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Examining ICT Innovation for Sustainable Terminal Operations in Developing Countries: A Case Study of the Port of Radès in Tunisia

Ahmed Sahraoui [1,*], Nguyen Khoi Tran [1], Youssef Tliche [1], Ameni Kacem [2] and Atour Taghipour [3]

1 Department of Supply Chain & Digital Management, Métis Lab, Campus of Le Havre, Normandie Business School, 76600 Le Havre, France; ntran@em-normandie.fr (N.K.T.); ytliche@em-normandie.fr (Y.T.)
2 Seafrigo Group, 76600 Le Havre, France; a.kacem@seafrigo.com
3 Nimec Lab, University of Le Havre Normandie, 76063 Le Havre, France; atour.taghipour@univ-lehavre.fr
* Correspondence: ahmed.sahraoui30@em-normandie.fr

Abstract: There is a lack of technology innovation studies in the maritime sector focusing on developing countries. Generally, these countries present various limitations due to their own social, economic, and political contexts. Moreover, the lack of leadership support, stakeholder involvement, training, resources, and financial and academic support affects successful implementation of technological innovation. The objective of this paper is to emphasize the implementation of Information and Communication Technology (ICT) in the maritime sector and port companies of developing countries by investigating the impact of an ICT solution on port operations from berth to gate through yard operations. Our case study consists of the implementation of a Terminal Operating System (TOS) in the Port of Radès, the main port in Tunisia. An examination of the port operations before and after the implementation of the TOS is carried out. Then, the effects of TOS implementation on terminal operations are studied through a survey based on Key Performance Indicators (KPI) and submitted to managers of three port stakeholders. Key findings indicate that TOS allows an increase in the level of productivity from the quay crane to the gate, allowing decisions to be made based on real-time data and ensuring that the terminal is operating at its full potential. More specifically, berthing and delivery service times are improved thanks to the Electronic Data Interchange (EDI) and the streamlining of the gate and yard activities system. The results also indicate that reputation is progressively improving due to the ability to locate and monitor hazardous goods flowing through the port, and the ability to dispatch engine movement inside the port using the new terminal layout. However, in contrast with the port authority, the results highlight a lack of adaptability on the part of the stevedoring company, which requires time to progressively adapt to the new rules and constraints.

Keywords: information and communication technology; innovation; port operations; terminal operations management; port performance

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1. Introduction

World trade has been growing, contributing to the development of the global economy. Maritime trade represents one of the essential elements of global trade. According to the Review of Maritime Transport, the growth in international maritime trade has increased by 30.88% between 2010 and 2018, reaching 11,005 million tons loaded for all cargo types [1]. Among the cargo types, a growing number of containers in cargo ton-miles has been observed over the years, indicating the high efficiency of the maritime sector and the influence of containerization on it.

In fact, a terminal can be regarded as a chain because it consists of consecutive links such as vessel unloading, storage transfer, and hinterland loading. Those links are divided between the two sides of the terminal layout. The first side is Quayside, where the vessels dock at berths, and respectively unload and load inbound and outbound goods using cranes. The second is Landside, where trucks and trains handle goods arriving by road or railway. Between the two sides lie transport, storage, and stacking operations.

While these operations are being performed, problems can occur when using traditional process-based systems, such as there being no practical communication between the community members, causing delays in cargo delivery and client dissatisfaction. To address these problems, maritime actors need to implement technology to enhance the performance of their processes and to improve the quality of the services provided by companies or institutions [2,3].

When compared to the performance of developed countries such as the US or China [4–6], developing countries display poor sustainability indicators, necessitating further integration of technologies [7,8]. More specifically, to enhance operation efficiency and support the rapid growth of the maritime trade, the implementation of innovative systems and Information and Communication Technologies (ICT) in the maritime sector has become vital, especially in light of the challenges faced by the industry. These challenges consist of the increasing quantities of cargo being transported, the need for low transportation fees, and the efforts of shipping companies and stevedoring contractors to address these changes by increasing vessel revenue through a reduction in the time vessels remain in ports.

This paper addresses the impacts of the implementation of information technology on the performance of port operations by analyzing the issues faced on the basis of a real case study of the Port of Radès in Tunisia. In the last decade, Tunisia has dropped 45 places in the international ranking of the competitiveness of port services (https://lpi.worldbank.org/international/global/2018, accessed on 1 January 2021) established by the International Bank for Reconstruction and Development (IBRD), based on the Logistic Performance Index (LPI), dropping from 60th place in 2007 to 105th place in 2018, as a result of political and economic collapse following the "Arab spring" revolution [9]. According to the World Bank, the Port of Radès, in which 80% of the country's container traffic is concentrated, is the major link in Tunisia's integration into global value chains. The average stay of containers at the Port of Radès was 18 days in 2019, whereas it was 10 days ten years ago. In Morocco, by way of comparison, the average stay is 6 to 7 days. This indicates the inefficiency of the various stakeholders: customs, technical control, the Tunisian Stevedoring and Handling Company (STAM), the Tunisian Shipping Company (COTUNAV), etc. A reduction of ten days would correspond to an annual cost saving of USD 500 million (1.25% of gross domestic product).

According to the technical report of 2021 [10] on the Container Port Performance Index (CPPI) developed by the World Bank (WB) and S&P Global Market Intelligence, which measures and compares the performance of port infrastructure around the world and serves as a benchmark for major players in the global economy, the Port of Radès was ranked at the bottom of the international rankings, in 232nd and 237th place, respectively, out of the 370 ports surveyed. The scores recorded in this context are negative, reaching -0.821 using the first approach and -0.164 using the statistical approach.

This work addresses the main research question as to what the impacts of ICT solutions are on the operations of ports in view of mediocre performance. To answer this research question, we focused on two main aspects. The first was to study the limitations of terminal operations processes that do not include ICT solutions, or only very limited ones. On the basis of these limitations, a company would identify the issues and obstacles to achieving a better operations organization, planning and efficiency. The second was to study a newly implemented system's impacts on the whole process, covering different perspectives (communication, reputation, efficiency, impact on the environment, customer satisfaction, infrastructure, storage, reliability, etc.).

Our case study consists of the integration of a Terminal Operating System (TOS) into operations at the Port of Radès in Tunisia, where the STAM has recently implemented one. TOS refers to a wide range of software applications used by ports to manage information flows, container movements, and workload planning. It is based on the real-time tracking of containers at the port enclosure and the optimization of gear movements.

This paper is structured as follows. Section 2 reviews the main related works on ICT solutions at port terminals and, more precisely, the TOS and performance measures used in the maritime sector. Section 3 reports the research methodology used to analyze our case study of the Port of Radès, while Section 4 details the main findings. Section 5 discusses the results of the reported analysis. Finally, Section 6 summarizes the main conclusions of this research.

2. Literature Review

2.1. ICT Solutions in Port Terminals

Maritime transportation has dramatically increased in recent decades, presenting many advantages, such as reducing the risk of product damage and the quantity of packaging. However, ports have always faced a number of different challenges related to optimizing their work plan, reducing costs, securing sensitive data, increasing vessel revenue, and reducing the time vessels remain in port. Thus, there is a need to use new facilities to improve business procedures and to coordinate the different actors within a port, which can be achieved through the implementation of ICT solutions and optimization methods.

The implementation of ICT can have many positive impacts on supply chain agility and economic efficiency, including with respect to the smartness, safety, and sustainability of the systems [11–14]. In fact, technology can be used to minimize human error, increase performance, and reduce the time and cost of supply chains through continuous innovation such as Big Data, Internet of Things (IoT), and artificial intelligence [15,16].

The impact of ICT solutions has been studied regarding different aspects, such as the legal one, where Fedi et al. [17] analyzed the influence of ICT solutions on the Verified Gross Mass (VGM) implemented, along with other new mandatory constraints, in port operations in 2014 by the International Maritime Organization. It was found that ICT contributed to enhancing not only port operations but also port safety. Another aspect, knowledge sharing, was studied by Caporuscio et al. [18]. The authors explored the impact of ICT solutions on knowledge sharing through a case study of an E-port platform used by the port authority of Genoa in Italy. They found that this platform improved the inter-communication of the different actors in terms of both data sharing and virtual communication. More recently, Pagano et al. [19] discussed the implementation of ICTs in future ports and proposed a set of contents for the standardization of business actions. The authors grouped these actions into four categories: vessel and marine navigation; freight and logistics; passenger transport; and, finally, environmental sustainability.

A categorization of information system used in ports into ten different types was proposed by Heilig and Voß [20]. The authors distinguished the information systems based on whether they were used on the landside, the seaside, or in terminal operations. Additionally, they provided a full description of enabling technologies such as global navigation satellite systems, Electronic Data Interchange (EDI), and Radio-Frequency Identification (RFID), as shown in Figure 1. Among the available software applications detailed in [20], this paper focuses on a specific type of application called TOS, which has recently gained much attention in the maritime sector [21,22].

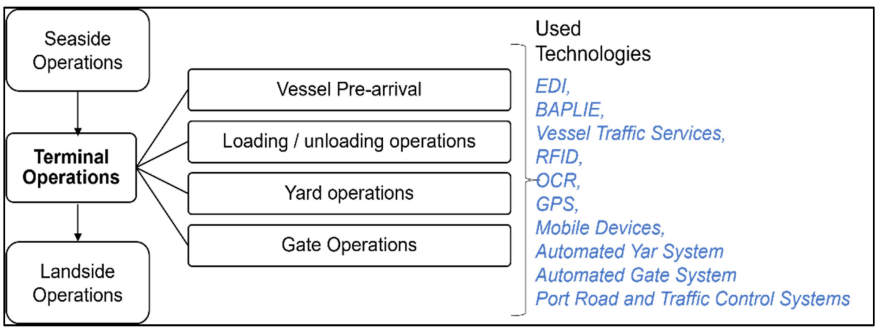

Figure 1. Categorization of the information systems and technologies used in terminal operations.

