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Artificial Intelligence Implementations Towards Shaping the Future of Digital World

THE ADOPTION OF SMART PORT TRANSFORMATION IN EGYPTIAN PORTS: CONCEPTUAL FRAMEWORK

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ABSTRACT:

The rapid advancement of digital technologies has transformed the global maritime industry, with many ports adopting smart port technology to enhance operational efficiency, sustainability, and safety. However, the readiness of Egyptian ports for smart port transformation has not been comprehensively explored. This study aims to assess the readiness of Egyptian commercial ports for smart transformation, focusing on key areas such as human resource development, automation, sustainability, safety, and cybersecurity. A significant gap exists in the literature regarding the specific challenges Egyptian ports face, including operational, technical, environmental, and human resources-related limitations.

Using a qualitative deductive approach, semi-structured interviews were conducted with port managers, experts, and stakeholders to gather insights into the current state of smart port implementation in Egypt. Thematic analysis of the interview data revealed that significant progress has been made in port automation, aided by technologies like the Terminal Operating System (TOS). However, human resource development remains a major challenge, with training deficits and resistance to change hindering progress. While cybersecurity in Egyptian ports is a relative strength, further investment is needed to address evolving threats.

In terms of sustainability, there has been progress, but more efforts are required, particularly in waste management and the adoption of green technologies. Additionally, the integration of port communities continues to be an obstacle, with a need for improved system standards and coordination through digital solutions such as a single-window system.

The study concludes that for Egyptian ports to successfully transition to smart ports, targeted investments in infrastructure, sustainability initiatives, and human resource development are essential. Enhanced collaboration among stakeholders via digital platforms is also crucial for optimizing processes and improving the global competitiveness of Egyptian ports.

Keywords: Smart ports, Port operations, Digitalization, Human Resources Development, Sustainability.

1. INTRODUCTION

The worldwide maritime industry is gradually endorsing digital transformation, with ports all over the world headed for becoming "smart ports" by integrating modern technologies, automation, and data-driven processes. Yang. et al ,2024 [1]. Nevertheless, levels of readiness for this shift vary greatly, particularly among developing countries such as Egypt.

Transport firms and ports actors in the maritime transport industry are at various phases of their digital transformations. While highly digitized seaports like those in Rotterdam and Singapore could be regarded as the most successful models of digital transformation, several other seaports, their stakeholders, and even maritime supply chain organizations are far behind their pace. Tijan et. al., 2021[2]
As a result, ports are increasingly interested in smart solutions to optimize operations, increase efficiency, promote sustainability, and address safety and security concerns. Switching to smart ports is the adoption of such technologies to address contemporary difficulties. Molavi.et. al, 2019 [3]. The digital transformation required to transform a port into a smart port involves the utilization of digital technology, but it also needs a comprehensive digital strategy and a societal shift. Simultaneously, transforming a traditional port into a smart port is a strategic challenge for the port sector as a whole Boullauazan, et al. 2023[4].

This paper evaluates Egyptian ports' preparedness for smart port transformation by a detailed examination of interviews with port managers, experts, and ports stakeholders. As a consequence, the findings of this study will enable stakeholders in the maritime industry to adopt practical port digitalization strategies to improve Egyptian ports' operational efficiency and boost their competitive advantage. Port operators and shipping companies can use the study's results to identify critical success factors of smart ports. Due to this, the main research objectives for this work are firstly, Identifying the main pillars of implementing smart ports. Secondly, assessing the current Situation of Egyptian ports. Finally, providing recommendations to port managers and stakeholders to adopt the smart port concept in the Egyptian context. This study is significant for creating a holistic framework that combines cybersecurity, safety, sustainability, operation, digitalization and human resources in the the unique operational context of Egyptian ports. This study offers practical insights for localized smart port transformation by highlighting the unique obstacles and facilitators in developing nations, in contrast to earlier research that concentrates on sophisticated global ports.
The next section of the research gives a detailed review of the literature and previous research on smart port transformation. This review intends to put the current study into context by analyzing previous findings, identifying relevant trends, and noting research gaps.

