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Towards attaining efficient management of berth maintenance in Saudi Arabian Industrial Ports

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Abstract. Despite the significance of ports as critical economic infrastructure, the berth facilities usually deteriorate due to heavy loading, unloading, aging, environmental weather conditions, marine growths, and lack of efficient maintenance management. Marine berths require proactive maintenance management to limit deterioration and defects as no berth facility is maintenance-free. Thus, delay in carrying out maintenance work for the marine berths can be devastating to the operational process involving ship entry, loading, and unloading operations. The aim of this research is to coordinate both operations work, and maintenance works that take place inside the berth of a local industrial port in Saudi Arabia, by developing a novel framework that integrates both works without affecting the efficiency and functionality of the berth. The study focused on defining the operational process of the port and identifying the elements with direct and indirect effects. In addition to determining the priority for the entry of ships inside the berth, it also identified the factors involved in designing a framework that included maintenance work as a component of the monthly berth occupancy schedule. By applying a mathematical model, a framework was established, which includes all the important elements of the process. As a result of the mathematical method formulation process, a database was designed that organizes and coordinates the operations of all berths within the port. This creates time to carry out the required maintenance work monthly as well as ease of coordination with the contractors responsible for the implementation of those works.

Keywords: berth maintenance; container terminal; industrial seaport; maintenance management; maritime transportation; time windows

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1. Introduction

Sea transportation and logistics contributes immensely to economic growth, development, as well as globalization as it accounts for four fifths of the world's total merchandise trade (Zavistas *et al.* 2018). Maritime cargo is generally classified as either general cargo or bulk cargo. General cargo includes break bulk (sacks, bags,), neo bulk (paper bundles, heavy machinery, vehicle parts, etc.) and containerized goods whereas, the bulk cargo could be either dry or liquid (Mabrouk *et al.* 2022). Dry bulk cargo includes grains, sand, metals, coals, fertilizers, and liquid bulk cargo includes LNG, petroleum, chemicals, vegetable oils. The bulk port terminals can be categorized in two categories such as docking zones where sea-freight docks on the allocated berths, and buffer yards, where it is loaded, unloaded, or transshipped (Umang *et al.* 2011). Although container ports can be separated from the performance of their customers' supply chains, bulk ports are much more closely linked and the efficiency of their operations affects the entire supply chain on an upstream and downstream level. However, bottlenecks in supply chain due to operational inefficiency in ports can ruin international trades sustainability. Sustainable development is achieved by an optimal allocation of port resources (Xu *et al.* 2018). Therefore, such port services must demonstrate operational efficiency, reliability, and productivity. In order to optimize supply chains with bulk port, it is important to capture the performance characteristics of all elements and eliminate bottlenecks that could occur along the way. Handing capabilities and operational limitations of port terminals play an important role in performance efficiencies in supply chain pertaining to bulk cargo ports (Kammoun and Abdennadher 2022).

The periodic preparation of various operating activities that take place in the port is referred to as operational planning in ports. When it comes to efficient terminal operation and planning, most of the port terminals depend on logistics processes such as quay-side, yard-side, and landside areas (Wang *et al.* 2021). The quay side operations largely rely on berthing and vessel allocations. Other key quayside decisions includes issues such as berth capacities, berth layout design, berth space allocation, etc. The majority of berths are located alongside a quay or a jetty. It is possible to use general berths or specific berths for different types of vessels. It is imperative to plan ahead when allocating berths for incoming and outgoing vessels (Xu *et al.* 2018). Thus a berth allows port operations to run smoothly while also preventing shipping bottlenecks. Plans for berthing a ship and surrounding facilities are detailed documents that specify how all of the facilities and resources will be allocated for the ship (Song 2021).

1.1 The study area

The transition of Saudi Arabian economy from a raw material exporter to a gas/oil industrial producer led to the establishment of an industrial port in 1974 to serve the local industrial area and offer convenient access to the Gulf and international sea routes. It is one of the major industrial ports in the Middle East and serves as the gateway to and from the largest petrochemical complex in the world. The proximity to such a large scale industrial and petrochemical complexes also help reduce the cost of importing and exporting materials. The industrial port is a bulk cargo type port designed to handle raw materials, petrochemicals, refined petroleum products, chemical fertilizers, and other similar type materials. The port has unmatched 34 berths, the highest in the region to serve the bulk and general cargo. In addition, the port has 5 terminals over the area of 6.8 km^2 with a capacity of 70 m tons. The port operations, management and maintenance are carried out by 10 terminal operators. The majority of the cargo throughput comprised of bulk cargo along with a small share

CARGO TYPE	DISCHARGED	LOADED
BULK CARGO (SOLID)	7,067,920	8,949,325
BULK CARGO (LIQUID)*	2,952,691	45,721,388
GENERAL CARGO	15,500	-
CONTAINERS	-	-
RO-RO & VEHICLES	-	-
LIVESTOCK	-	-
TOTAL	**10,036,111**	**54,670,713**
TOTAL PORT THROUGHPUT	**64,706,824**	

Fig. 1 Summary of Cargo Throughput in Year 2019 (Source: Cheimanoff *et al*. 2021)

of general cargo as shown in the summary of cargo throughput in Fig. 1.

The central aim of this paper is to develop a framework for carrying out maintenance work on berths without affecting ship entry or loading and unloading operations. This would be achieved by using some mathematical equations to obtain the expected times of the actual time that the ship needs to stay in berth, considering all the factors that have a direct and indirect impact on the operational process. Generally, ports are subjected to persistent heavy loading from human activities and harsh environmental conditions particularly the berth structures, which are integral components of port facilities (Agra and Oliviera 2018). The durability of the berth structures is also affected due to the ship berthing and mooring forces acting on the bollards positioned on berth front.

