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Case Study: Berth Allocation Problem in Ma'alla Port

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ABSTRACT: Nowadays, port terminals play an important role as members of a supply chain. Maritime transportation is a major channel of international sea trade which has increase significantly over the past few decades. From the past researches, it is well established that operations research methods and techniques can be successfully used to optimize port operations and enhance terminal efficiency. While significant contributions have been made in the field of container terminal management, relatively little attention has been directed to bulk port operations. As a consequence, the optimization of port operations is becoming highly needed in order to meet the requirements of the sector. For this reason, in this paper the focus is given on Berth Allocation Problem BAP as it incorporates some of the most important decisions that haveto be made in order to achieve maximum efficiency in a port. Especially, this paper study the BAP in bulk ports which plays an essential factor in planning the vessels which haven't arrive yet in the port in order to program their berthing. The paper provides a multi-objective mathematical model that takes into account several parameters involved in terminal berth operation. Then, the problem was solved using MATLAB; finally, numerical experiments are conducted to prove the performance of the model.

KEYWORDS: Berth Allocation Problem, Bulk, planning, MATLAB.

I. INTRODUCTION

Maritime transportation is a major channel of international sea trade which has increased significantly over the past decades. The international sea borne has increased by more than. Some of the major contributing factors to the continuing growth in maritime transportation are population growth, increasing standard of living, rapid industrialization, exhaustion of local resources, road congestion and elimination of trade barriers. Since the beginning of the decade all forms of cargo (general, dry, bulk and liquid bulk) have registered an increase in shipping tonnage. The figures for dry bulk, liquid bulk and containerized cargo are particularly impressive at 52%, 48% and 154% respectively. It is also interesting to note that the total volume of dry bulk cargoes loaded in 2008 stood at 5.4 billion tons, accounting for 66.3 per cent of total world goods loaded. [1]

International seaborne trade lost momentum in2018, with volumes only increasingat a modest 2.7per cent, after a surge of 4.1 per cent in 2017. As shown in Figure 1, since2013, growthin seaborne trade has been relatively sluggish, as compared to the aftermath of the2009 financial crisis, when annual growth rates rangedbetween 4.4 and 7 per cent.

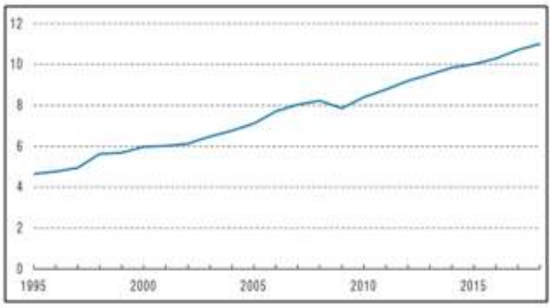

Figure 1: Goods loaded worldwide (Billions of tons) [1].

Nevertheless, in 2018, world seaborne tradevolumes rose to a new all-time high of11 billiontons.

Asia was by far the largest trading region. In 2018,4.5 billion tons of goods wereloaded, and 6.7billion tons unloaded in Asian seaports [1]. The othercontinentsregistered less than half of these amounts.Of the 11 billion tons shipped internationally in2018, 7.8 billion tons were classifiedas dry cargo. Crude oil, the most transported cargo in the 1970s,has lost marketshare over the last four decades, andby 2018 it accounted for less than one fifth ofthegoods delivered by sea.

In 2018, developing economies still accounted forthe largest share of global seabornetrade, both interms of exports (goods loaded) and imports (goodsunloaded) as shown in Figure 2. Theyloaded 59 per cent and unloaded 64per cent of the world total. With a volume of4.2billion tons loaded and 5.9 billion tons unloaded, Asian and Oceanian developingeconomies togetheraccounted for most of that share.

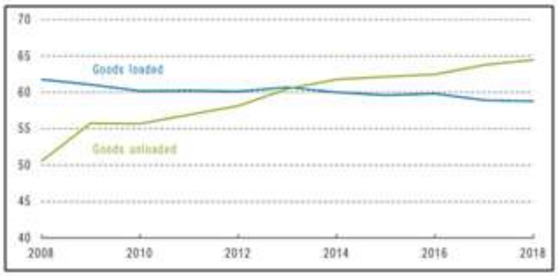

Figure 2: Seaborn trade of development economics [1].