2. LITREATURE REVIEW

Ports are in competition with each other for market share. Facilities offer a much more efficient and safer movement of goods across the globe. High performing ports make use of Smart technologies that help manage their operations more effectively while meeting new challenges to keep facilities safe, secure, and energy efficient at minimal environmental consequences. That's how Smart Port evolved. However, there is no well-defined uniform definition of a smart port. Molavi et al.,2020 [5]. The term "smart port" refers to a broad topic that covers many areas of port services. The present strategic placement of the ports becomes obvious as a result of the benchmarking and indexing of the ports. Through this, each port classifies the relevant strategic suggestions for a smart port. Robert Philipp, 2020 [6].
Over the past few years, almost every industry has launched a variety of initiatives to explore and exploit new digital technology. This would commonly include the conversion of key business operations that would impact products, services, and processes, alongside organizational structures and managerial techniques Matt et al., 2015[7].

Transport firms and ports actors in the maritime transport industry are at various phases of their digital transformations.
As a result, the maritime transport sector is seeing a rise in the need for digitization and new technologies, as well as a rise in the number of ports integrating 4IR technology with current port offerings. By using 4IR technology, ports can become smarter, stakeholders can make better decisions, procedures can be improved, and port operations can become cleaner and more efficient. ESCAP, 2021 [8].
Digital technologies are an important aspect in the process of automating transportation and port operations. It allows for the development of smarter and more automated terminals, as well as port monitoring operations, autonomous reception and delivery, driverless freight transportation, automated ship loading and unloading services, and unmanned and automated vessels, all of which make ports smarter and require fewer human resources. Sensors, wireless technology, drones, blockchain, green technologies, communications protocol, and other developing technologies will be widely used at ports in the future. Kern. J, 2021[9],

Nevertheless, without intelligent people, there can be no smart ports. To face the new difficulties of smart ports, every transition process will require a major component of training, change management, transformation, and skill-building Ameilia. M, 2020[10]. However, current port solutions primarily rely on digital solutions, which are insufficient for ports to attain to the role of intelligent, the transformation process demands integration on several levels, beginning with the social, economic, and technical components. The mature concept of Smart Port is still a long way off, and it is unlikely to be the ultimate stage in port development. Karas'.A, 2020 [11] Furthermore, optimizing the use of the current infrastructure is the primary objective of digital innovation, which is one of the most crucial components of a port's competitiveness. Additionally, once they have faster access to better information, port customers—which may include shippers, freight forwarders, and transportation companies—can make better decisions. For instance, an integration of their business systems could enable the port's track and trace features, allowing for the digital inquiry of a container's status. Digitalization has now become an imperative for ports to take part in the global supply chain Carlan et al 2017 [12]. Customers at ports increasingly request the additional adaptability and flexibility that digitalization provides in order to more effectively maximize their time, money, and resource usage.

By removing the need to declare one's arrival at port entry, digitizing processes such as access management for truck journeys increases customer efficiency. Additionally, digitalization offers the possibility of a track and trace feature, allowing carriers to monitor the condition of their cargo in the port and utilize this information to inform more informed planning choices. Douaioui et al 2018 [13]
Additionally, ports have the potential to harm the environment through industrial activities, land transportation, and maritime transit. Air pollution, noise pollution, water pollution and consumption, and garbage generation are only a few of the environmental effects of port operations that lower social welfare and jeopardize the survival of living things. These effects present significant issues for port management and jeopardize the ports' long-term viability. Smart ports look for answers to today's environmental problems. (Molavi. et. al, 2019)