Despite the significance of ports as critical economic infrastructure, the berth facilities usually deteriorate due to heavy loading, aging, environmental weather conditions, marine growths, and lack of efficient maintenance management (Valdapenas *et al.* 2020, Jiang *et al.* 2021). Marine berths require proactive maintenance management to limit deterioration and defects as no berth facility is maintenance-free (Mukhti *et al.* 2018; Zhang *et al.* 2020). At present, managing the maintenance of berth facilities is generally based on request or when there is a need for ascertaining the total costs of some pending repair works. Although this reactive approach of managing the maintenance of berth structures is unsustainable, it simply works for the elements on the upper side of the port structures.

On the other hand, this approach often leads entire to structural failure of the berth structures as the repairs of other critical elements on the lower side of the berth structures that are not easily visible like corroded piles are delayed or neglected (Zheng *et al.* 2019, Kaewunruen *et al.* 2021). Berth maintenance as described in this paper refers to the sustainable care and protection involving all forms of intervention works carried out to berths with the aim of preserving them in good operational order, thereby prolonging the life of such berth for as long as possible. Thus, efficient maintenance management practices are crucial in keeping the berth in an extremely good operational order and avoiding the need for potentially expensive and disruptive repair works.

2. Literature review

Berth allocation is crucial in distributing vessels to berths based on the types of the vessel and cargo and the vessel's expected arrival time to the port. Accordingly, Grubisic *et al.* (2014) described the process of analyzing and optimizing such deployment of ships as Berth Allocation Problem (BAP). BAP describes how to arrange berths for a given set of vessels within a given planning period. It is usually an objective to minimize vessels' service times, though other objectives may be included such as minimizing port stays, rejecting fewer vessels, and minimizing deviations from planned and actual berthing. In the industrial ports of the Kingdom of Saudi Arabia, several parties have a direct relationship in the projects related to the berth. Since the industrial port deals with petroleum and petrochemical materials and international contracts, research on developing and updating the project system regarding berthing is important (Xin *et al.* 2014). It is evident that ports need to identify issues in advance in order to ensure the smooth operation of bulk terminals, and to prevent bottlenecks. In particular, if there is a maintenance operations needed for various berths at the terminals, it is critical to carry out optimization models for bulk port operations with emphasis on integrated planning and maintenance of operations and their representatives.

Studies on development and the use of optimization technique for terminal operations are rapidly increasing. A literature review of terminal operations reveals that more studies exist with regard to optimization and planning of container operations than with respect to any other type of cargo. However, there are various studies that have been conducted on container terminals, which may serve as the starting point for bulk port research. There exist numerous methods to optimize the vessels arrival time and berthing time for efficient operations in different scenarios such as maintenance of the berths. Xin *et al.* (2014) classified port operations related to planning into analytical and simulation methods. The analytical methods focus on the mathematical formulation of the management problem and search for optimal solution for the performance considering similar scenarios. However, the simulation approach models the dynamic behavior by the use of computational software's (Atencio and Casseres 2018). There are no available reports, especially in the gulf region where berth operation and maintenance are investigated at the same time. In order to maintain port terminal operations efficiently and productively, berth operations and maintenance must be integrated into a framework. This study analyzes the industrial port berth using an analytical approach. This paper will focus on berth number 21, which is highly utilized during terminal operations.

Within the last five years, some closely related studies have proposed various systems for managing the maintenance of ports. A framework was developed by Zhang *et al*. (2017) for assessing and enhancing sustainability of maintenance management strategies for port infrastructures. The authors used the randomized structural deterioration model to create the framework. However, the study fell short in providing a reliable criterion for determining the benefits of a maintenance program, which is important in achieving an optimal maintenance strategy. Mukhti *et al*. (2018) introduced a basic system for managing the maintenance of berth structures in Indonesian ports. This was because the berth facilities owned by national port operators were deteriorating and regulated maintenance management system was non-existent to detect any early deterioration. The developed system involves periodic inspection and monitoring of the berth structures while taking into consideration the constraints of the national port operators in other branches. Despite the significance of the authors' work, the study fell short as other branches of the Indonesian National Port Operators (NPOs) had difficulty in applying the system in their respective areas of jurisdiction. Not that alone, it became problematic to readjust the component classification to modify how damages to the component can influence the structural integrity of the berth facilities.

On the other hand, Zheng *et al.* (2019) combined berth allocation as well as quay crane assignment with maintenance activities to develop a linear programming that will seek to reduce the total turnaround time and will further decrease the possibility of facilities' failure since the structures require proactive maintenance strategy. However, the study failed to capture the cost for frequent movement of the facilities during their dynamic assignments. The study also failed to provide remedies for the sudden breakdown of the facilities and in case of emergency maintenance as well.

Meanwhile, Valdepenas *et al*. (2020) employed the concept of building information modelling approach in the maintenance management of port infrastructure, which indicates a fundamental innovation to the way the maintenance of port structures are managed. Although the using of the BIM approach enables efficient organization of information and visual problems between the various stakeholders in managing port infrastructure, however, there are not clear categorization for the existing components of marine ports. Thus, it became essential to propose an expansion along with monitoring sheet templates that would help to facilitate effective management of any maintenance work required.