TOS is among the most widely used systems for automating terminal operations, including gate, berth, yard, and loading/unloading operations. It is defined as “a computer system that is designed to plan, track, and manage the movement and storage of all cargo, the use of assets, and the deployment of people in and around the seaport terminal or the port (including the hinterland) on a real-time basis” [22]. This definition highlights a very important aspect of the TOS, which is the fact of it operating in real time, where other systems cannot provide data immediately or request it instantly.

TOSs generally contribute to the maritime sector and the supply chain by controlling the organization, storage space, and capacity of all cargo within container terminals. These systems optimize labor force, equipment, and assignment planning. Moreover, they are used to exchange data in real time, locate containers and equipment in the port, and automate tasks. These tasks were previously performed manually, and required the consideration of many dimensions, such as arrival and departure rates (loading, unloading), container scheduling, and equipment allocation [23].

The TOS concept is similar to Enterprise Resource Planning (ERP), and has three fundamental elements: infrastructure, database, and development platform. As the TOS mission consists of collecting, storing, managing, analyzing, and dispersing information about terminal activities in order to provide a general and unified view of the core processes, the three elements should be stable, highly available, and effective in order to ensure the TOS’s success. Moreover, they should be precise, accurate, easily integrated, and personalized, and should be maintained over time.

Undoubtedly, TOS implementation requires a lot of effort and a comprehensive plan covering all of the essential components, including systems, processes, and people, which can vary from one port to another and depend on the situation and different elements in the port. These elements are interconnected, and each of them should be considered when selecting a TOS.

One of the first TOSs, proposed by Port of Singapore Authority (PSA) International, was Portnet, which is a nationwide business-to-business (B2B) port community solution [24]. It simplifies and synchronizes processes for customers both locally and globally. Another famous TOS is the Computer Integrated Terminal Operations System (CITOS), also proposed by PSA and deployed in Singapore port. It coordinates and integrates every asset, from prime movers, yard cranes, and quay cranes to containers and drivers. Octopi offers a modern web- and cloud-based TOS for small and medium-sized container and mixed-cargo terminals.

The most popular TOS, currently considered the leader in the field, is the Navis N4. The Navis N4 TOS has been used for over 27 years, and can be customized to meet the requirements of seaports, leading it to be adopted by more than 270 container terminals around the globe. According to the Validate Survey, conducted in 2017, 63% of customers had chosen Navis N4 TOS because it was able to optimize their operational processes.

2.2. Performance Measures Used in the Maritime Sector

Port operations can be evaluated by studying their performance, and future port development can be planned accordingly. Cullinane et al. [25] highlighted that port performance cannot be assessed based on a single measure. However, they assumed that many indications or measures could be used, and in particular that many key areas could be considered when evaluating the performance of a port, such as those proposed by the United Nations Conference on Trade and Development (UNCTAD) in 1976, which are considered to be a reference in this field [26].

Since then, performance evaluation has been enhanced through the implementation of more measures. For instance, some research works have focused on proposing performance frameworks, such as Ha et al. [27], who proposed a conceptual decision-making framework for studying port performance improvement strategies. They proposed a prioritization-based framework by comparing 30 strategies of a benefit feature in two Korean ports: Busan New Port and Busan North Port. More recently, Hervás-Peralta et al. [21] used the Analytic Hierarchy Process (AHP) approach to analyze different port operations such as yard management, berth management and scheduling, port and vessel operations, gate in and gate out management, inventory and warehouse management, and track/trace management.

Other researchers and practitioners have focused on performance measures and indicators, such as Hinkka et al. [28], who proposed a list of indicators for evaluating terminal performance that they divided into three types: the first type included easily obtained indicators based on simulation models; the second type covered those that could be obtained through simulation, but only with the use of additional computation; and the third type included indicators that were difficult to obtain through simulation. They distinguished the different Key Performance Indicators (KPIs), namely Operational (intermodal terminal throughput (volume), equipment utilization, gate utilization, etc.), Financial (terminal's profitability, operating efficiency, corrective maintenance cost, etc.), Quality (turnaround time, waiting time, easiness of entry and exit from highways and rail network, etc.), Environmental (energy consumption per handled unit, Carbon footprint per unit, etc.), and Safety (number of accidents, accidents related to hazard cargo, etc.).

Konsta and Plomaritou [29] detailed different approaches and techniques used to measure performance, such as Six Sigma, KPIs, Balance Scorecard (BSC), the Business Excellence Model (BEM), and the Capability Maturity Model (CMM). In the work of Min et al. [22], the authors compared integrated and non-integrated TOS systems based on different KPIs based on 10 terminal operators in the Inner Harbor of the Incheon Port in Korea. Another range of works analyzed environmental performance indicators using qualitative and quantitative approaches [30,31].

Elbert et al. [32] studied the influence of digitalization on port choice behavior through an analysis of decision makers in southwest Germany. The analysis was based on various indicators, such as efficiency, obtained by measuring the cycle time of container handling at the port; customer satisfaction, as represented by the capacity to rapidly react to customer requirements; reputation, which is related to damages and safety; the infrastructure serving the port and the terminal layout and facilities; storage, which can be defined as the capacity of terminals; and reliability or punctuality, which can be measured based on the capability to adhere to the planned schedule.

Table 1 presents some of the research work that has been performed in this field according to two types of approach: those focusing on providing a whole framework/model of performance, and those using Key Performance or Port Performance Indicators. Similar to the latter category, the aim of this paper is to study performance following the implementation of the TOS in the Port of Radès.

Table 1. Research approaches in terms of Port Performance.

Authors	Performance Framework	Performance Indicators	Approach
[1]		X	Different types of indicators
[30]		X	Survey—Environmental performance indicators
[27]	X		Analytic Hierarchy Process—Fuzzy technique for order preference
[32]		X	Exploratory research study with 8 KPIs
[22]	X	X	Exploratory analysis—Analytic Hierarchy Process
[28]		X	KPIs from different stakeholder groups' perspectives
[21]	X		Analytic Hierarchy Process
[31]		X	Entropy approach—Environmental performance indicators

3. Materials and Methods

In this work, a case study of the implementation of a TOS in the Port of Radès in Tunisia is performed. This is used to investigate how the ICT solution impacts the terminal operations and the communication between the different stakeholders: the port authority, OMMP, the port operator, STAM, and the maritime agents, in addition to the customs and the borders police. Thus, exploratory research was conducted through the following elements:

- A mapping and a comparison are performed between the port operation processes before and after the implementation of the TOS was conducted. The comparison was performed based on the following operations: pre-arrival and vessel planning, loading operations, unloading operations, yard operations, gate operations, and equipment handling and control. This mapping and comparison made it possible to identify the limitations and problems of the previous process, creating a need for the automation and implementation of an ICT solution.
- Analysis of the impacts of TOS implementation in the Port of Radès was performed through a statistical analysis. Unlike qualitative analysis, quantitative research methodologies the data to be interpreted and the findings to be presented straightforwardly and objectively. One of the common ways is to use surveys, which allow data to be gathered from individuals using a list of questions. For each question, a range of answers is provided. Thus, standardized and structured data can be obtained. This method is used at all levels, ranging from small-scale surveys such as might be used students or for small projects, to large-scale international surveys. The most important stage of the questionnaire is its design. Once the design of the questionnaire has been completed, the researcher will have determined the questions and answers, and it is not possible to go back in the process [33]. This analysis is based on a survey designed based on specific KPIs. The questions and answers were inspired by a survey performed by Navis (https://www.businesswire.com/news/home/20171024005433/en/Navis-N4-Customers-Report-Strong-Productivity-Improvements-and-Reduction-in-Operating-Costs, accessed on 28 May 2023), the company providing the TOS to STAM, and were related to the KPI categories defined by Elbert et al. [32], as shown in Figure 2.

Figure 2. KPI categories used to analyze the performance of port operations.

The main goal of the survey is to gather data on individual viewpoints and perspectives about the impacts of the implementation of the TOS on the overall performance of the Port of Radès based on the KPI categories defined above. Specifically, the stratified sampling method consists of dividing the population into smaller sub-groups called strata [34]. Thus, two questionnaires were sent out: the first was for the stevedoring company, STAM, and the port authority, OMMP, while the second was for the maritime agents.

3.1. Comparison of the Terminal Operations before and after TOS Implementation

A comparison of terminal operations before and after the implementation of the TOS in the Port of Radès was performed based on the following main aspects: (1) pre-arrival and vessel planning, loading/unloading operations, (2) yard operations, (3) gate operations (4) re-stow operations, and (5) equipment handling and control.

3.1.1. Pre-Arrival and Vessel Planning

As shown in Figure 3, STAM did not maintain the berthing window for pre-arrival vessels before implementing the TOS. Vessel information flowed between the shipping agent and STAM, and was provided manually. The maritime agent would submit the ship pre-arrival document to the port authority and the stevedoring company during the morning meeting, which was held in the port authority's office. Vessel operations using the TOS start with the receipt of information about the vessel using EDI, and this is discussed during the berthing meeting. The system provides a module to support terminals in reducing uncertainty when planning the berthing schedule of a vessel thanks to the EDI, and more specifically thanks to a "Baplie" message. A Baplie message is "A message to transmit information about equipment (mostly containers) and goods on a means of transport (typically a container vessel), including their location on the means of transport" (https://service.unece.org/trade/untdid/d15b/trmd/baplie_c.htm, accessed on 3 June 2023). This allows the maximization of berth space, the increase in throughput, the irrelevant stowage, and the reduction of cost per move.