Ports face safety and security risks that can negatively impact operations, reputation, and profitability Fabiano et al., 2010 [14]. Direct terrorist attacks, the use of ports as a route for the transportation of weapons Altiok, 2011[15], natural hazards, and inherent dangers in port activities related to safety and security are the most pressing challenges in this sector. For instance, ports may be subject to both low frequency, high severity

occurrences (major accident risk) and high frequency, low severity events (occupational risk). Vairo et al., 2017 [16]. Smart ports incorporate solutions such as rules, standards, personnel training, periodic facility control, risk assessment, suitable designs, and monitoring systems to detect any security issues.
In this regard, Operations, digitalization, human resources, sustainability, safety, and cyber security are the aspects which the literature remains to indicate as important in regard to port transformation. On the other hand, it also established that there still remains quite a significant gap in the literature with respect to how these elements influence the readiness of Egyptian ports for this transformation. These are the most essential pillars on which the level of readiness for a smart port transformation is assessed.
Therefore, the framework proposed in Figure (1), indicates that smart port readiness is considered the dependent variable to be influenced by five independent variables that is derived from previous studies.

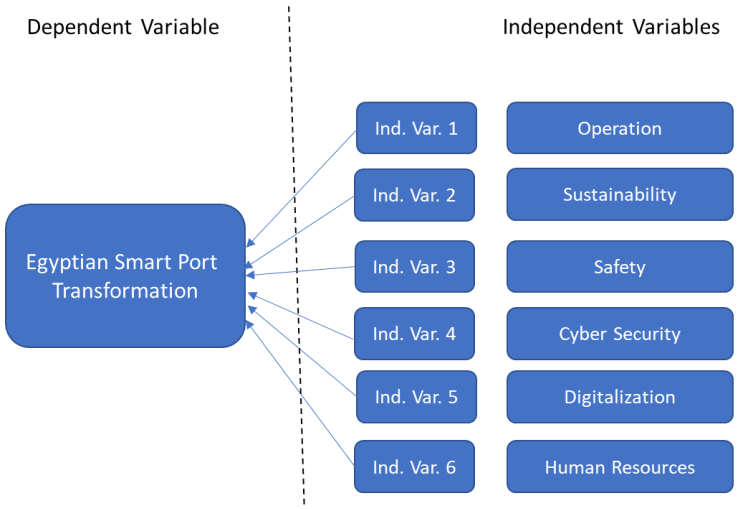

Figure (1) Theoretical framework

3. RESEARCH METHEDOLOGY

This study outlines a qualitative deductive approach used to investigate the readiness of Egyptian ports for the smart port transformation. The research is divided into two phases the first phase the Smart port pillars is identified by a thorough review of the previous studies, resulted with the theoretical framework. The second phase is a semi-structured interview based on a positivism philosophy, to verify the theoretical framework. None the less, obtain in-depth information from experts, port managers and stakeholders. Moreover, the interview data is used to assess the current situation of Egyptian ports generate recommendations for Egyptian ports on the crucial requirements for transforming into a smart port.

The interview is basically divided into two major parts. The aim of the first part is to assess the current level at which Egyptian ports are utilizing smart applications. The second part examines the validation of previously discovered research pillars to verify the research framework. Finally, the interview concludes with an open-ended question aimed at gathering the interviewee's thoughts on the research pillars and determining whether there are any additional variables they would like to include or exclude from consideration.