Various studies have investigated the circumstances affecting the container terminals' operating performance to improve efficiency of the terminal. Most of the extant studies reported by Cheimanoff *et al*. (2021), Lalla-Ruiz *et al*. (2016); and Imai *et al.* (2008) addressed problems at the operational level. This is a major problem in berth operation management. Researchers called it the berth allocation problem (BAP). It essentially improves the appropriation of berthing resources and also reduces the ship waiting and handling time as deduced from different studies Zhang *et al.* (2010) and Yang *et al.* (2012). However, the BAP approach became more ineffective in meeting the integrated scheduling demand of container operations due to the arrivals of more mega ships and booming port handlings (Imai *et al*. 2001).

2.1 Terminal management

Generally, the management of terminal deals with enhancing the efficiency of its operations. This is achieved by enhancing the way the terminal facilities are utilized to attract more container terminals. This explains why most efforts directed towards managing berth allocation problems are predominantly based on container terminals (Umang *et al.* 2011).

Accordingly, the literature is amassed with studies related to operations and maintenance of berth terminals while some studies had been conducted on ship-berth connection preparation. The interface between the land and water is addressed by the ship-berth connection. The ship-berth relation preparation issue entails assigning incoming ships to berthing positions as well as the scheduling of quay cranes (QCs), which are critical components of port operations management. Furthermore, a ship's service period is determined by its berthing point and is proportional to the amount of QCs allocated to it Xin *et al*. 2014). A yellow rectangle is used to indicate each vessel while the vessel handling time is denoted by its width. The length on the other hand, signifies the length and protection margin, which is well captured in a 2-dimensional space time diagram. As depicted in Fig. 2, the horizontal axis indicates the quay position, while the time along the scheduling horizon is represented by the vertical axis (Mukhti *et al*. 2018).

2.2 Container terminal queuing mechanism

As shown in Fig. 3, the container terminal queuing system is divided into free and no free berths. The quay crane travels along the quay line between each berth. Where there are no free berths in the anchorage, the vessel joins a single queue for a job; otherwise, it berths and accepts the loading and unloading operation before it is done (Imai *et al.* 1997). The number of berths determines the service

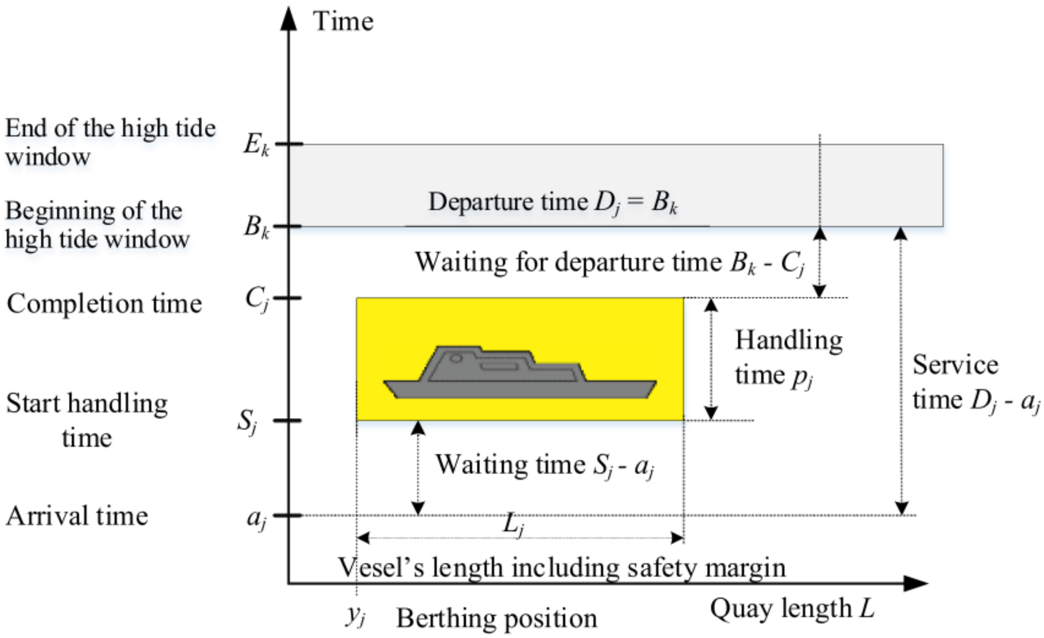

Fig. 2 Berth two-dimensional space-time diagram. (Source: Jiang *et al*. 2021)

capability of the berth.

2.3 Ship unloaded allocation in bulk material handling port.

The existence of a single route for the entry of ships, which makes it difficult to transfer, is to transfer ships between the berths due to the different surrounding factors. The study focus was to solve this problem by improving the quality of the berth use and the priority in entering ships. Where the model was divided into two parts: 1- The finest plan for vessels to enter 2- focusing on decreasing the occupied berth. However, the study proposes a DSS to combining ship un-loader allocation with berth allocation to resolve them serially based on requests made by the ports. Essentially, this method is governed by factors like scheduling problems, waiting time reduction, and ultimately reducing the operating process time (He *et al.* 2021).

2.4 Integrating traffic limitations in resolving during berth scheduling problem

Integrating traffic limitations in resolving during berth scheduling problem in port navigation channels was studied by suggesting a mixed-integer linear programming model to devise an optimum berth utilization and increase customer service efficiency. This can be achieved by creating a more conceptual framework that can handle hybrid traffic in the navigation channel, such as one-way traffic, two-way traffic, and navigation channel closures. To minimize the computing time for large-scale problems, a hybrid simulated annealing algorithm was proposed, which employs a problem-specific heuristic (Umang *et al*. 2011).