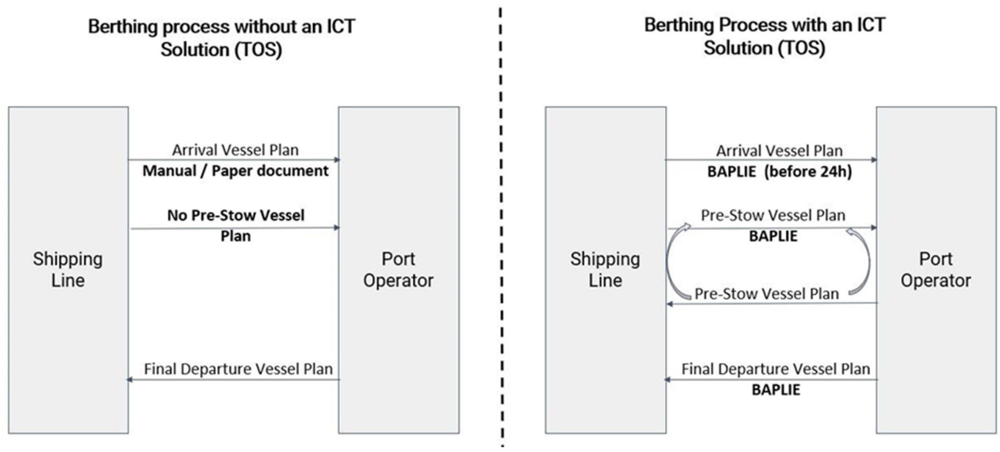

Figure 3. Berthing process before and after the implementation of the TOS.

3.1.2. Unloading Operations

Unlike for loading operations, STAM does not carry out a vessel loading plan determined by the shipping agents. Consequently, STAM executes vessel loading based only on the shipping agents' instructions. Vessel loading operations for full and empty containers at STAM are not directly done by Internal Transfer Vehicles (ITVs). Containers are first stacked in a heap area near quay cranes and loaded onto the vessel according to a designated vessel slot position in the shipping agents' instructions.

Since TOS implementation, as described in Figure 4, the planning starts 24 h before the loading process using the "Quay Commander" module, which affords the real-time monitoring of crane schedules and optimizes the planning, execution of containers, and movement of equipment such quay cranes (QCs), straddle carriers (SCs) and rubber tired gantries (RTGs).

3.1.3. Loading Operations

STAM acts as a coordinator for the shipping agents, providing handling services and equipment to support vessel operations. STAM did not plan vessel discharge to the yard, rather, shipping agents were responsible for vessel loading planning. STAM only executed vessel loading based on shipping agents' instructions. The STAM operation office checked whether the containers were all in the yard. A work queue was created to move the containers from yard blocks to the heap area. The allocation of equipment and human resources was performed. After completion of the loading operation, the STAM operation office received an updated cargo manifest list indicating the loaded and unloaded containers. Finally, the shipping agents were informed that the containers had been loaded. Since TOS implementation, the loading process is similar to the unloading process, which is based on the Quay Commander module. Figure 4 compares the two methods and evaluates the implementation of the TOS.

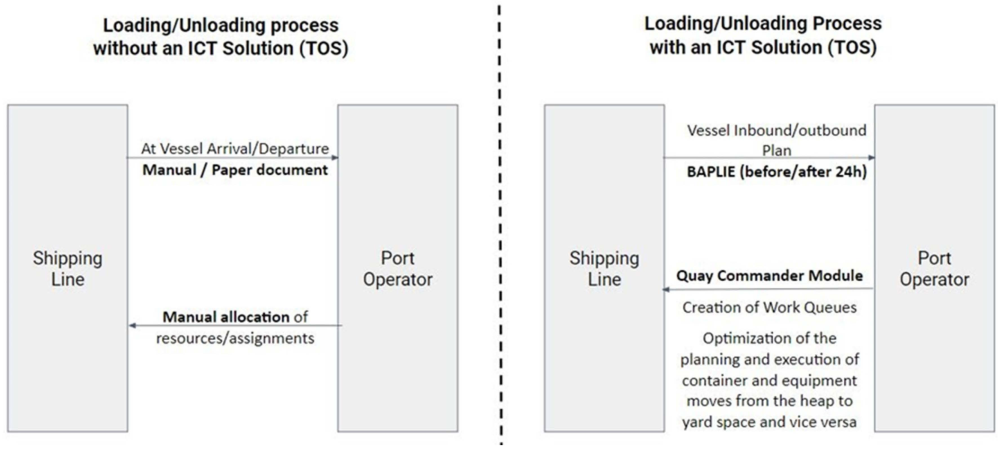

Figure 4. Loading/unloading processes before and after the implementation of the TOS.

3.1.4. Re-Stow Operations

Before TOS, under the instructions of shipping agents or the master of the vessel, two types of re-stows were performed by STAM: (1) From ship to quay and from quay to ship; and (2) from ship to ship. Using the TOS, the "AutoStow" functionality combines stowage factors (such as container length and weight) with yard constraints and operating parameters. Shipping agents request containers for re-stow to STAM planning. The STAM planner informs the yard planner of planned re-stows and the required yard plan is then made. The unload and load processes of re-stow containers are the same as those mentioned in the vessel discharge and vessel load processes.

3.1.5. Yard Operations

STAM uses SCs to cover yard zones rather than equipment linked to a crane. This is due to the layout specification and the limited area between the quays and the storage zones. The planner of the yard operations used to carry out physical checks for empty blocks and coordinate with SC operators by radio. Then, he recorded the containers' locations manually on the internal IT system. These operations were not carried out in real time. Yard planning, described in Figure 5, represents a critical component of the TOS, as it allows the implementation of a specific and strategic yard plan and ensures the fluid throughput of cargo. In fact, non-efficient decking decisions can be costly and time consuming. The feature of Navis used in yard operations is "Expert Decking", which allows increasing yard space to handle growth without adding new land, minimizing yard shuffles, and maximizing productivity.

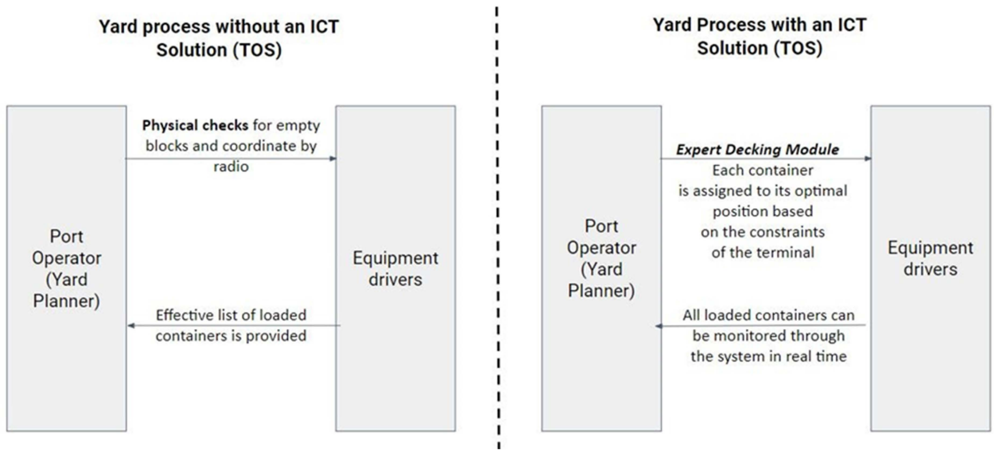

Figure 5. Yard process before and after the implementation of the TOS.

3.1.6. Gate Operations

There used to be a registration office in STAM known as the "Guichet Unique" (GU), which was physically located outside the terminal. This GU was a unique office that gathered STAM, customs and the port authority. In this pre-gate facility, all administrative paperwork was completed, some checks were also performed, and some services were then invoiced and paid. External trucks couldn't proceed into the terminal until they had been cleared at the GU. For this process, STAM used an in-house billing system for invoices and collecting payments. However, there was no appointment system to pre-register the trucks.

Since TOS implementation, an integrated appointment booking and online payment system has been used, as shown in Figure 6. At this level, there are two visit types: The first is "Receive Export", where Container Number, Vessel Visit, Booking Number, Weight, Hazards, and Damages are specified. The second is "Deliver Import", where Container Number, Release Number, Bill of Lading, Line ID are indicated. For both visit types, there are common pieces of information, such as Truck License, Driver License/Name, etc. This gate module allows hazards, damage, reefer data and processing containers to be recorded automatically or semi-automatically thanks to Optical Character Reader (OCR) and RFID. It also allows the status of gate transactions to be monitored in real-time, using Radio Data Terminals (RDT) for inspection, interacting with the yard planning application, efficiently managing trouble transactions, and validating bookings.

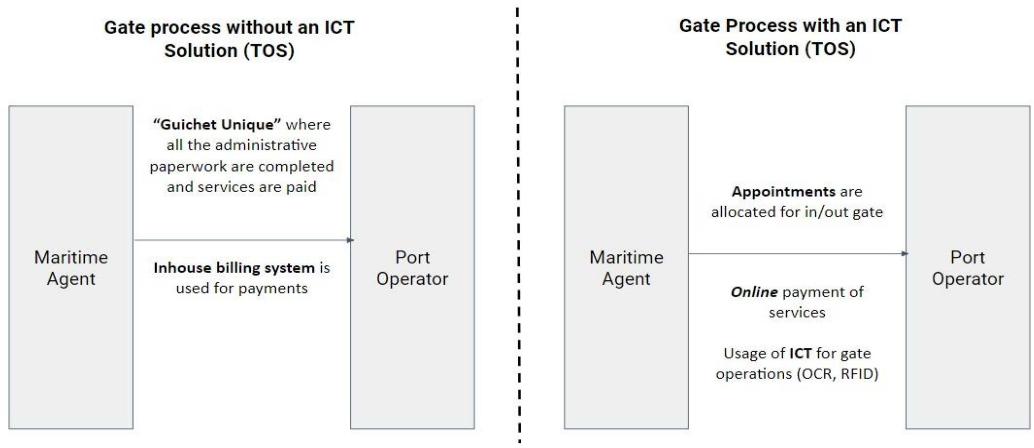

Figure 6. Gate process before and after the implementation of the TOS.