Economic growth of a nation depends majorly on import and export of materials. There are three modes of transportation via seaside, airside and landside, among them seaside is the cheapest and most robust one. Nowadays, most of the bulk transportation activities are carried out via sea. More than 80% percent of goods volume are delivered by sea, which means they pass through seaports [2].

Delivery of goods using sea transport is constantly increasing, which results in increase in ship traffic as well as in volume and frequency of loading and unloading at the terminals. However, this is not necessarily followed by an increase in terminal capacity. For this purpose, maximizing the quality of services and minimizing the costs of ships stay in one of the biggest challenges for shipping companies in port management. In context, the proper planning and management of port operations in view of this ever-growing demand represents a big challenge.

Berth allocation is an important issue in the operations of port terminal. Berth allocation problem (BAP) is the allocation of vessels to the berth as well as other resources during a certain agreed period of time in which the vessel can perform loading and unloading activities [3]. The decisions of berthing of ships to different berths are usually based on first in first out (FIFO) or priority rules set by port owner, which do not satisfy the customer demand. Priority can also be given according to commodity or other considerations.

II. MOTIVATION

Most of the researchers focus their interest in strategic and tactical issues, focusing more on container handling. A very few studies have been carried out for berth allocation as a ship scheduling problem for bulk material handling port. However, work done for container terminals can be used as a starting point for research in the context of bulk ports.

This research is motivated by the need to have a study on the Yemen ports, which are one of the main chain of the world maritime transportation due to their location.

III. LITERATURE REVIEW

In the literature, there are many workswhich have studied the BAP because of itscomplexity and its practical applicability.One of theresearches that studied ship queening in Ma'allaports is [4], in which Ahmed S. and Mohammed N.provide a basic mathematical modelling study toachieve the precise and rapid use of computer for ortperformance. They experiment different model toreduce the time spent in berth and waiting time of the ships in queue.

Imai et al [5] was the first who introduce the dynamic BAP, they solved the problem using a heuristic based on Lagrangian relaxation method. Two years later, Imai et al [6] improved their model considering different service priorities between ships; they resolved the problem using a Genetic Algorithm (GA). In a related study, Theofanis et al [7] studied the DBAP and proposed a resolution approach based on GA to minimize the total weighted service time of all ships.

According to Golias et al [8], they proposed the DBAP as a multi-objective combinatorial optimization problem, where the service rendered to ships is based on priority arguments and they developed a GA to solve the resulting problem. They presented also a plan for berthing of vessels which minimizes delayed departures of ships and emissions from ships in standby mode.

In [9], Zhi-Hua-Hu planned a bi-objective model that considers the preference to work within days with the objective of minimizing workloads late and workloads in the nights, a multi objective genetic algorithm is developed to solve this model.

Budipriyanto et al [10] developed a conceptual model of the ship berth allocation given the variability of vessel arrival and the time of service. The objective of this model is the reduction of the total processing time and improves the utility resources (berth, quay crane and container yard).

As seen in [11], Kordic et al used the exact resolution algorithm called Sedimentation algorithm to solve the mathematical model proposed by Rashidi and Tsong [12], this work addresses the DBAP and Hybrid Berth Allocation Problem (HBAP) with fixed handling times of vessels.

Lajjam et al [13], studied the Dynamic Berth Allocation Problem and provides a multi-objective mathematical model that considers the length and draft of each berth and each vessel.

In [14] Adi et al, examine how collaboration between berth terminals could affect the port performance when dealing with uncertainty. They used discrete event simulation to model the system and they evaluated two major scenarios: collaborative response and non-collaborative response.

IV. ADEN PORTS OVERVIEW

The ports of Aden is situated between the promontories of Aden (Shamsan mountain, 553m) and Little Aden (Muzalqam mountain, 374m) and is protected from the NE and SW monsoons by these hills and along the northern boundary by land, enabling it to operate without restriction all year.

The harbor covers an area some 8 nm east-west and 3 nm north-south. The port consists of the outer harbor, providing anchorage areas, the oil harbor at Little Aden on the west side of the harbor, the inner harborto the east hosts Aden Container Terminal (ACT), Ma'alla Port, a fishing harbor and a ship repair yard.