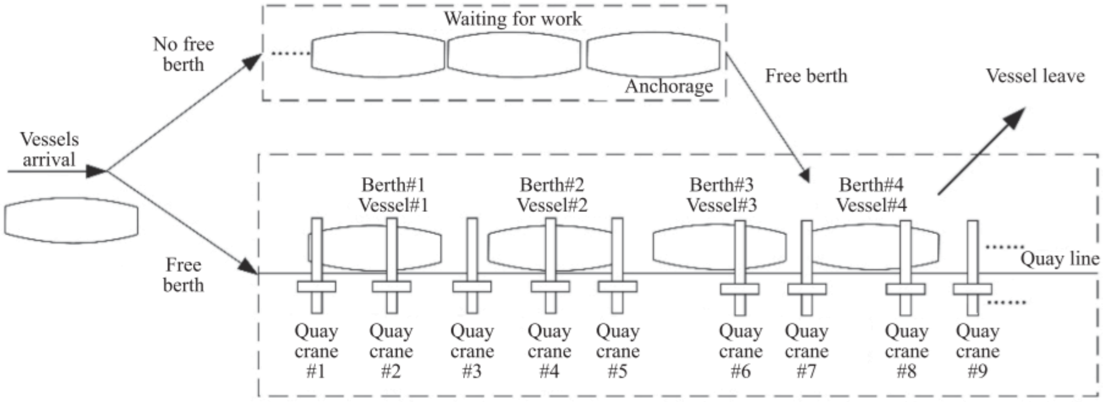

Fig. 3 Schematic diagram of container terminal queuing mechanism (Source: Xu *et al*. 2018)

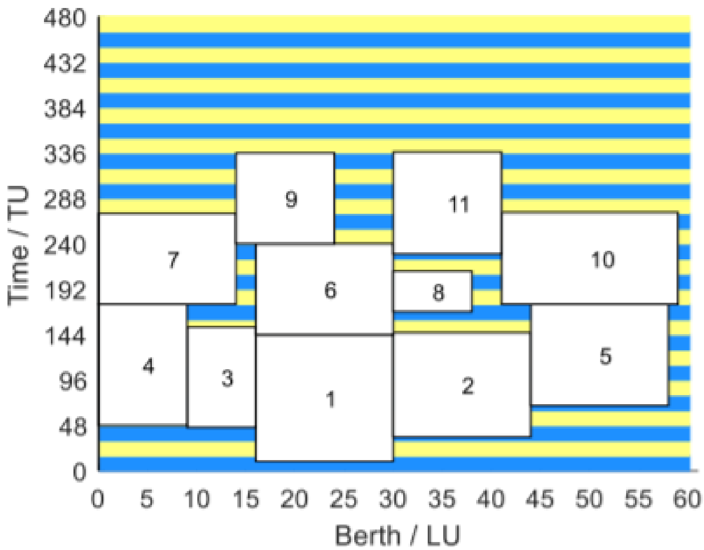

Fig. 4 The solution of berth scheduling for different traffic limit with different workloads [2]

3. Methodology

Berths are the main components of the operational process of ports, with readiness to receive ships from around the world. Characteristics such as maintenance, berth being occupied, and coordination/scheduling have a crucial importance to the efficient functionality of the operations of a port. The analytical method below was derived by considering the Berth number 21 of a local industrial seaport in Saudi Arabia, which is highly utilized during terminal operations.

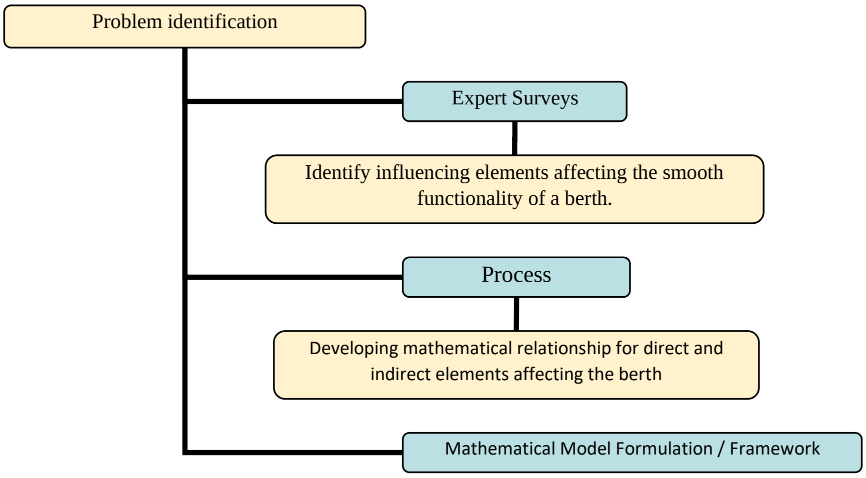

Fig. 5 Research methodology

3.1 Experts survey

In order to establish the mathematical equations in the appropriate way to solve the coordination problem in the seaport, a pilot survey was conducted by sending emails to 8 experts who were reached out by recommendations and social media channels. The experts are specialists considered to be well experienced and proficient in a particular area. Thus, the expert-based survey targeted industry practitioners through judgmental sampling approach. This was to ensure that only professionals that meet the requirements were selected to participate in the survey. Eventually, the 5 experts that responded were all working in seaports with experiences ranging from 10 to 20 years. Remarkably, the experts work in marine operations, marine management, marine specialist, marine maintenance, and marine project management respectively. In addition, 4 out of the 5 experts hold a bachelor's degree in marine engineering while the other expert holds a master's degree in project management.