3.1.7. Equipment Handling and Control

The Equipment Control module in the TOS provides functionality for managing real-time operations by container handling equipment in the yard. STAM used to have seven mobile cranes to support discharge and loading operations on the quay. Since TOS implementation, the yard operations have been supported by ITVs, Straddle Carriers, 6 RTG for storage space optimization, 12 Roll-On/Roll-Off (RORO) trucks, 12 trailers for the transfer of containers from the quays to the storage areas, and 2 new RS to strengthen container re-stow operations either unloaded or being loaded.

STAM installed tablets on SC, RS, ITVs, and RTGs, while RORO trucks and ITV do not have tablets onboard. Thanks to the TOS and, specifically, the Navis Prime Route module, carriers are joined across a wide array of work assignments, breaking them up into distinct components, allowing for efficient, real-time dispatch of the equipment to perform the available work. Table 2 summarizes all the terminal operations by highlighting the difference between the old process and the new one following the implementation of the TOS.

Table 2. Summary of port operations before and after implementing the TOS.

Actors	Process before TOS	Process after TOS	Used Technology
Pre-Arrival & Berth Planning			
Maritime Agent, STAM, Port Authority	Pre-arrival information shared through TTN (Tunis Trade Net). Documents (such as Cargo Manifest) are provided to the port authority and the stevedoring company during the daily morning meeting. Planning of operations done the day of the arrival.	Pre-arrival information shared the same way through TTN (Tunis Trade Net). Documents (such as Cargo Manifest) are shared using Electronic Data Interchange (EDI). Vessel discharge planning done at least 24 h before the vessel arrival. Quay Commander affords real-time monitoring of crane schedules, vessel container moves, vessel activities, and vessel labor assignments.	Electronic Data Interchange (EDI) expedites order processing, facilitates prompt customer responses, and effectively organizes and secures data. It replaces traditional methods such as fax, phone, and email, thereby streamlining and enhancing the overall efficiency of the process.
Loading/Unloading Operations			
STAM, Maritime agent, Drivers of equipment	Paper-based operations at the arrival of the vessel; manual allocation of resources/assignments.	TOS-based operations prior to vessel arrival; optimal resource planning, job scheduling, etc.	BAPLIE message helps to guide engine drivers to handle planned containers in terms of accuracy without making mistakes or losing time and provides real-time visibility. Defined as a message to transmit information about equipment and goods on a means of transport and location.
Yard operations			
STAM	The planner of the yard operations used to carry out physical checks for empty blocks and coordinate with SC operators by radio.	AutoStow combines stowage factors (such as container length and weight) with yard constraints and operating parameters. Expert Decking allows utilization increase in yard space in order to handle growth especially with the new terminal layout and equipment	Expert Decking ensures that every container is allocated to its ideal location, resulting in significantly improved utilization of yard space. This innovative approach leads to a remarkable reduction of up to 90% in the need for re-handling containers. Moreover, it maximizes the efficiency of equipment usage, enabling businesses to accommodate growth without the necessity of acquiring additional land.
Gate operations			
STAM, Maritime Agent, Customs	Operations managed manually. All administrative paperwork at the registration office "Guichet Unique". An in-house billing system is used for invoices and collecting payments.	Appointment booking system. "Receive Export" gate operation where Container Number, Vessel Visit, Booking Number, Weight, Hazards, and Damages are specified. "Deliver Import" is where Container Number, Release Number, Bill of Lading, Line ID are indicated.	This module incorporates various technologies to enhance its functionality: • OCR (Optical Character Reader): employs advanced algorithms to convert text from an image into a format that can be easily interpreted by machines. • RFID (Radio Frequency Identification): by utilizing electromagnetic fields, it establishes communication with RFID tags installed on vehicles and containers, enabling efficient tracking and identification. • RDT (Radio Data Terminals): these terminals facilitate wireless connectivity to logistics automation software, allowing operators to receive instructions and exchange data seamlessly.
Equipment Control			
STAM	STAM uses straddle carriers, which are used as equipment that cover yard zones (similar to an RTG) rather than equipment that is linked to a crane.	Navis PrimeRoute joins carriers across a wide array of work assignments, breaking them up into distinct components, allowing for the efficient, real-time dispatching of the equipment to the work available.	The software application employs contemporary operational research optimization techniques to maximize the utilization of Container Handling Equipment.

To increase this study's reliability and trustworthiness, which represent two main features of any research study [33], firstly, an observation and a detailed description of the port processes before and after TOS implementation was provided. Second, the results of the statistical analysis are presented while restricting the sample population to employees involved in the TOS from STAM and OMMP, and from among maritime agents. This makes it possible to better analyze the research question from different points of view and from the perspectives of different port actors.

3.2. Survey Design and Sample Population

The survey (see Appendix A) was disseminated to target stakeholders that worked directly with the TOS, and who had 5+ years of experience in the port using Google Forms. The survey was sent along with an email explaining the aim of the research and its context. The survey contained different questions:

- Checklists contain a list of items, and the participant can check any of them that apply in the situation.
- Yes/No questions limit answers to these alternative responses.
- Multiple-choice questions contain different possible answers, and the participant is asked to select the most applicable ones.
- Percentage-rating scales require the participant to choose a percentage of improvement of several aspects using the following ranges: Up to 10%, 10–24%, 25–49%, 50–74%, 75% and greater.

The structure of the survey was inspired by a survey performed by Navis, the company providing the TOS to STAM, and related to the KPI categories shown in Figure 2, which were proposed by Elbert et al. [32]. Thus, we specify the following groups of issues/KPIs:

- Productivity: How much would you estimate the following aspects have improved since TOS? The response consists of choosing a percentage of improvement of the following aspects: gate productivity, yard productivity, vessel handling, productivity, safety, reporting quality;
- Cost: In what areas has TOS helped to lower operational costs? The answer includes the following options: yard planning, quay crane planning, yard operations, gate operations, monitoring and reporting;

For the following questions, Yes or No answers can be selected:

- Efficiency: Do you find that the delivery service time has been improved since TOS implementation?
- Reputation: Do you think that thanks to the TOS, the reputation of the Port of Radès (damages, accidents, safety, etc.) has been improved?
- Reliability: Do you find that the reliability in terms of punctuality (the capability to adhere to the planned schedule) has been enhanced since TOS implementation?
- Infrastructure: Do you find that the installed infrastructure (new port and terminal layout and facilities) has had a positive impact on work performance?
- Collaboration: Do you think that collaboration between port stakeholders has been improved since implementing the TOS?
- Customer Satisfaction: Has the service quality progressively improved since the implementation of the TOS?

As mentioned previously, to increase the reliability and significance of this study, participation was limited to employees directly working or involved with TOS implementation in the Port of Radès. Thus, the survey was submitted to eight STAM directors and managers, of which 62.5% submitted answers, 6 directors of the port authority, of which 83.33% answered the survey, and only 8 maritime agents who dealt in the Port of Radès, of which 62.5% submitted answers. Participants having an in-depth knowledge and experience of TOS usage, such as the director of the port, the Chief Technical Officer (CTO), the Chief Operating Officer (COO), and stevedoring manager, were involved in the survey.

4. Results

In order to answer the research question addressed in this paper, the impacts of the implementation of the TOS in the Port of Radès were analyzed on the basis of two surveys carried out between February and April 2021. In order to obtain relevant results, the number of respondents was limited, in order to be able to select expert stakeholders in TOS who had an in-depth knowledge of this ICT solution. The first survey was sent to STAM, as the port operator contractor, and to the port authority OMMP, as the actor ensuring and surveying the sustainability and control of the port. Its purposes were to analyze and identify the accuracy and the gap between the two types of respondent (STAM and PA). Regarding the second survey, questions were submitted to maritime agents to obtain their feedback on the implementation of the TOS.

4.1. Statistical Analysis of the Survey

The first part of our survey included questions related to the challenges faced by the Port of Radès and those addressed by TOS implementation. Regarding the challenging aspects in the Port of Radès, the results show that all actors (the stevedoring company, the port authority, and the maritime agents) agreed that the main ones were the optimization of operations to improve productivity (100% of the answers) and the efficient handling of more Twenty-feet Equivalent Units (TEUs) (between 80% and 100% of the participants), as shown in Figure 7. This is because these challenges have a direct and joint impact on all of the stakeholders' interests. In fact, improving productivity and the handling of TEUs have many benefits, such as increased customer satisfaction, which leads to an increase in the reliability of the port operator, thus meeting the concession contract requirements signed by the port operator and port authority, which increases the attractiveness of the port, and decreasing both the berthing cost and the berthing time, which provide more profit to the port operator.