In this paper, we will only focus the research on Ma'alla Port and below will provide more details on the port in brief.

The area inside the boundary wall of the Ma'alla Wharf has been declared as the "Aden Free port". Customs inspections are carried out in a separate customs area at the eastern end of the Ma'alla Wharf where trucks enter and leave as seen in Figure 3. The wharf has berths at different depths, from west to east:

- A RORO berth 150 m long, depth 7.6 m, with a ramp width of 20 m. General cargo ships of up to LOA 114 m use it.
- Four main berths, no. 1 – 4, each 187.5 m in length along 750 m of quay with a depth alongside of 11 m. The turning area north of these berths is 280 m wide and extends the full length of the main berths. These four berths can be operated as continues mode if needed.
- Two berths, 5 and 6, for 'Home Trade' ships and dhows at the Home Trade quay, which has a total length of 250 m and depth alongside of 6.7 m. It has a turning area of the same depth extending 250 m from the quay wall over the length of the berth.
- 800 m of higher and dhow quays at depths of between 1.8 and 2.7 m.

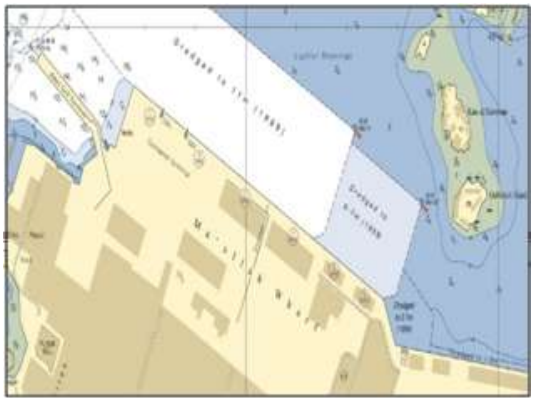

Figure 3: Ma'alla wharf [15].

Berth 1 and 2 are used for container handling, also for bulk and general cargo vessels. These berths are equipped with two Liebherr ship to shore gantry cranes that are Panamax capable with a 38 m outreach. Crane capacity is 40 ton under the spreader and 50 ton under hook for heavy lifts. The cranes are not currently in use and the berth is used on demand by general container ships, mainly those carrying aid cargo [15].

Some berths are more in demand than others; like berth no. 3 and 4 by cement and clinker vessels and RORO berth. In particular, specialized equipment such as conveyors and pipelines installed on certain berths enhance the demand for those berths.

Key issues and source of disruption

During several visits to Ma'alla port, some key issues and sources of disruption at the port was identified. In particular, it was seen that the delays at the berth were significant resulting in high waiting times for vessels at the berths and anchorage. These delays can be attributed to:

- Unavailability of berths due to congestion of incoming vessels.
- Unavailability of required number and type of equipment at the desired time, either because the equipment is engaged in other tasks, or owing to unexpected breakdown in equipment disrupting the schedule of operations.
- Uncertainty in arrival of cargo trucks for picking or delivery of cargo.

Assumption and Limitation

To achieve efficiency, firstly, there must be good arrangement of port yard, there should be no traffic congestion among the import and export cargo and yard equipment are used in proper way. Secondly, the gate operation hour must be efficient, and the inspection, weighting and documentation must be properly checked. Thirdly, the labourer's

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need to be well trained, highly skilled, motivated and work in safety manner. This will promote higher productivity of workers employed in waterside, landside and gate operations.

V. BERTH ALLOCATION PROBLEM

Berth space is one of the most important resources in seaports and its assignment to the incoming ships is commonly known as the berth allocation problem (BAP) on the berth scheduling problem. Mostly, BAP refers to the problem of serving a set of vessels for a given berth layout within the given planning horizon. Objectives for BAP include minimizing total flow time, though there could be several other objectives such as minimization of port stay time, minimization of number of rejected vessels, minimization of deviation between actual and planned berthing schedules etc.

BAP is, not likely, the maritime operations problem that deals with the most unreliable information, as the ships arrival time can be affected by weather conditions and mechanical issues. Furthermore, some contracts are for berth-on-arrival, which gives ship operators the right to quick and prompt berthing upon arrival. Therefore, normal functioning of a seaport can be disrupted, thus requiring quick on-line re-allocation algorithms.