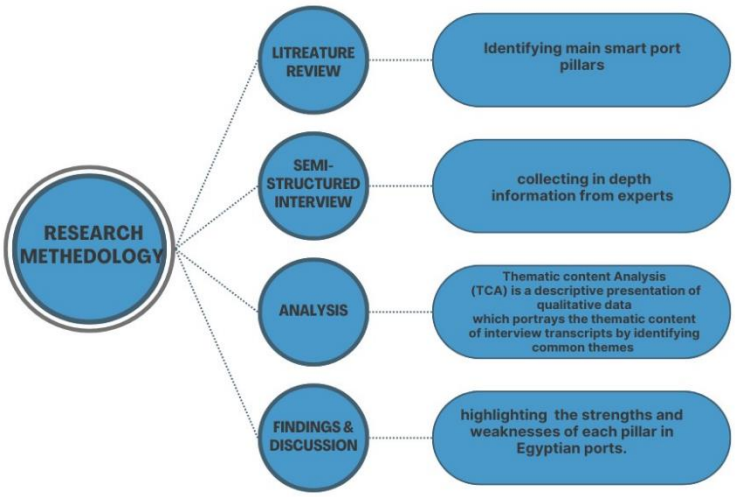

Figure (2) Research Methodology

The interview process involves both telecommunications and face-to-face meetings with nine participants of the port's managerial level and port's stakeholders, experts & researchers in the port operation field. The choice to focus on this sample of participants is driven by their pivotal role in organizational decision-making and planning. Nonetheless, all nine participants held managerial roles in the port industry and each interviewee had more than two decades of experience in this field, resulting in a comprehensive understanding of port operations. The diversity of expertise not only validates the study, but also gave it great intellectual worth. The research used open-ended questions throughout the semi-structured interviews to encourage a larger flow of creative ideas. Ethical considerations were carefully considered during this interview to ensure all participants' respect and confidentiality. All interviews were recorded with the participants' explicit and informed consent. Participants were fully informed about the goal of the study, the voluntary nature of their participation, and their freedom to withdraw at any moment without consequence.

Finally, Thematic content analysis was used to extract common themes and patterns from the interview responses. The process encompasses examining the feedback to identify common themes, thoughts, and opinions. This method of analysis unveiled key themes and provided deep knowledge of the interviewee's perspectives and experiences. Thematic content analysis helped to organize and assess the interview material, providing additional in-depth insights into the research.

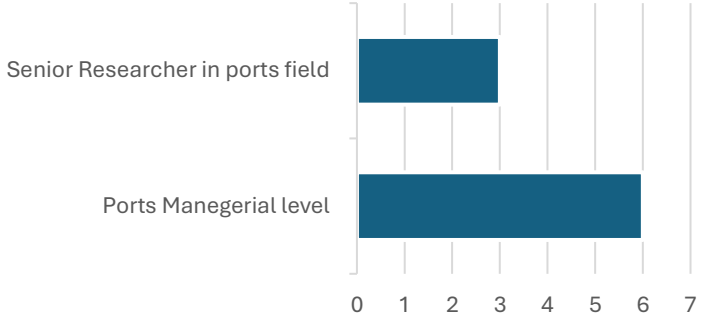

Figure (3) number of interview participants and their roles

The following section of this paper will present the research findings obtained from the semi-structured interviews, and then a discussion will follow.

4. RESEARCH FINDINGS AND DISCUSSION

The interview questions have been meticulously created to validate research pillars gathered from earlier studies. These pillars (Operation, Safety, Cybersecurity, Sustainability, and Human Resources) were evaluated for their relevance to the Egyptian setting and ability to appropriately illustrate the research area.
The following data analysis highlights the strengths and limitations of each pillar in Egyptian ports, table 1 shows how the interview participant reacted regarding each question related to each pillar. The interview questions were specifically developed to validate the research pillars found in prior investigations. These pillars (operations, safety, cybersecurity, sustainability, and human resources) were evaluated for their applicability and relevance in the Egyptian port setting. Each question aimed to obtain participants' thoughts on the current state and issues related with these crucial areas. The replies were thoroughly examined to discover common themes, strengths, and limits within each pillar. Table 1 summarizes participants' responses, showing how each pillar is evaluated and its readiness level in the context of Egyptian ports. A detailed analysis of the results for each pillar is provided after the table, identifying the main findings.