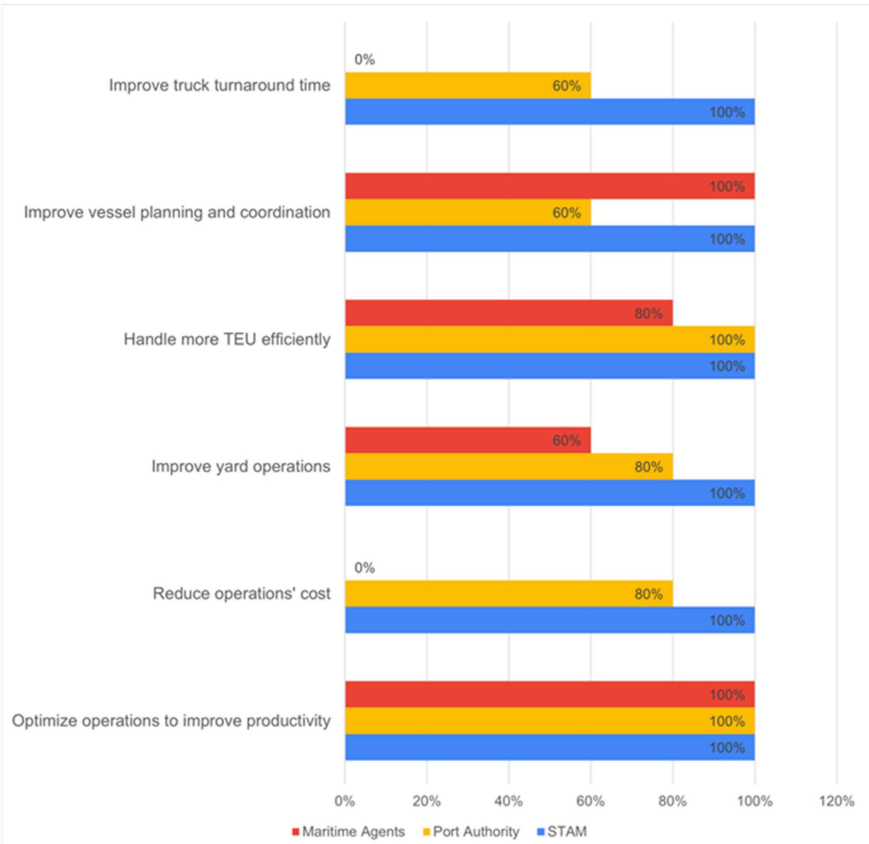

Figure 7. Main challenges in the Port of Radès.

The participants from STAM and OMMP were asked to specify the areas in which TOS implementation benefits them. As presented in Figure 7, the results show that the participants from both entities agreed that they benefitted from efficient gate operations with faster truck turn times (gap of 20%), better monitoring tools to improve operations (gap of 20%), better visibility and reporting (no gap), improved yard planning (gap of 20%), helping the team to work better (gap of 20%), and improved safety of operations (gap of 20%). Nevertheless, STAM, as an operator contractor, and OMMP, as an actor ensuring the sustainability and control of the port, have different perspectives regarding improved equipment utilization, with a gap of 60%, greater stability of operations, with a gap of 40%, and optimized crane assignment, with a gap of 40%. This implies that both groups assume that TOS has benefits in the different areas specified: gate operations, monitoring, visibility, reporting, teamwork, consistency, safety, yard planning, and equipment utilization. This difference in points of view is relevant, because STAM is best able to judge the benefits regarding equipment utilization, stability of operations, and crane assignment, as their managers and employees are more involved in these daily operations.

The second part was dedicated to the estimation of the improvement on the basis of percentages for the different following features: gate productivity, yard productivity, safety, reporting quality, and vessel handling productivity. The participants were asked to rank each of the following aspects based on percentage intervals presented in Figure 8, ranging from "Up to 10%" to "75% and greater". The results are discussed in the following:

- Impact of the TOS on gate productivity: Figure 9a shows that the three stakeholders were almost in agreement on an improvement between 10% and 24%. This improvement remained limited because the enhancement of yard productivity leads to an increase in the number of gate flows, which requires new solutions such as the establishment of new gates in order to enhance both gate fluidity and yard operations. These results are in agreement with the of the Navis survey (https://www.businesswire.com/news/home/20171024005433/en/Navis-N4-Customers-Report-Strong-Productivity-Improvements-and-Reduction-in-Operating-Costs, accessed on 28 May 2023).
- Impact of the TOS on yard productivity: Figure 9b shows that 40% of maritime agents and port authorities evaluated yard productivity to be limited to between 25% and 49%, but 60% of the stevedoring company participants estimated the yard productivity to be between 50% and 74%. This implies that there was an improvement in the storage operations, and there is a relationship between the respondents, despite the slight gaps between the STAM respondents and the rest of the stakeholders. This is a result of the mitigation of the amount of manual work and the benefits brought by automation, which provides real-time visibility, accurate work performance, time gains, better work coordination between operations departments, and freedom from errors.
- Impact of the TOS on safety: Figure 9c shows that the results obtained from the three stakeholder groups were in agreement. Most of their answers lay in the interval from 50% to 74%. This can be explained by the contribution of the TOS to making vessel visits safer, improving the visibility of hazardous goods flowing through the port, and organizing the movement of engines inside the port with the new terminal layout.
- Impact of the TOS on reporting quality: Most of the respondents regarded the reporting quality to have been improved by the TOS, as shown in Figure 9d. This can be explained by the reporting functionality of the TOS, which helps by allowing real-time operational analysis when making strategic decisions on the basis of instant insights. However, based on the historical data provided via an in-house system, delays could affect decision making, especially when conclusions must be drawn immediately.
- Impact of the TOS on vessel handling productivity: Figure 9e shows that the OMMP respondents found that vessel handling was improved using the TOS by 25% to 49%, while 40% of the stevedoring company participants estimated that the improvement was between 50% and 74%. Nevertheless, 80% of the maritime responses varied between 25% and 75%.

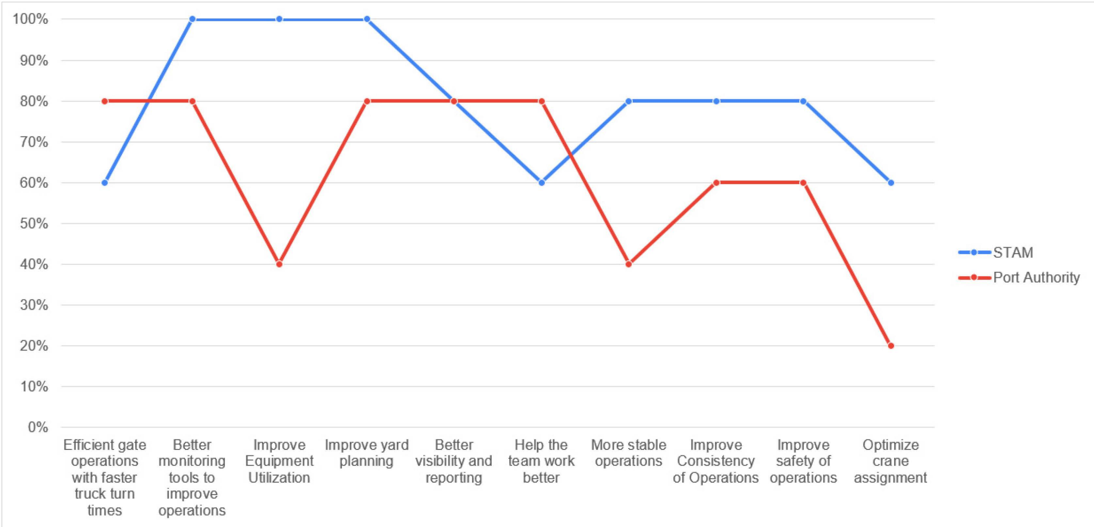

Figure 8. Most important benefits of the TOS implemented in the Port of Radès according to the STAM and OMMP participants.