Another complicating issue in the BAP is that not every ship can be located in any berth as ships have different sizes and depth requirements. The space requirements are related to ship size, particularly its length, while the depth requirements are determined by the vertical distance between the waterline and the ship keel [16]. Among all possible locations, we wish to choose for each ship, one that optimizes a certain performance metric.

Many different metrics have been used in the literature. Here, following the works by Cordeau et al [17] and Imai et al [18], three measures are considered and minimized, namely unused berth time, unused berth space and ship service time. The longer the berthing horizon (as long as the accurate arrival time of ships is available), the better the berth allocation plan.

BAP consist of planning an allocation of quay to a set of ships in order to minimize their waiting time and handling time in the port. According to Biewrith and Meisel [19], the BAP can be classified in four attributes:

- Spatial attribute that has three dispensations: (1) Discrete (Figure 4), the quay is divided into a specified number of posts. (2) Continuous (Figure 4), the quay is not divided; therefore, the ships can carry out the berthing according to their need of space on the quay. (3) Hybrid (Figure 5), the quay is split in a discrete manner except that the big ships can be positioned into two or three berths and small vessels can share a single berth.
- Temporal attribute represents the type of ship's arrival, which is defined according to the literature in two types: (1) Static Arrival: Considers that all ships are in the port before starting the assignment. (2) Dynamic Arrival: It is necessary to schedule in the beginning of planning the berthing of ships that aren't arrived yet in the port.
- Handling time attribute depends on several factors namely the numbers of available cranes, the position attributed to the ships and the amount loaded and unloaded cargo.
- Performance measured attribute varies depending on the needs. Among the usual objectives, we can cite the minimization of delay realize from ships, minimizing the handling time and minimizing time spent by ships in the terminal.

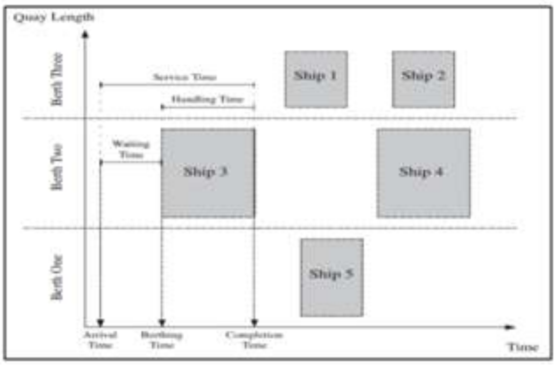

Figure 4: The berthing of ships. [20]

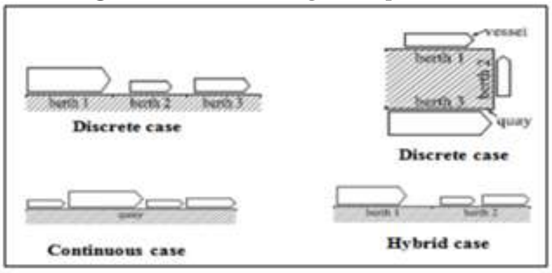

Figure 5: Type of quay. [21]

VI. MODEL DEVELOPMENT

The fundamental of model development based on the nature of cargos, characteristics of arriving ship like tonnage, cargo handling capacity and terminal characteristic such as closing time and cargo handling time [20]. These are vital guidelines to the research in order to minimize ship queuing time.

The model development has seven parameters from physical capacities and the operational efficiencies. The mathematical model can be used in two different conditions, either to determine the productive average waiting time, or to define the required quay length for a new port. The parameters are arrival rates, ship length, berthing time, average waiting time, number of berths, number of gant cranes being operated and crane rates.

The optimization strategies cater the berths and cranes required to reduce the queue number of ships and arrival serious congestion in the port [20], but in Ma'alla port case, as there are no cranes currently operating, the only strategy available is the number of berths. Handling rates is an important indicator to achieve efficiency, which is the key to maintain good port productivity even if the number of ships increases.

Efficient port can produce high turnaround of ships at certain time. High number of berths does not necessarily mean no delay; nevertheless, still provides adequate facilities to cater high number of incoming ships [21].