Table (1) Summary of interviewees' opinions regarding smart port pillars

Smart port pillars	*Interviewees*							
	A	***B***	***C***	***D***	***E***	***F***	***G***	***H***
Operations	Terminal Operating System (TOS)	Smart port is applied to port operation to some extent.	Pre-payment transactions to reduce waiting time	Technically existing sites should be wide enough for all processes and automated equipment, but this is not the case at the moment	certain lines, and stacking structures, need to be adjusted	Synchronization between transfer equipment and slots of stacking yard	Trade Lense operating system	There is a Difficulties in the integration of multiple stakeholders
Safety	The benefits arising from automation are therefore twofold; on one hand lies the health and safety aspect, and on the other the productivity aspect.	Safety regulations are applied	ISPS	Safety regulations are applied	work safety will be enhanced when transform to digitalizing as serious accidents are prevented as the workforce is mainly employed in offices rather in the dockyards, where accidents might happen more often.	Safety regulations are applied	Safety regulations are applied	ISPS

Cyber Security	Applicable	Applicable	Applicable	necessity of keeping the software and hardware systems used constantly new and up-to-date, difficulties of integrating multiple systems,	Applicable	Applicable	Applicable	Applicable
Sustainability	"Electric power infrastructure in port areas needs to be strengthened	Comprehensive Port Waste and Garbage Management Plans.	Green hydrogen production initiatives	minimize emissions and environmentally harmful substances	Efforts in applying SDG goals is recognized in Egyptian ports	expand green spaces in ports	Desalination of water and renewable energy projects	electricity has been supplied to ships from shore to minimize harmful gas emissions
Digitalization	Containers Tracking and tracing	Electronic gates	customs procedures and a single window system, should be improved	Electronic gates Trucks & Cars identification	Semi-Digitized quay equipment is available	All documents are electronically archived	system for the withdrawal and addition of warehouse items	Single window
Human Resources	Port labor needs more training	the need for qualified personnel with the skills to use technology has arisen in ports, as in other sectors. The critical skills shortages make it difficult to employ people and to manage human resources	Port labor is resisting change	Training is available for all port labor	Lack of skilled management	More training is needed	lack of internal digital culture and training	habits of employees lead them to resist to change from time to time

4.1. Human resources development

In conjunction with improvements in technology, there has been a growth in the demand for qualified workers with technology-related skills in ports and other sectors. All participants agreed that a lack of education and capacity building is a significant barrier to achieving ideal smart port performance. Without proper training and education efforts, port personnel may lack the skills and knowledge needed to effectively deploy and manage smart technologies. Furthermore, a lack of capacity-building initiatives hinders the ability to respond to recent technological developments and industry best practices. Addressing this challenge requires serious training programs aimed at enhancing digital fluency, expanding technological competency, and fostering a culture of continuous learning and innovation in port operations. By focusing on education and capacity-building programs, ports may overcome challenges and reach the full potential of smart applications. In addition to a lack of knowledge and capacity development, workers' low salaries are a primary source of labor resistance to change in the context of smart port plans. When workers fear that embracing new technology could risk their livelihoods or result in job loss, they may become more resistant to change.

4.2. Port operations

Port operations involve a lot of tasks regarding management and facilitating the movement of ships and goods in marine ports.

These activities are pivotal for ensuring the smooth operation of seaports. Innovations in terminal operations typically target enhanced efficiency, such as boosting the frequency of movements or minimizing unnecessary cargo handling.

Therefore, participants were asked about the extent to which the smart port principle is being implemented in "Port operations" at Egyptian ports. One of them stated that many applications have been used in Egyptian ports, hence facilitating cargo movement within the port, such as terminal operating System (TOS) and Radio Frequency Identification (RFID) for the tracking and tracing of goods. Moreover, electronic gates have been established for truck and car identification, as well as pre-payment electronic transactions to reduce waiting times.

Most of the participants agreed that there are considerable smart port operational initiatives in Egyptian ports. This includes launching an automated container and cargo trading system, as well as renewing the previously neglected and ceased cargo monitoring system for automated tracking. In addition, an automated vehicle and equipment recognition system was installed and activated. Furthermore, integration with the port community system has been accomplished via a unified single-window interface. despite this, greater maneuvering spaces are needed for autonomous handling equipment, and larger port areas are needed for digital operations in Egyptian ports. In addition, field operations entail several sophisticated corporate procedures. In addition, there are extra customs inspections in the port locations. Among the main challenges mentioned by the participants were these complicated business procedures. Interviewees also highlighted our country's electricity problem. Furthermore, for ports to become digital, all parties involved in the port system must have the infrastructure in place to use these technologies at the same time.

