	x							x	x					x		x	x		x	
1.10 Availability of information and technology for cargo tracking system such as IoT, RFID, real-time tracking, etc.	x	x		x						x	x				x		x	x		x	
1.11 Strategies and investment in digital and smart technology (IoT, big data, cloud, edge computing, robotics, autonomous, AI, AR, VR, 5G, etc.)	x	x											x							x	
<b>2. SMART PORT ENVIRONMENT AND ENERGY</b>																					
2.1 Environment management certification and implementation.			x	x	x	x										x		x	x		
2.2 Water consumption management implementation.			x	x	x	x							x					x	x	x	
2.3 Implementation of technology for water quality measurement.			x	x	x								x	x			x	x	x	x	

Table 2. Continued

Domain/smart port indicators	Reference																				
	ADB (2020)	UNESCAP (2021)	Rodrigo González et al. (2020)	Molavi et al. (2020b)	Molavi et al. (2020a)	Buiza et al. (2015)	Tan et al. (2018)	Douaioui et al. (2018)	Rajabi et al. (2018)	Jović et al. (2019)	Yau et al. (2020)	Philipp (2020)	Zhao et al. (2020)	Durán et al. (2019)	Heilig and Voß (2017)	Chen et al. (2019)	Yang et al. (2018)	Sakty (2016)	Kariri et al. (2021)	D'Amico et al. (2021)	
2.4 Amount of wastewater generated by all terminal activities.			x	x	x								x	x		x		x	x	x	
2.5 Sustainable waste management implementation.	x	x	x	x	x	x										x		x	x	x	
2.6 Automation facilities for air quality assessment implementation.	x	x	x		x	x							x	x			x	x	x	x	
2.7 Amount of GHG emissions by all terminal activities.	x	x		x	x	x	x				x					x	x	x	x	x	
2.8 Implementation of technology in noise pollution detection.	x			x	x	x											x		x	x	
2.9 Energy management plan certification and implementation.			x		x	x										x	x	x	x		
2.10 Implementation of clean and sustainable energy for port vehicles.	x		x						x								x	x	x	x	
2.11 Implementation of renewable electricity production such as solar power system, wind energy.	x		x	x	x	x		x	x									x	x	x	
<b>3. SMART PORT SAFETY SECURITY</b>																					
3.1 Availability of smart technology and systems for Safety and security management (AI, AR, VR, intelligent CCTV, etc.).	x	x	x	x						x						x	x	x	x	x	
3.2 Safety and security certification.			x	x	x	x		x					x					x	x		
3.3 Rate of accidents in port.		x	x	x	x			x					x				x				
3.4 Investment in safety, cyber security, and security.	x		x	x	x																x
3.5 Security, cyber security and safety training conducted for port workers and implementation of smart technology for training systems (digital twin, AR, VR, etc.)	x	x	x		x								x				x	x			
3.6 Cyber security measures implementation	x	x	x					x			x			x						x	x
3.7 Digitization/smart access automation for security	x	x	x							x				x			x			x	

IoT, Internet of Thing; AGV, automated guided vehicle; ASC, automated stacking crane; QC, quay crane; RFID, radio frequency identification; WSN, wireless sensor networks; OCR, optical character recognition; AI, artificial intelligence; AR, augmented reality; VR, virtual reality; GHG, greenhouse gases; CCTV, closed circuit television system.

#### 4.2.3 Smart port safety and security

The smart port safety and security domain refers to safety and security activities in smart ports. In addition, cyber security