Further, the respondents were interviewed individually where they were introduced to an actual scenario and requested to identify the influencing elements that would affect the smooth functionality of a berth. Moreover, the different steps that should be adhered to in the process have been explained to the experts to help in defining the elements of the process. The first step was that the ships heading for the local industrial port pass through the regional sea and the Arabian Gulf via a sea lane designated to the seaport. Then, those ships stand inside the territorial sea in an area designated for berthing and waiting, which is called the Anchorage Area. After that, all the ships required to dock on the berth are expected to get the required approval to enter the port crossing, which takes between 2 and 6 hours. After a ship reaches the berth, loading and discharging operations begin from the tanks area through pipes designated for products. This requires a period of time depending on the quantities required for loading or unloading. After the completion of the crisis operations, the process of departing the ship and entering another ship starts. These two operations are not completed simultaneously because the corridor was designed for one vessel in each operation. So, the 5 experts defined a total of 10 elements after the process had been analyzed where those elements amongst which were direct and indirect as shown in Table 1.

Table 1 Definitions and notation of key elements affecting berth functionality in a local industrial port

No.	Direct Factors	Definition	Notation
1	Arrival time of ship	The time that the ship actually has finished the tying works.	At
2	Departure time of ship	When the captain was in the command post and the ship had begun to move.	Dt
3	Quantity of products on ship	The amount of product the ship will load or unload.	Q
4	Loading Rate	Each berth has a different loading ship and each one has a different loading rate.	L
5	Priority of ship	The latest publication of the Joint Industrial Security Department at the port to classify the most dangerous materials in the port, and their survival constitutes a general danger to the region. The ships for loading the materials will be approved as the basic criterion in the classification. International agreements and deadlines for delivery of materials to other countries is one of the criteria in the classification.	Ps
6	Berthing order of ship	The time that the captain has requested to have a time for berthing.	Bo
7	Number of ship unloads	The number of ships is waiting in the encourage area.	Ui
8	Berthing time of ship	The time that the ship needs from, in and to the berth	Bt
No.	**Indirect Factors**	**Definition**	**Notation**
1	Wind Speed	Wind speed is one of the most important factors affecting marine operations. They are classified according to 3 categories: 1- Up to 27 Knot Normal Operation (Wn) 2- Up to 30 Knot Only Travel (W30) 3- More 30 Knot STOP Operation (Wm)	W
2	Time from anchorage area to berth	The limit inside the seaport is up to 5 Knot. Moreover, it depends on the ship size: 1- A1Large Size6 hrs (Ta.b6) 2- A2Mid Size4 hrs (Ta.b4) 3- A3Small Size2 hrs (Ta.b2)	Ta.b

3.2 Mathematical model / framework formulation:

The use of mathematics in solving real-world problems is often referred to as 'mathematical modelling', which could be defined as the process of describing a real-world situation using mathematics. However, it must be done in such a way that it helps in the solution of the given problem. The idea of 'modelling' is emphasized as it helps to remind us that we must pay attention to things other than mathematics. The modeller must first become acquainted with the dilemma he/she is attempting to solve and be clear about his goals. The next step is to begin building the model. The modeller would then determine which aspects of truth can be used in the model and which can be ignored. The formulation of the mathematical problem is the third stage. Skill and experience are obviously necessary virtues in this situation. The method of solution (analytical or numerical) must be chosen, as well as whether to use a straightforward approximate method or a more complex precise method. The effects of the model are interpreted in the fifth step. If any of the parameters are changed, one should wonder whether the model behaves fairly. Other factors to remember are the predicted precision and the area of validity of the model. It is beneficial to split the modelling process into four different categories of activity: constructing, research, evaluating, and application. While it would be good to believe that modelling designs go seamlessly from construction to use, this is rarely the case. Defects discovered during the studying and measuring periods are usually repaired by returning to the construction stage. After determining the configuration of a model, mathematical equations must be chosen to explain the system. It is important to choose these equations carefully because they could have unintended consequences for the model's conduct.

According to previous studies, the mathematical model formulation method may help to solve coordination problems in the operational process of seaports. So, the mathematical model is used to solve the current problem in the selected local industrial port. Since ships arrive at various hours, with different lengths; in several quays and berths, and also different capacities of QCs, and so on, the ship-berth link becomes complicated (Pratap *et al.* 2017). These systems' modeling must be split into many parts, each with its own set of input parameters as indicated in Table 1 above.

The start of ship operation is when the ship arrives at the port anchorage area. The latter will have to wait in the anchorage area depending on the condition of congestion or the priority of the approaching boats. Containers are unloaded/loaded from/on the ship after berthing. Finally, when the ship's operation is done, it departs the port. The objective function of this model is to determine the actual time for a ship to stay in the berth considering all influencing parameters (see Eq. (1)).

$$\sum_{TBO}^{n}(Dt - At) \tag{1}$$

With TBO being time for berthing order of ship and (n) the duration of the process, then, the arrival time of a ship (At) is to be found by knowing the berthing time of that ship (Bt) plus the time from the anchorage area to the assign berth (Tab), see Eq. (2).

$$\sum\ (\mathrm{At}) = Bt + Tab \tag{2}$$

The berthing time of ship (Bt) is the Priority of ship (Ps) 'International agreements and deadlines for delivery of materials to other countries is one of the criteria in the classification.' and the berthing order time (Bo), see Eq. (3).