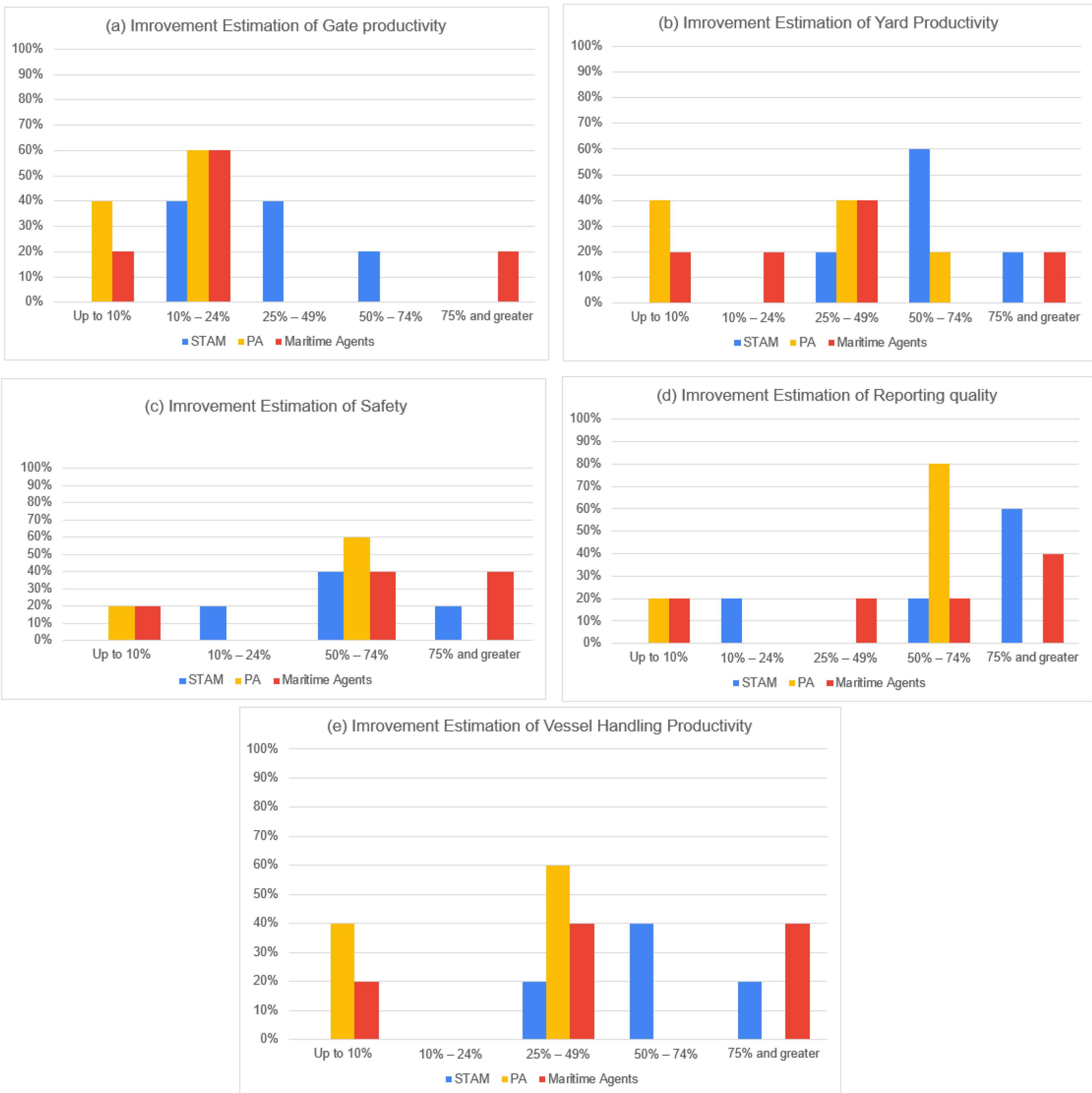

Figure 9. Results for estimated improvement since TOS implementation.

These results are again in alignment with the Navis survey results, even though the percentages of improvement were limited to 25–49% in the Navis survey. The results indicate a concrete improvement in vessel handling productivity when using an optimization module to generate automatic plans for the vessels and setting specific rules based on the instructions of the ship planner.

The third part included two questions regarding cost reductions when using the TOS. The results of the first variables presented in Figure 10 show that between 60% and 100% of STAM and OMMP participants placed importance on cost reduction, firstly with respect to yard operations and yard planning, because these are considered to be the core of the port's activity, while at the same time being linked directly to quay operations and gate operations. This newly developed system allows the port operator to optimize the movement of engines in the port by reducing unnecessary equipment usage. This also leads to decreased costs due to fuel consumption, and reduced time wastage, while avoiding accidents and damage, providing rapid and relevant decisions, and increasing the return on investment [35].

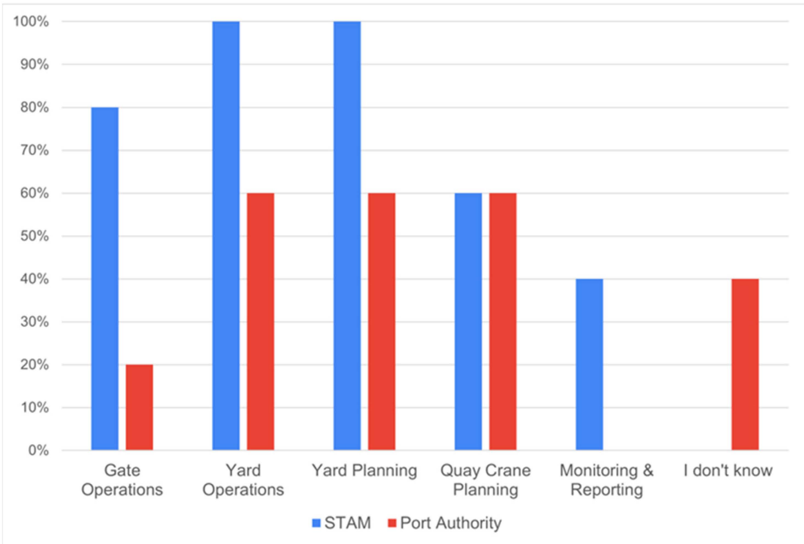

Figure 10. Results for the areas in which TOS helped to lower operational costs according to the STAM and OMMP participants.

The second question regarding cost reduction was related to fuel consumption. All STAM respondents and 20% of OMMP participants agreed that fuel consumption decreased thanks to the TOS. These results can be explained by the improvement of the whole activity of port planning, coordination, and real-time visibility. Due to the optimization of engine movements and usage, as well as their dispatch and monitoring, fuel costs are reduced. Similarly, participants of the Navis Survey agreed that the use of N4 TOS lowered the cost of different port operations: by 61% for yard planning, 59% for yard operations and vessel operations, 49% for gate efficiency and 46% for monitoring and reporting. We conclude that both surveys demonstrate the importance of cost reduction, especially with respect to yard planning and operations.

4.2. Main Contributions

Table 3 presents the results of the benefits of the TOS for the Port of Radès according to the perception of the port actors. In terms of delivery service time, Table 3 shows a strong relation between the responses, with 100% of the STAM and 80% of the maritime agent respondents regarding the delivery service time to have been improved since TOS implementation thanks to the streamlining of the gate and yard activity system. The delivery was simplified. After gate identification, the recipient of a container can go directly to the location of their container. Similarly, the RTG operator is instantly notified of the delivery of the container when the truck goes through the gate.

Regarding the reduction in berthing time, 80% of respondents, both from the stevedoring company and among maritime agents, regarded the berthing time to have been reduced after TOS implementation. This can be explained by the ability to share information about the vessel before its arrival using EDI and the enhancement of different operations (loading/unloading, storage, and delivery).

Another KPI category included in the survey is Reputation. This performance measure represents damage, accidents, and safety issues. Table 3 shows that 100% of the stevedoring company participants and 80% of the maritime agents agreed that Reputation was progressively improving. This is due to the ability to locate and monitor hazardous goods flowing through the port, and the ability to dispatch engine movements inside the port as a result of the new terminal layout. Table 3 also shows that only 20% of the stevedoring company participants adapted easily to the new system, and 100% of the port authority members agreed. This can be explained by the difficulty of adapting to the new system for the different actors. STAM used to act as a coordinator with the shipping agents, providing container handling equipment and handling services to support vessel operations. Under the new system, maritime agents need to adapt to the new rules by providing all information at least 24 h before export operations.

Similarly, adaption was also addressed at the gate level, where 60% of STAM and 20% of OMMP participants regarded gate fluidity to have been improved. This was due to the increased yard and vessel productivity, which created increased flow at the gate. Again, the stevedoring company is getting used to the new system and adapting progressively to its rules and constraints.

The two final results presented in Table 3 show the agreement among the different stakeholders on the positive impact of the new port and terminal layout and facilities on work performance, the increase in the storage capacity of the port using the newly installed RTGs, the decrease in the number of accidents involving engines as well as their useless movement, the increased safety and decreased number of damaged or robbed containers. Moreover, these results show that the number of useless engine movements, fuel consumption, the indicator of air pollution were significantly decreased.

Table 3. Results of the survey regarding the benefits of the TOS according to the port actors: port operator (STAM), port authority (OMMP) and maritime agents.

Results after the Implementation of the TOS		Port Operator STAM	Port Authority OMMP	Maritime Agents
Improvement in delivery service time	Yes	100%	N/A	80%
	No	0%	N/A	20%
Berthing time reduction	Yes	80%	N/A	80%
	No	20%	N/A	20%
Improvement in the reputation of the Port of Radès (damages, accidents, safety, etc.)	Yes	100%	N/A	80%
	No	0%	N/A	20%
Adaptation to the new system	Yes	20%	0%	N/A
	No	80%	100%	N/A
Improvement in gate fluidity	Yes	60%	N/A	20%
	No	40%	N/A	80%
Positive impact of the installed infrastructure (new port and terminal layout and facilities)	Yes	100%	100%	100%
	No	0%	0%	0%
Storage capacity increase after installing 6 RTG and changing the terminal layout	Yes	100%	100%	100%
	No	0%	0%	0%
Contribution to decreasing air pollution and improving the environment	Yes	80%	100%	80%
	No	20%	0%	20%

5. Discussion

According to the continuous evolution of maritime transport in terms of technology and the volume of the containers transported, STAM, as the operator contractor of the biggest port in Tunisia, which specializes in handling container and RORO cargo, implemented a TOS to ensure the continuity and sustainability of its port activities and to address competition from neighboring ports. In addition to the increasing competition, STAM was facing many management challenges related to port operations, such as irrelevant container inventories, the manual planning and assignment of moving containers, substantial operational costs, and issues related to safety, damages, and security. The company sought efficient ways of working and integrating newly developed systems in order to enhance the productivity of the port operations (vessel operations, yard operations, delivery, and gate operations). From the analysis of the previous way of handling the terminal, described in Section 4.1, berth planning and yard planning were performed by employees, and no automated systems or optimization functions were used. Rather, they were performed based on the professional experience of the planners. To answer the research question specified in the introduction and to check whether these shortcomings of the previous systems were addressed by implementing the TOS, a survey was submitted to three different types of actor within the Port of Radès: the stevedoring company STAM, the Port Authority OMMP, and maritime agents. All respondents had experience in this field, and interacted directly with the implemented TOS.