**Table 3. Smart port indicators and measurement variable**

Domain	Smart port indicators	Measurement variable
<b>1. Smart port operation</b>	1.1 Terminal management efficiency (output/input, throughput)	- Annual throughput TEU /Total terminal area - Average annual terminal working hours - Annual throughput TEU /Annual working hours - Etc.
	1.2 Yard management efficiency (output/input, throughput)	- Annual throughput TEU /Total yard area - Average annual yard working hours - Annual throughput TEU /Annual working hours - Etc.
	1.3 Integrated smart technology in terminal management such as IoT, big data, cloud, edge computing, Robotics, 5G, etc.	- Existence of technology in terminal management: Cloud, 5G, Cloud computing, Edge computing, Localization Technology, IoT, big data & prediction analysis, AI, Robotics, Drone, etc.
	1.4 Availability of digital platforms for exchanging information among stakeholders in the port community (cloud, blockchain, etc.)	- Availability of digital platform with open data for exchange information about process, online forms, announcements, etc. among stakeholders in port community (cloud, blockchain, etc.)
	1.5 Capacity and smart technology for terrestrial connectivity (roads, railways).	- Connection with high capacity roads - Connection with railways in the terminal
	1.6 Availability of automation in quay side cranes, yard gantry cranes and equipment for internal cargo movement (AGV, ASC, QC, robots, etc.)	- Percentage of automated quayside crane - Percentage of automated yard gantries - Percentage of automated quayside crane, yard gantries and equipment for internal cargo movement (AGV, ASC, QC, Robot, etc.)
	1.7 Availability of real-time weather data analysis	- Number of digital stations for observation and forecasting weather and sea condition
	1.8 Digitization in custom processes (customs single window)	- Availability of customs single window system
	1.9 Integrated technology in port traffic and roads control such as RFID, WSN, OCR, real-time tracking systems, truck queue systems, etc.	- Existence of technology in port traffic and roads control such as RFID, WSN, OCR, real-time tracking system, Truck queue system, etc.
	1.10 Availability of information and technology for cargo tracking system such as IoT, RFID, real-time tracking, etc.	- Existence of information and technology for cargo tracking system/shipment status: IoT, RFID, real-time tracking, etc.
	1.11 Strategies and investment in digital and smart technology (IoT, big data, cloud, edge computing, Robotics, Autonomous, AI, AR, VR, 5G, etc.)	- Existence of strategies in digital and technology - Investment in digital and smart technology (cloud, 5G, cloud computing, edge computing, localization technology, IoT, big data & prediction analysis, AI, robotics, drone, etc.)
<b>2. Smart port environment and energy</b>	2.1 Environment management certification and implementation.	Environment management certified by international standard (ISO 14001)
	2.2 Water consumption management implementation.	- Water consumption management plan implemented - Annual water consumption/terminal service area - Total water consumption of reuse/treated water per total of water consumed (%)
	2.3 Implementation of technology for water quality measurement.	- Implementation of technology or smart sensors for monitoring and assessment water quality
	2.4 Amount of wastewater generated by all terminal activities.	- Total wastewater generated by all terminal activities/Total terminal area. - Total wastewater generated by all terminal activities/TEU
	2.5 Sustainable waste management implementation.	- Sustainable waste management plan implemented - Amount of recycled wasted
	2.6 Automation facilities for air quality assessment implementation.	- Number of automated systems for measuring air quality
	2.7 Amount of GHG emissions by all terminal activities.	- Total annual GHG emissions/TEU - Total GHG emissions/ Terminal area

Table 3. Continued

Domain	Smart port indicators	Measurement variable
	2.8 Implementation of technology in Noise pollution detection.	- Number of acoustics screens - Speed limitation in port - Number of noise monitoring systems/ noise sensors
	2.9 Energy management plan certification and implementation.	- Energy management plan certified by international standard (ISO 50001) and implemented. - Electricity consumption/terminal service area - Energy saved due to conservation and efficiency
	2.10 Implementation of clean and sustainable energy for port vehicles.	- Implementation of clean and sustainable energy for port vehicles: Electric, Natural gas
	2.11 Implementation of renewable electricity production such as solar power system, wind energy.	- Implementation of renewable electricity production: Solar power system, wind energy - Total renewable electricity consumption/Total energy consumption (%)
<b>3. Smart port safety and security</b>	3.1 Availability of smart technology and systems for Safety and security management (AI, AR, VR, intelligent CCTV, etc.).	- Number of Safety and security arrangement and covered to all port activities - Existence of smart technology in safety and security management/arrangement (AI, AR, VR, intelligent CCTV, etc.)
	3.2 Safety and security certification.	- Number of safety and security management certificate base on international standard (e.g., ISO 45001, ISPS)
	3.3 Rate of accidents in port.	- Frequency of accident in port - Number of accidents
	3.4 Investment in safety, cyber security, and security.	- Investment in safety - Investment in security - Investment in cyber security
	3.5 Security, cyber security and safety training conducted for port workers and implementation of smart technology for training systems (digital twin, AR, VR, etc.)	- Number of safety, cyber security and security meeting - Number of safety, cyber security and security training - Number of safety, cyber security and security drill - Existence of smart technology for training or Pre-verification through simulation (Digital twin, AR, VR, etc.)
	3.6 Cyber security measures implementation	- Cyber risk security plan available and implemented
	3.7 Digitization/smart access automation for security	- Available use of digitization/smart and access automation such as intelligent CCTV, Biometric access control systems, Automatic license reading systems, Sensors, RFID, etc.

TEU, twenty foot equivalent unit; IoT, Internet of Thing; AGV, automated guided vehicle; ASC, automated stacking crane; QC, quay crane; RFID, radio frequency identification; WSN, wireless sensor networks; OCR, optical character recognition; GHG, greenhouse gases; AI, artificial intelligence; AR, augmented reality; VR, virtual reality; CCTV, closed circuit television system.

when the infrastructure, superstructure, and port operating systems are connected with 4IR technologies in the cybersphere can address the threat of security risks. The smart port will increase performance in safety and security including monitoring to detect security and cyber security threats (Yau et al. 2020; Molavi et al. 2020a). This domain focuses on the implementation of safety management, security, and cyber security management. The 4IR technologies to be applied for training of port workers include the encouragement of safety, security, and cyber security in port activities and port areas. The smart port safety and security domain is developed by the main indicators of 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, cyber security, and security (SAF4), security, cyber security and safety training conducted for port workers and implementation of smart technology for training systems (digital twin, AR, VR, etc.) (SAF5), cyber security measures implementation (SAF6), and digitization/smart and access automation for security (SAF7).