$$\sum\ (\mathrm{Bt}) = Ps * Bo \tag{3}$$

The time from the anchorage area to the assigned berth (Tab) depends on the wind speed (Ws), which is how much knot is in the time that the ship coming inside the port, and the number of unload ships (Ui) waiting in the encourage area, see Eq. (4).

$$\sum\ (\mathrm{Tab}) = Ws * Ui \tag{4}$$

Considering the wind speed (knots) and the ship sizes, the arrival time was further expressed as shown in Eq. (1). In addition, when the wind speed is lower than 25 knot, there is a factor to be multiplied by the time from the anchorage area to the assigned berth (Tab), which depends on the types of the ship; where the factor of a big type of ship is 6, a factor for mid type ship is 4 and the factor for small type ship is 2. Table 1 provides more details about the indirect factors. Thus, the interpretation of the equations will be as follows

Table 2 Ships loading rates and required destination at a local industrial port

Zone	Total of Loading rates (∑L) (Ton/MT)	Berth to Terminal
Zone 1	900	Terminal 1
Zone 2	1400	Terminal 2
Zone 3	1250	Terminal 3
Zone 4	1300	Terminal 4
Zone 5	1400	Terminal 5

Table 3 The possibilities encountered for ships in the local industrial port and the required decisions

No	Possibilities	Decision
1	IF w≤25knot and Ta.b6	As the wind speed is less than or equal to 25 knots, the ship is allowed to enter and depart the berth regardless its size.
2	IF w≤25knot and Ta.b4	
3	IF w≤25knot and Ta.b2	
4	IF w>25knot and Ta.b6	As the wind speed is more than 25 knots, the ship is not allowed to enter the berth but is allowed to depart regardless its size.
5	IF w>25knot and Ta.b4	
6	IF w>25knot and Ta.b2	

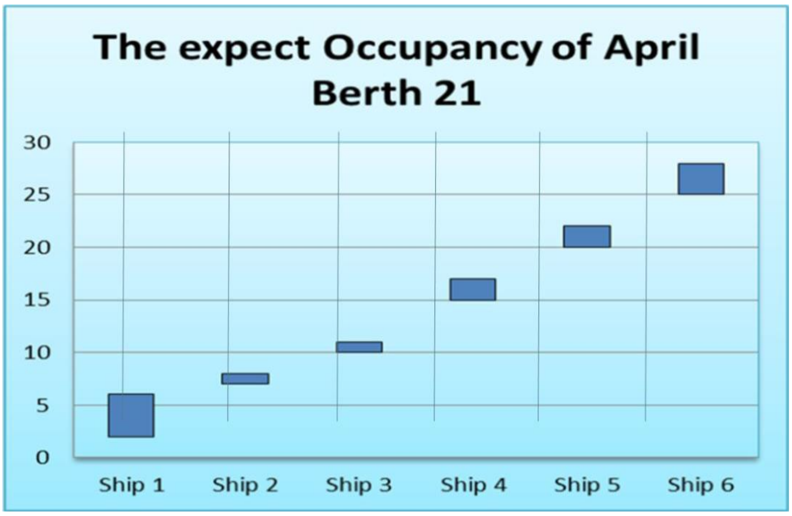

Fig. 6 The expectation time of the monthly occupancy for berth no.21

$$If, W < 25\ \ Knot\ \ If, Tab < 6\ \ ; If,\ Tab < 4; If,\ Tab < 2$$

The arrival time for big type ship is

$$\sum\ (\mathrm{At}) = Bt + (Ta.b * 6) \tag{5}$$

The arrival time for mid type ship is

$$\sum (\mathrm{At}) = Bt + (Ta.b * 4) \quad (6)$$

The arrival time for small type ship is

$$\sum (\mathrm{At}) = Bt + (Ta.b * 2) \quad (7)$$

Determining of the departure time (Dt) depends on knowing the berthing order time of ship in addition to the loading rate which depends on the material that the ship will be loading it or unloading it and the number of berths the ship assign to berthing, see Eq. (8).

$$\sum (\mathrm{Dt}) = Bo + L \quad (8)$$

The loading rate (L) depends on the material handling and the berth the ship assigns to berthing, as shown in Table 2.

According to the data and variables with respect to the specified factors, there are 6 possibilities encountered in seaport that need to be considered in the study as shown in Table 3.

4. Results and discussion

Based on the mathematical equations related to the operational process of the marinas inside the port, a database was designed, which includes all the factors affecting the operational process directly or indirectly. The database includes all the information on berths, loading rates, weather forecast and other key information. It requires entering some information about the ship, such as the load on the ship, the required berth, the expected date of arrival, the importance of the ship, and the size of the ship. This database applies to all berths inside the port.

To apply the formulated mathematical model, a particular Berth no.21 of the local industrial port was used as model to test and validate the database. All required entries have been added to the database to find the expected times for the actual ship remaining on the berth during April 2021. According to the data on the berth, there were 6 ships that would be coming to the berth and so the basic data of those ships were entered into the database. Then, the database provided us with the