The survey study showed that most respondents regarded TOS to have had a positive impact and produced a lot of advantages for the Port of Radès. In fact, implementing TOS allowed an increase in the level of productivity at a number of different stages, from the quay crane to the gate, making decisions based on real-time data, accessing performance indicators instantly, and ensuring that the terminal was operating at its full potential. A key benefit of the TOS is information sharing between all stakeholders, including maritime agents, customs, and the Tunisian e-payment system. Regarding pre-arrival and vessel operations, TOS affords real-time monitoring of crane schedules, vessel container moves, vessel activities, and vessel labor assignments. For loading and unloading operations, optimal resource planning and job scheduling are proposed by TOS. Yard operations were enhanced thanks to the combination of stowage factors (such as container length and weight) with yard constraints and operating parameters, and the proposal of a new terminal layout and equipment. This allowed an increase in the yard space that could be utilized, making it possible to handle growth. Thanks to the pre-booking and online billing system, customized for the Tunisian e-payment system, gate operations were improved, and cargo information could be shared among all eligible actors. Regarding equipment control, TOS is able to join carriers across work assignments, breaking them up into distinct components, allowing for efficient, real-time dispatch of the equipment to perform the available work.

Although these results indicate positive perceptions of TOS implementation, as detailed in Table 3, they could have been better, as TOS was implemented just as the pandemic crisis started spreading all over the world, which has affected the global economy generally and maritime transport specifically. In addition, political and social stability are an important aspect to consider, as Tunisia has faced issues related to economic growth and political instability since the revolution. Consequently, all ports in Tunisia have been affected, including the biggest port, the Port of Radès. This instability has also led to strikes and requests for salary increase from among the workforce. All these facts have resulted in financial problems for the stevedoring company. Nevertheless, in order to successfully implement an ICT solution, external factors such as political, economic, and social factors should also be considered. Table 4 summarizes the main problems addressed by and contributions of the TOS implemented in the Port of Radès.

Table 4. Summary of TOS benefits and problems occurred before its implementation in the Port of Radès, Tunisia.

Problems Occurring before TOS	TOS Benefits
• No real-time visibility • No shared information between the carrier and the port operator • No efficient collaboration between the port stakeholders • Planning errors: irrelevant handling and stowage • Irrelevant use of equipment • Increased operation costs • Time wastage • Increasing customer claims • No real-time reporting • No real-time planning • No accurate and instant results	• Collaboration • Reduction in planning time • Optimal allocation of equipment and human resources • Real-time container processing • Real-time planning • Efficient collaboration between the stakeholders and the different departments of the stevedoring company • Processing time reduce in the different stages • Cost reduction • Live reporting • Customer satisfaction • Decreased pollution level • Reduced delivery time • Enhancement of equipment use

Finally, in systems such TOS, companies such as Navis will always be enhancing their systems and modules in order to meet users' requirements, using new technologies that will help to enhance efficiency, safety, and sustainability. Below, we have summarized the existing technologies, their future trends, and any potential bottlenecks.

- Automation and Robotics: Automated stacking cranes improve container handling efficiency by autonomously moving containers from storage yards to trucks or vessels. In addition, automated guided vehicles (AGVs) transport containers within the port, optimizing logistics and reducing the amount of manual labor required [36].
- The adoption of Machine Learning (ML) algorithms will enhance automation and robotics in ports. Advanced AGVs with autonomous decision-making capabilities, swarm robotics, and cooperative operation are expected to become more prevalent. However, high investment costs, challenges related to integration with existing infrastructure, and concerns regarding job displacement are some of the bottlenecks hindering the widespread implementation of automation and robotics in ports.
- Internet of Things (IoT) and Sensor Networks [37] is used in TOS and other platforms through the integration of sensors into containers in order to provide real-time data on location, temperature, humidity, and other relevant parameters. These devices and sensors monitor the movement and location of assets within the port, improving visibility and reducing the risk of loss or theft. Thus, the integration of IoT with blockchain technology enhances supply chain transparency, security, and traceability. As a future trend, edge computing and 5G networks will enable faster and more reliable data processing and communication within port ecosystems. However, challenges related to data security, the interoperability of diverse IoT devices, and the scalability of IoT deployments present significant bottlenecks. Additionally, the large volume of data generated by IoT devices requires effective data management and analytics solutions.
- Big Data Analytics is widely used in the context of predictive maintenance, predictive analytics, recommendations, and risk management. Future trends related to this area include the use of Artificial Intelligence (AI) and Machine Learning (ML), as they can play a significant role in enhancing the capabilities of big data analytics. Predictive models will become more accurate and adaptable, allowing for proactive decision making and the optimization of port operations [38]. Nevertheless, there are some potential bottlenecks, such as data quality and accessibility, privacy concerns, and the need for skilled data analysts. Additionally, the integration of data from various sources and systems can be complex.

- Green Technologies [39] have recently found use in the incorporation of shore power, whereby vessels are able to connect to the electrical grid while docked, thereby reducing emissions and noise pollution. In addition, alternative fuels can be used through the adoption of liquefied natural gas (LNG), hydrogen, or battery-powered vehicles and machinery in order to reduce carbon emissions. Renewable energy can also be incorporated through the implementation of solar panels, wind turbines, and energy storage systems in order to power port infrastructure. The increased use of renewable energy sources and the exploration of innovative solutions like green hydrogen production will be significant trends. However, the high upfront costs of implementing green technologies, the limited availability of and infrastructure for alternative fuels [40], and regulatory challenges regarding standards and incentives for green initiatives could hinder their widespread adoption [41].

6. Conclusions

In this paper, the impacts of integrating ICT solutions on port operations in developing countries were investigated. When employing manual planning and data exchange, certain inefficiencies lead to additional time being required for planning, crane delays, yard re-handles, an inability to adapt instantly to scheduling and berthing changes, and weaker quayside productivity. Thus, many terminal companies aim to integrate up-to-date technologies into their terminals and to renovate the terminal layout and facilities, including the incorporation of equipment that can reduce the time for which vessels stay in port, thus ensuring that the terminal is operating at its full potential. Such intelligent systems have become one of the most critical topics for researchers and practitioners in the maritime sector because of their high potential to improve processes and information flows. ICT solutions allow the handling of the massive volumes of data used daily by transport and port companies.

In this context, our case study consisted of the implementation of a TOS in the Port of Radès in Tunisia. A comparison of the different port operation processes (loading, unloading, yard, and gate operations), and a survey analyzing the consequences of this ICT solution for the port based on different KPI categories, such as Productivity, Cost, Efficiency, Reputation, Reliability, Infrastructure, Customer Satisfaction, and Collaboration, were carried out. The survey was sent to a number of port actors, including the directors of the stevedoring company, the managers of the port authority, and maritime agents.

The results of this research, based on a comparative study of the terminal before and after TOS implementation, led to the identification of the best practices to adopt to improve the effectiveness of terminal operations. This positive impact of the integrated ICT solution was also highlighted via the survey results, as its many benefits include the mitigation of the amount of manual work, shifting rather to automation, which provides real-time visibility, accurate work performance, time gains, better work coordination between operational departments, and freedom from error. Moreover, ICTs help analyze real-time operational and strategic decisions on the basis of instant insights.

The findings of this paper could be improved by adding port data to evaluate and compare other KPIs, such as operational, financial, and environmental costs. In addition, the study could be extended to explore the impacts of a deployed terminal ICT solution throughout the entire series of transport logistics nodes from the foreland to the hinterland.

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Appendix A. Survey on the Impact of the TOS on Performance in the Port of Radès

1. What are the main challenges in the Port of Radès? (You can choose more than one answer)
    - Optimize operations to improve productivity
    - Reduce cost of operations
    - Improve yard operations
    - Efficiently handle more TEU
    - Improve vessel planning and coordination
    - Improve truck turnaround time
    - Other
2. What do you see as the most important benefits of the implementation of the TOS in the Port of Radès? (You can choose more than one answer)
    - Improve consistency of operations
    - Improve equipment utilization
    - Improve yard planning
    - Helps the team to work better
    - Improve the safety of operations
    - Optimize crane assignment
    - Efficient gate operation with faster truck turn times
    - Better visibility and reporting
    - Better monitoring tools to improve operations
    - More stable operations
3. How much would you estimate the following aspects have improved since TOS?
    - Aspects: gate productivity, yard productivity, vessel load productivity, safety, reporting quality
    - Percentage choice: Up to 10%, 10–24%, 25–49%, 50–74%, 75% and greater.
4. In what areas has TOS helped to lower operational costs?
    - Yard planning
    - Quay crane planning
    - Yard operations
    - Gate operations
    - Monitoring and Reporting
    - I don't know

The following are Yes or No questions:

5. Has the cost in terms of fuel consumption, for instance, decreased since TOS implementation?
6. Do you find that the delivery service time has been improved since TOS implementation?
7. Do you think that thanks to the TOS the reputation of the Port of Radès (damages, accidents, safety, etc.) has been improved?
8. Do you find that the reliability in terms of punctuality (the capability to adhere to the planned schedule) has been enhanced since TOS implementation?
9. Does the TOS contribute to decreasing air pollution and improving the environment?
10. Do you think that collaboration between port stakeholders has been improved since implementing TOS?
11. Do you think that collaboration between different departments of STAM has been improved since implementing TOS?
12. Do you find that the installed infrastructure (port and terminal layout and facilities) has a positive impact on work performance?
13. Has the storage capacity been increased since installing 6 RTG and changing the terminal layout?