4.3. Cybersecurity

The majority of participants indicated that Egyptian ports' cybersecurity is effective, and that data is highly safeguarded. They added that the state and political leadership's efforts have pushed cybersecurity for information infrastructure to the top of Egypt's priorities list. This occurs in an expanding digital revolution across multiple sectors,

recognizing the significance of implementing comprehensive protection measures for data transmission networks and electronic archiving systems. The emphasis is on ensuring resilience against cyber threats by utilizing cutting-edge technological tools, with the goal of addressing any weaknesses in electronic applications. It was highlighted that the development of the largest and most advanced safe and intelligent information complex in the Middle East and North Africa helps to strengthen the foundations of digital transformation by establishing a more secure environment for information infrastructure.

4.4. Safety

On the issue of the standard of safety, the majority of participants reported that Egyptian ports were still keen about safety measures and adhered to the relevant laws and regulations. In their view, this did not pose any obstacle or challenge to the Egyptian ports. However, one opposing view was that while much has been done in the implementation of safety regulations in Egyptian ports, they are challenged in disaster preparedness and crisis management. More specifically, this participant recalled that the Egyptian ports were not ready, right at the start of the COVID-19 epidemic, to address this issue. In relation to this, some participants made a point that additional health and safety training should be given to port personnel.

4.5. Sustainability

All participants agreed on the sustainability variable, stating that environmental responsibility is one of the most important factors that ports prioritize to improve sustainability in operational processes, to ensure increased customer satisfaction and stakeholder welfare within the port. As a result, ports try to develop creative solutions for lowering costs and eliminating waste, thereby boosting the value-added of operational processes.

They further stated that Egyptian ports are actively involved in vigorous attempts to abide by environmental standards. Several steps have been implemented to specifically and practically minimize pollutants, manage trash effectively, and reduce emissions and environmentally harmful elements. Key activities include the creation of ecologically friendly waste incineration facilities, the improvement of air quality through the installation of pollution monitoring systems on the port, and the expansion of green spaces.

Compatibility with the international convention for the reduction of gas emissions has been strictly maintained, under the International Maritime Organization's requirements for the provision and use of maritime fuel with a sulfur content of no more than 0.5%. Efforts to reduce thermal emissions include providing shore-based electricity to vessels, which reduces the emission of dangerous gasses from ship operations by Annex VI of the MARPOL 73/78 convention. Zulfiqar, et. al, 2023 [17] Furthermore, the port's energy infrastructure has been expanded with the addition of solar power resources.

From the personal interviews, in response to the question about the research variables and whether they were enough to assess the readiness regarding the implementation of a smart port system at Egyptian ports, eight out of nine participants stated that the variables in the research were sufficient and precise. Still, one of the participants opposed this view by implying that integration between port community and port institutions was an important pillar when switching from a traditional port to a smart one.

In response to this finding, the theoretical framework is modified as shown in Figure 2 to include the integration between port community's variables. Subsequently, the conceptual framework is developed.