Therefore, these terminals would like to upgrade port operation to the smart port that must consider this conceptual framework (Figure 5) in terminal practice planning and communicate this concept to stakeholder of smart port operation. Practically smart port upgrading is responded by operational port section and safety/environment sections for cooperating the SPIs activate and performance measurement of smart port management.

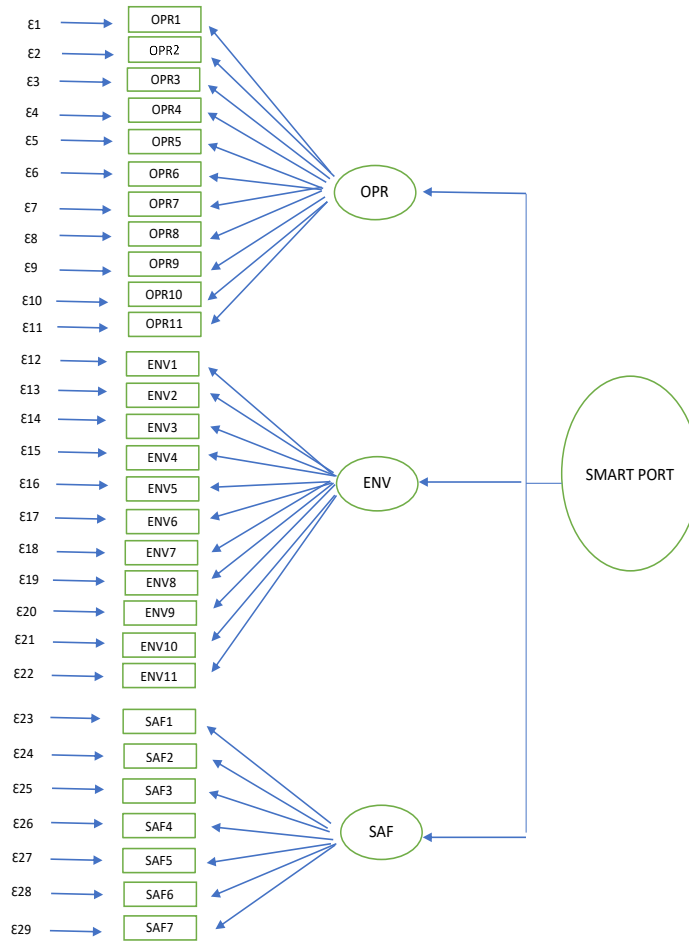


Figure 5. Conceptual framework of smart port management.

## 5. Conclusion

A smart port can be considered as a tool for facilitating the maritime logistics flow and the global supply chain by applying advanced smart technologies. The 4IR technologies, including cloud, 5G, edge computing, IoT, big data, blockchain, AI, etc., are considered for application in the smart port operation domain, the smart port environment /energy domain, and the smart port SAF. The advantages of smart ports include the increased competitiveness of the port as well as the enhanced overall efficiency of economic, social, and environmental performance.

On the subject of port development level, a recent report issued by UNESCAP (2021) defines port level in four phases. Most ports in the EEC of Thailand are at level 1 (Port information) and level 2 (Automatic port). The most advanced terminal in Thailand is terminal D, Laem Chabang port, which is currently reached level 3 (Digital port) and to be the first complete smart port (Level 4) in Thailand. Thai government is trying to drive both policy and investment to encourage and develop the ports, especially the ports in the EEC toward smart ports.

However, in performing activities related to the operation, environment and energy, and safety and security of smart ports, including the development and transformation to smart ports in the EEC in Thailand, there is no SPIs for performance measurement. This research is developed by analytic induction and content analysis using the triangulation data collection, resulting in the determination of three domains of smart ports and 29 indicators of smart ports for measuring of adaptation of the smart port performance. The conceptual framework of smart port management presented in this research will be a logical system to maintain consistency in smart port management and in port development and transformation.

The contribution of academic field found that the lack of research regarding smart port conceptual framework and indicators, this research results are presented in conceptual model for studying the smart port operation. While, port and shipping industry

can be applied these SPIs to practice for evaluating port performance (e.g. checklist, etc.) which terminals can be used for upgrading smart port operation and increasing global competitiveness advantage through smart ports. Future research will confirm these SPIs findings using confirmatory factor analysis.

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