References

1. Sirimanne, S.N.; Hoffman, J.; Juan, W.; Asariotis, R.; Assaf, M.; Ayala, G.; Benamara, H.; Chantrel, D.; Hoffmann, J.; Premti, A. *Review of Maritime Transport 2019*; United Nations Conference on Trade and Development: Geneva, Switzerland, 2019.
2. Wang, Q.; Huo, B.; Zhao, X. What makes logistics integration more effective? Governance from contractual and relational perspectives. *J. Bus. Logist.* **2020**, *41*, 259–281. [CrossRef]
3. Gleghorn, G.D.; Harper, A. Logistics and Supply Chain Management and the Impact of Information Systems and Information Technology. In *Technology, Innovation, and Enterprise Transformation*; IGI Global: Hershey, PA, USA, 2015; pp. 295–301.
4. Castillo-Manzano, J.I.; Castro-Nuno, M.; Laxe, F.G.; López-Valpuesta, L.; Arévalo-Quijada, M.T. Low-cost port competitiveness index: Implementation in the Spanish port system. *Mar. Policy* **2009**, *33*, 591–598. [CrossRef]
5. Baştuğ, S.; Haralambides, H.; Esmer, S.; Eminoğlu, E. Port competitiveness: Do container terminal operators and liner shipping companies see eye to eye? *Mar. Policy* **2022**, *135*, 104866. [CrossRef]
6. Fan, G.; Xie, X.; Chen, J.; Wan, Z.; Yu, M.; Shi, J. Has China's Free Trade Zone policy expedited port production and development? *Mar. Policy* **2022**, *137*, 104951. [CrossRef]
7. Kuznetsov, A.; Dinwoodie, J.; Gibbs, D.; Sansom, M.; Knowles, H. Towards a sustainability management system for smaller ports. *Mar. Policy* **2015**, *54*, 59–68. [CrossRef]
8. Yadav, G.; Kumar, A.; Luthra, S.; Garza-Reyes, J.A.; Kumar, V.; Batista, L. A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. *Comput. Ind.* **2020**, *122*, 103280. [CrossRef]
9. Matta, S.; Appleton, S.; Bleaney, M. The impact of the Arab Spring on the Tunisian economy. *World Bank Econ. Rev.* **2019**, *33*, 231–258. [CrossRef]
10. World Bank. *The Container Port Performance Index 2021: A Comparable Assessment of Container Port Performance*; World Bank: Washington, DC, USA, 2022.
11. Balfaqih, M.; Alharbi, S.A. Associated Information and Communication Technologies Challenges of Smart City Development. *Sustainability* **2022**, *14*, 16240. [CrossRef]
12. Sanders, N.R.; Boone, T.; Ganeshan, R.; Wood, J.D. Sustainable supply chains in the age of AI and digitization: Research challenges and opportunities. *J. Bus. Logist.* **2019**, *40*, 229–240. [CrossRef]
13. Zhang, X.; Xu, R.; Lu, K.; Hao, Z.; Chen, Z.; Cai, M. Resource-Based Port Material Yard Detection with SPPA-Net. *Sustainability* **2022**, *14*, 16413. [CrossRef]
14. Taghipour, A.; Ramezani, M.; Khazaei, M.; Roohparvar, V.; Hassannayebi, E. Smart Transportation Behavior through the COVID-19 Pandemic: A Ride-Hailing System in Iran. *Sustainability* **2023**, *15*, 4178. [CrossRef]
15. Cepolina, S.; Ghiara, H. New trends in port strategies. Emerging role for ICT infrastructures. *Res. Transp. Bus. Manag.* **2013**, *8*, 195–205. [CrossRef]
16. Tliche, Y.; Taghipour, A.; Mahfod-Leroux, J.; Vosooghidizaji, M. Collaborative Bullwhip Effect-Oriented Bi-Objective Optimization for Inference-Based Weighted Moving Average Forecasting in Decentralized Supply Chain. *Int. J. Inf. Syst. Supply Chain. Manag. (IJISSCM)* **2023**, *16*, 1–37. [CrossRef]
17. Fedi, L.; Lavissiere, A.; Russell, D.; Swanson, D. The facilitating role of IT systems for legal compliance: The case of port community systems and container Verified Gross Mass (VGM). *Supply Chain. Forum Int. J.* **2019**, *20*, 29–42. [CrossRef]
18. Caporuscio, A.; Ferretti, M.; Leone, D.; Schiavone, F. Exploring knowledge sharing in sea-land logistics networks: Lessons from the port of Genoa. *J. Innov. Econ. Manag.* **2020**, *33*, 31–52. [CrossRef]
19. Pagano, P.; Antonelli, S.; Tardo, A. C-Ports: A proposal for a comprehensive standardization and implementation plan of digital services offered by the "Port of the Future". *Comput. Ind.* **2022**, *134*, 103556. [CrossRef]
20. Heilig, L.; Voß, S. Information systems in seaports: A categorization and overview. *Inf. Technol. Manag.* **2017**, *18*, 179–201. [CrossRef]
21. Hervás-Peralta, M.; Poveda-Reyes, S.; Molero, G.D.; Santarremigia, F.E.; Pastor-Ferrando, J.P. Improving the performance of dry and maritime ports by increasing knowledge about the most relevant functionalities of the Terminal Operating System (TOS). *Sustainability* **2019**, *11*, 1648. [CrossRef]
22. Min, H.; Lim, Y.K.; Park, J.W. An integrated terminal operating system for enhancing the port security. *Int. J. Logist. Syst. Manag.* **2017**, *34*, 193–210. [CrossRef]
23. Hervás-Peralta, M.; Poveda-Reyes, S.; Santarremigia, F.E.; Molero, G.D. Designing the layout of terminals with dangerous goods for safer and more secure ports and hinterlands. *Case Stud. Transp. Policy* **2020**, *8*, 300–310. [CrossRef]
24. Keceli, Y.; Choi, H.R.; Cha, Y.S.; Aydogdu, Y.V. A study on adoption of port community systems according to organization size. In Proceedings of the 2008 Third International Conference on Convergence and Hybrid Information Technology, Busan, Republic of Korea, 11–13 November 2008; Volume 1, pp. 493–501.
25. Cullinane, K.; Song, D.W.; Ji, P.; Wang, T.F. An application of DEA windows analysis to container port production efficiency. *Rev. Netw. Econ.* **2004**, *3*, 184–206. [CrossRef]
26. Ha, M.H.; Yang, Z.; Notteboom, T.; Ng, A.K.; Heo, M.W. Revisiting port performance measurement: A hybrid multi-stakeholder framework for the modelling of port performance indicators. *Transp. Res. Part E Logist. Transp. Rev.* **2017**, *100*, 1–16. [CrossRef]
27. Ha, M.H.; Yang, Z.; Heo, M.W. A new hybrid decision making framework for prioritising port performance improvement strategies. *Asian J. Shipp. Logist.* **2017**, *33*, 105–116. [CrossRef]

28. Hinkka, V.; Porkka, J.; Fatima, Z.; Hyvärinen, J.; Huovila, A.; Morales-Fusco, P.; Martin, E.; Soley, G. Terminal planning: The selection of relevant KPIs to evaluate operations. In Proceedings of the 7th Transport Research Arena, TRA 2018, Vienna, Austria, 16–19 April 2018.
29. Konsta, K.; Plomaritou, E. Key performance indicators (KPIs) and shipping companies performance evaluation: The case of Greek tanker shipping companies. *Int. J. Bus. Manag.* **2012**, *7*, 142. [CrossRef]
30. Seguí, X.; Puig, M.; Quintieri, E.; Wooldridge, C.; Darbra, R.M. New environmental performance baseline for inland ports: A benchmark for the European inland port sector. *Environ. Sci. Policy* **2016**, *58*, 29–40. [CrossRef]
31. Teerawattana, R.; Yang, Y.C. Environmental performance indicators for green port policy evaluation: Case study of Laem Chabang port. *Asian J. Shipp. Logist.* **2019**, *35*, 63–69. [CrossRef]
32. Elbert, R.; Scharf, K.; Müller, J.P. The influence of digitalisation on the port choice behaviour—An analysis of decision-makers in South-West Germany. In Proceedings of the 3rd Interdisciplinary Conference on Production, Logistics and Traffic (ICPLT), Darmstadt, Germany, 25–26 September 2017; pp. 1–4.
33. Matthews, R.; Ross, E. *Research Methods: A Practical Guide for the Social Sciences*; Pearson Education Ltd.: London, UK, 2010.
34. Parsons, V.L. Stratified sampling. In *Wiley StatsRef: Statistics Reference Online*; Wiley: Hoboken, NJ, USA, 2014; pp. 1–11.
35. Kenyon, G.N.; Goldsmith, M.; Neureuther, B.D.; Zhou, D. Improving the return on investment in ports: Opportunities in data management. *Marit. Econ. Logist.* **2018**, *20*, 514–530. [CrossRef]
36. Liu, L.; Qu, T.; Thürer, M.; Ma, L.; Zhang, Z.; Yuan, M. A new knowledge-guided multi-objective optimisation for the multi-AGV dispatching problem in dynamic production environments. *Int. J. Prod. Res.* **2022**, 1–22. [CrossRef]
37. Wang, Y.; Yang, Y.; Qin, Z.; Yang, Y.; Li, J. A Literature Review on the Application of Digital Technology in Achieving Green Supply Chain Management. *Sustainability* **2023**, *15*, 8564. [CrossRef]
38. Dalaklis, D.; Nikitakos, N.; Papachristos, D.; Dalaklis, A. Opportunities and challenges in relation to big data analytics for the shipping and port industries. In *Smart Ports and Robotic Systems: Navigating the Waves of Techno-Regulation and Governance*; Palgrave MacMillan: London, UK, 2023; pp. 267–290.
39. Chen, J.; Huang, T.; Xie, X.; Lee, P.T.W.; Hua, C. Constructing Governance Framework of a Green and Smart Port. *J. Mar. Sci. Eng.* **2019**, *7*, 83. [CrossRef]
40. Deng, G.; Chen, J.; Liu, Q. Influence Mechanism and Evolutionary Game of Environmental Regulation on Green Port Construction. *Sustainability* **2022**, *14*, 2930. [CrossRef]
41. Di Vaio, A.; Varriale, L. Management Innovation for Environmental Sustainability in Seaports: Managerial Accounting Instruments and Training for Competitive Green Ports beyond the Regulations. *Sustainability* **2018**, *10*, 783. [CrossRef]