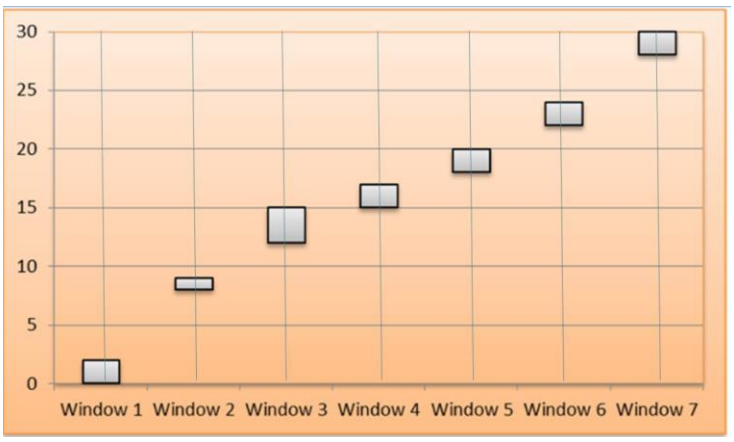

Fig. 7 The unoccupied times of the berth during the month

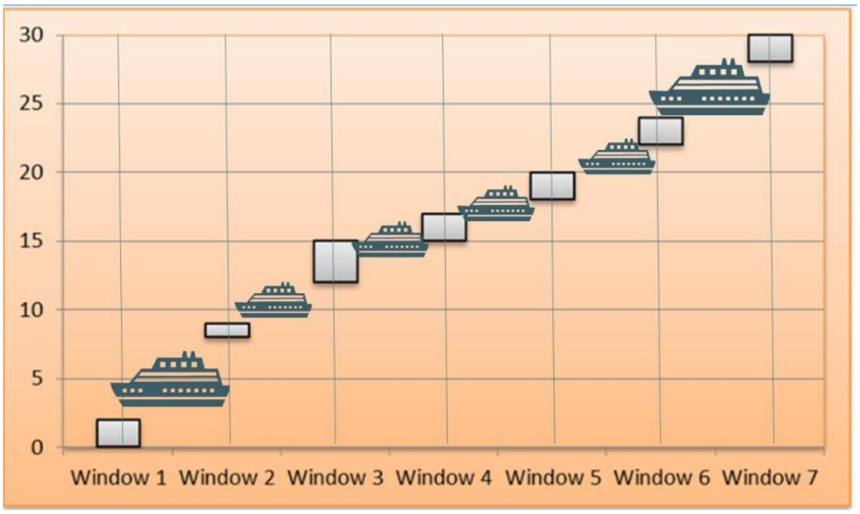

Fig. 8 The expected monthly schedule of the berth

A. PAINTWORK:	Days
1. Catwalk	1
2. Aluminum Handrails	1
3. Ladder	4
4. Bollard	8
B. MARINE JACKET:	
Dolphin pile jackets require regular maintenance and should be inspected regularly, in conjunction with paint, for damage or failure and repairs carried out as soon as necessary.	9
C. CATHODIC PROTECTION (Sacrificial Anodes)	3
D. CATWALK BEARINGS	3
E. FENDERS	2
F. ELECTRIC LIGTINGS	5
G. ROADWAY	7
H. MOORING HOOKS	5
I. DAVIT TOWER AND GANGWAY	3
J. LIFEBOUYS	1
K. PLATFORM/SHELTER	1
1. Concrete slabs and other civil works.	14

Fig. 9 Classification of maintenance work on the berth

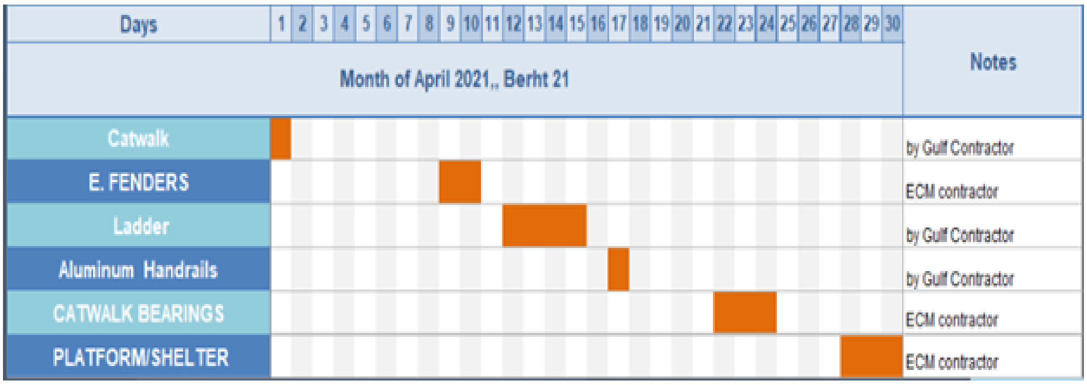

Fig. 10 The proposed maintenance work schedule

dates for the times when the berth was occupied due to the presence of the ship on the berth as shown in Figs. 6 and 7.

Depending on the times allocated to the ships during the month, the unoccupied times of the berth are illustrated in Fig. 6, which were being computed and allocated as times designated for carrying out the necessary maintenance works. In addition, the expected monthly schedule of the berth is illustrated in Fig. 8. The berth was determined between the times of the ship remaining on the berth and the times available to carry out maintenance.

Based on that, the times allocated for carrying out maintenance work and the number of days for each window were shown and available. To take advantage of those times, the maintenance work that takes place on the berth has been classified according to the work that has been done during the past five years as shown in Fig.9. The maintenance work for berth is classified into 11 items, which includes paint work, marine jacket, cathodic protection, catwalk bearings, fenders, electric lighting, roadway, morning hooks, davit tower and gangway, lifebuoys, and platform shelter. The maintenance time for each item was specified to come up within 14 days that were needed to do all the work.

As a result of the database, the works were determined according to the priority and the time needed for maintenance as a timetable for the implementation of those works, see Fig. 10. The implantation of the mathematical model was applied to one berth in the seaport; however, the framework was designed to be applied to all berths within the industrial port.