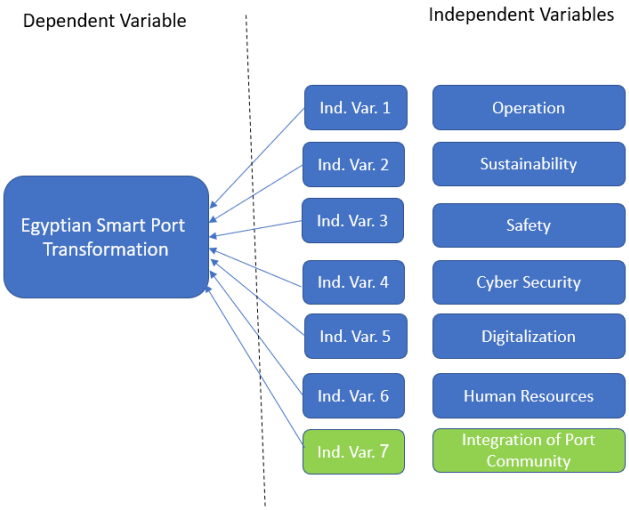

Figure (2) Conceptual Framework

4.6. Discussion

The study's conclusions highlight the progress and obstacles Egyptian ports must overcome to transform into smart ports, offering a comprehensive picture of the crucial areas that need focus. Development of human resources, as revealed by interviews, continues to be a major challenge. There is an obvious perception from the participants that there is a lack of instruction and training, hence fall in line with previous studies done on the transformation of smart ports. Researchers like Molavi et al. 2019[3] stress the need to balance technology improvements in the ports with the available human resources. While a skilled workforce in the fields of innovation and digital proficiency has received attention on a global basis, Egyptian ports have been suffering from a serious shortage in manpower. Low salaries further worsen the inequality by making workers even more hesitant toward technological development. The results showed that unless these challenges are resolved through specific capacity-building programs, Egyptian ports will hardly catch up with their competitors who have already aligned human capital in the process of digital transformation.

The research also identified that the Egyptian ports have evenly made equal strides in the port operations with special emphasis on radio frequency identification (RFID) and Terminal operating System (TOS) technologies' implementation. Such developments, indeed, align with the general trends of the industry, targeted at applying automation and digital technologies for advancing the handling of freight to reduce delays in operations which harmonize with Tijan et al., 2021[2]. Indeed, some vital infrastructure issues were raised by the participants: the need for larger spaces and maneuvering spaces in view of autonomous handling machinery. This chimes with the concerns raised by Molavi et al, 2020 [5], who argue that enhanced digital infrastructure cannot stand alone without improvements in physical infrastructure at the same time. The detailed nature of business processes, particularly customs inspections—continues to be a significant barrier, underscoring the necessity of profound operational process improvements.
On the other hand, Egyptian ports tend to perform relatively well in the area of cybersecurity. The participants emphasized the importance of cybersecurity to various

industries in Egypt and considered confident that the Egyptian government is conserve critical information infrastructure protection. This is coherent with the increasing attention the shipping industry globally shows toward cybersecurity because of increased dependency on interrelated digital systems that are becoming increasingly prone to all sorts of attack Tijan et al., 2021.[2] Hopefully, the establishment of sophisticated information complexes has positioned Egyptian ports as regional leaders in this respect. However, since cyber-attacks become more sophisticated with each passing day, cybersecurity tools must be financed and improved continuously.
Egyptian ports have also made sustainability a top priority in recent years, with considerable efforts being made toward reducing emissions and adhering to global standards on environmental protection. The participants said the ports have implemented policies to comply with the IMO rules of reduction of emissions, such as shore-based electricity for ships and the infrastructure of solar power. This complies with Othman, et, al 2022 [18] who agreed that these are serious steps toward raising sustainability in port operations. Although Egyptian ports have made progress in this regard, there is still much to be done, especially concerning the institution of more sophisticated practices of waste management and the use of greener technologies. According to Molavi et al, 2019 [3], the existing focus on basic methods of environmental management hinders innovation, that is required for sustainability.