4.1 Practical implications

The implications inferred in this paper are efficient maintenance management of seaports for better operational efficiency and safety. Efficient management of berth maintenance is essential to ensure that vessels can safely and efficiently dock and unload their cargo. The outcomes as well as the managerial implications of this paper are likely to provide vital guide to all key stakeholders and decision makers to create sustainable policies for improving the efficient management of berth maintenance in order to ensure smooth operation of ports and terminals.

By way of emphasizing on the managerial implications of this paper, it is important to note that efficient maintenance management of berths can improve the flow of cargo and vessels in and out of ports, reducing delays and increasing operational efficiency. This can lead to lower costs and higher profits for shipping companies and improved service for customers (Kammoun and Abdennadher 2022). Moreover, efficient management of berth maintenance can reduce the risk of accidents and damage to vessels, cargo, and infrastructure while regular inspections and repairs can identify potential hazards and prevent them from causing harm (Mabrouk *et al.* 2022). Not that alone, the lifespan of the berths and other related infrastructure can be extended through regular and proactive maintenance, thereby reducing the need for costly replacements and upgrades in the future (Wang *et al*. 2021). Meanwhile, effective management of berth maintenance can enhance the reputation of ports and shipping companies as reliable and trustworthy partners for customers and stakeholders. This can lead to increased business opportunities and partnerships (Zhang *et al*. 2019).

In essence, managing berth maintenance is an important aspect of port management that requires careful planning and coordination. The maintenance of berths is affected by a number of factors, including the type of vessel using the berth, the frequency of use, and environmental conditions (Mabrouk *et al.* 2022). Managing berth maintenance can be challenging, but a number of strategies can be employed to improve maintenance management, including adopting a proactive maintenance strategy and prioritizing maintenance activities based on risk assessments. Although the cost of maintenance can be a major challenge for port authorities and terminal operators, however, in order ensure cost-effective maintenance, Kammoun and Abdennadher (2022) suggest prioritizing maintenance activities based on the level of risk associated with each berth. This can help to ensure that resources are directed toward the maintenance activities that are most critical for maintaining port operations and safety.

Essentially, regular inspections play a critical role in managing berth maintenance. According to Wang *et al.* (2021), inspections should be conducted at least once a year to identify any potential issues or damage to the berth structure. This can help to prevent minor issues from turning into major problems that could disrupt port operations or lead to safety hazards. Also, the use of technology cannot be simply ignored as Zhang *et al*. (2019) suggest using sensors and other monitoring equipment to detect changes in the structural integrity of the berth, such as cracks or changes in vibration patterns. This can help to identify potential problems early on and allow for proactive maintenance to be carried out. Similarly, effective management of berth maintenance requires collaboration between port authorities and terminal operators. According to Huang *et al*. (2019), port authorities should work closely with terminal operators to develop maintenance plans that take into account the operational needs of the terminal. This can help to ensure that maintenance activities are carried out at times that do not disrupt vessel traffic or cargo operations.

Overall, effective management of berth maintenance is critical for ensuring the safe and efficient operation of ports. By adopting proactive maintenance strategies, using technology, collaborating between port authorities and terminal operators, prioritizing maintenance activities, and ensuring compliance with regulations and safety standards, port authorities can effectively manage berth maintenance and minimize disruptions to port operations.

While the evidence on which the outcomes of this paper is founded is directly obtained from practices related to seaport operations and management in Saudi Arabia, the outcomes can be applied to other neighboring countries in the region. This can help to not only reduce downtime and increase efficiency but also contribute to the overall sustainability of marine terminals by improving resource utilization and reducing their carbon footprint. Not that alone, the implementation of the outcomes could further lead to cost savings for port and terminal operators. These savings may come from reduced operational costs, including maintenance expenses and fuel consumption, as well as improved customer satisfaction due to reduced delays.

4.2 Study limitations

Notwithstanding the fact that the primary objective of this paper has been accomplished, it would not be out of place if the limitations of the study were highlighted. It is properly conceded here that the research presented in this paper was likely to be influenced by some biases and constraints, as the sample size for the selection of the experts was relatively small. Although this is typical for any research work that obtained some of its data through a survey questionnaire, the choice of judgmental sampling technique in selecting the sample of experts enables the authors to minimize the severity of the potential likely biases and decrease the level of bias by offering the authors certain extent of control. While the size of the study sample could be considered reasonably small, the outcomes of this paper provide significant information that can be utilized in providing enhanced and efficient management of berth maintenance.

5. Conclusions

The aim of this paper was to create a framework for carrying out maintenance work on berths without affecting ship entry or loading and unloading operations. This was done by using some mathematical equations to obtain the expected times of the actual time that the ship need to stay in berth, considering all the factors that have direct and indirect impact on the operational process. Meanwhile, the factors affecting the process were identified and categorized based on their level of importance and impact. Accordingly, a database was accessed to show the expected results of the ships remaining on the berth and the allowed times for carrying out maintenance work based on the mathematical equations. Accordingly, the maintenance works were defined and classified and the time periods required to be combined between the permissible times and the required work.

This has increased the coordination process between the main operations activities inside the port and the reduction of the aggravation of the problems related to the berths and the implementation of preventive works at the required times. Whereas the calculation of the priority of entry of the ship will be added to the database, depending on the requirements of the country’s High Commission For Industrial Security, as well as the risk of the loaded materials and the readiness of the materials in the tanks.

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Declaration of competing interest

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