A closer look at global benchmarks such as Singapore and Rotterdam finds considerable differences in preparedness and implementation. Ports such as Singapore and Rotterdam have been recognized as pioneers in smart port transformation, primarily due to a mix of advanced technology adoption, robust human capital initiatives, and smooth port community system integration. Singapore, for instance, has widely deployed automation technology such as fully automated cranes and self-driving vehicles, which are supported by a trained workforce in data analytics and smart technologies Maritime and Port Authority of Singapore – Singapore's Next Generation TUAS Port Project – World Port Sustainability Program, n.d. [19]. Similarly, Rotterdam's prosperity is supported by its commitment to sustainability through initiatives such as deploying sensors to accelerate innovation in the Port of Rotterdam and contribute to the port's sustainability. Smart Infrastructure, n.d. [20]

In contrast, Egyptian ports lag short of meeting such standards, notably in terms of human resource development and infrastructure. While progress has been made in the implementation of RFID and TOS technology, Egypt's port automation scale and efficiency remain limited in comparison to worldwide leaders. Furthermore, the integration of stakeholders through digital platforms, as seen in Rotterdam's Port Community System, is still in its early stages in Egyptian ports. To close this gap, focused investments in advanced training programs, infrastructural improvements, and stakeholder participation will be required.

Finally, it was also realized that one of the key elements that make up the concept of the smart port is integrating the port communities. The participants perceive that standardization of the system and coordination among the stakeholders is an area that still has room for improvement. This observation by the participants matches with Heilig et al. 2017[21] and also Moros-Daza et al., 2020 [22], who believe that effective communication and close coordination among the port users is the key to the success of a smart port. The development of a single window might bridge the gaps and increase productivity in many of the Egyptian ports' operations. This is very critical, because most of the ports are continually relying on developing digital interfaces while managing core operations to ensure smooth data exchange among parties concerned.

5. CONCLUSION AND FUTURE AGENDA

This research presents a holistic assessment of the readiness of Egyptian ports toward smart port transformation by discussing all critical aspects of human resource development, port operations, automation, safety, cybersecurity, and sustainability. The results showed that although the support of the government for the Egyptian ports in various aspects such as cybersecurity and port operations with the aid of automation technologies like RFID and TOS has helped them achieve great milestones, there are still numerous obstacles to get through. Human resources development is especially important to deal with issues such as an inability to completely deploy smart port technology due to a lack of education, training, and salary increases. Certainly, even while sustainability initiatives such as the use of shore-based electricity and compliance with environmental standards are in place, more advanced green technology along with fully integrated waste management solutions still need to be developed. The need for closer coordination and better communication between all the stakeholders was also underlined while mentioning that more growth was needed regarding port community integration.

To discuss these difficulties, infrastructural improvements, stronger port user cooperation, and targeted education and training initiatives are necessary.

Addressing these issues will enable Egyptian ports to maximize the opportunity provided by smart port technology and make them more competitive in the global maritime industry. Based on the conceptual framework developed in this research, a number of key areas have been identified that need to be pursued further for the advancement of readiness toward smart port transformation for Egyptian ports.

The framework establishes a precise research agenda for the comprehensive development of smart ports by highlighting areas that need more investigation. These include improving community integration, infrastructure, cybersecurity, sustainability practices, and human resource development. The following are the areas for future studies:

(1) Further research may conduct an empirical study to assess the current level of adoption of the smart port concept in Egyptian ports and analyze the relationship between key smart port pillars—such as automation, digitalization, human resource development, sustainability, and cybersecurity—and operational efficiency in smart port systems. This study may utilize surveys, and data analysis to provide evidence-based insights on how adopting smart port pillars affects port productivity and competitiveness.
(2) Developing a comprehensive roadmap for smart port transformation tailored to Egyptian ports. This roadmap would outline strategic milestones, key infrastructural upgrades, human resource development initiatives, and technological implementations.
(3) More studies on scenarios will be conducted to eliminate training and education disputes and to provide port personnel with the technological qualifications required to adopt new technologies.
(4) Research studies concentrate on infrastructure requirements, such as physical port transforms, supporting autonomous systems and optimize customs procedures.
(5) Continuous research to upgrade cybersecurity measures in response to evolving digital threats.
(6) Advanced waste management and green technologies need more studies and investigation to meet with global environmental standards.
(7) collaborations with international organizations or technology providers.

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