Efficient port services will attract ship owners to dock at the port, and this may lead to the high number of arrival rates. Firstly, high number of ships call requires faster productive speed to handling rates at each berth. Proper arrangement of queue number of ships to the available berth plays important role to avoid traffic congestion at the port [22]. Secondly, optimization strategies need to be applied to maintain excellent cargo handling and the productivity of port. The handling rates productivity is directly related to the transfer function of terminal, the number and the movement rate quay cranes, the use of yard equipment, and the productivity of workers employed in waterside, landside and gate operations.

VII. MATHEMATICAL MODEL

Considering the parameters in VI, a mathematical model has been formulated as below:

$$Q_L = A_r \times \Sigma_{k-1}^{n} \frac{(S_L \times B_t)}{C_w} \times [C_n] \times [w_t] \ldots 1$$

where Q_L represents quay length of the port. Dependent parameters B_t, w_t represents berthing time, C_n number of cranes operated, number of existing berths and average waiting time. Independent parameters A_r, S_L and C_w represents arrival rates, ship length and cargo weight.

Simulation Analysis

The mathematical model had to be simplified in a proper way in order to suit the MATLAB environment and to start the simulation proses. The formula was rearranged in order to determine the waiting time of a queue number of ships:

$$\frac{w_t = Q_L \times C_w}{A_r \times C_n \times \Sigma_{k-1}^{n}(S_l \times B_t)} \ldots 2$$

$$w_t = \frac{M}{PR} \ldots 3$$

With, $M = Q_L \times C_\omega$, $P = A_r \times C_n$ and $R = \Sigma_{k-1}^{n}(S_l \times B_t)$ MP and R are constant values.

$$W_t = \frac{L}{R} \ldots 3$$

Where L=M/P. The final equation was then used in the MATLAB program where L refers to the constant value, while R is the variable.

VIII. RESULTS DISCUSSION

Here we will discuss the simulation results based on the proposed mathematical modelling. As the proposed mathematical model consists of the parameters that should give some impacts to the desired average waiting time. Ma'alla port have different draft depth of berths, considering that will affect the waiting time to the approbate berth, ship length reflects the capacity of cargo that are going to be discharged at the port and the mode to be chosen. All results were tabulated in the form of tables and graphs by MATLAB, these results would give more understanding on the relationship between the average waiting time and other parameters.

The data presented were from the ships call for the first quarter of 2020, hence, the period after that were affected due to COVID 19 and a drop of ship call accrued. The results were based on waiting time produced by simulation according the mathematical model. The waiting time was measured in hour unit and the input data were referred to the previous number of berths and cranes.

Figure 6 shows the average waiting time according to the number of cranes being operated on each vessel. The average waiting time is inversely proportional to the number of cranes. As it shows, the more number of cranes operated the less waiting time occurred.

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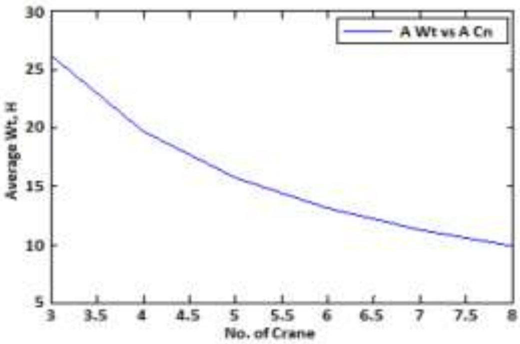

Figure 6: Waiting time against the number of cranes.

The berthing time is significantly related to the number of cranes as shows in Figure 7. The graph indicates that the efficient berthing time is when 8 cranes were used per berth although maximum cranes actually operated on vessels called Mua'lla port are 4. Indeed, additional numbers of crane and berth will contribute to the efficiency of cargo handling operation and reduction of average waiting time, hence will reduce queuing time of ships at the port.

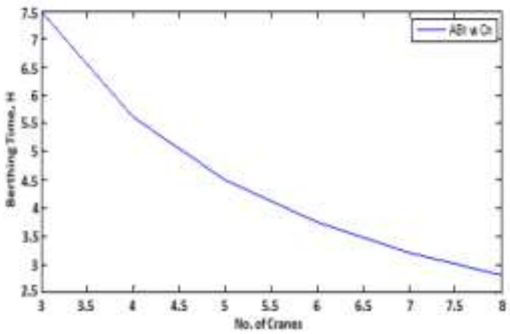

Figure 7: Berthing time against number of cranes.

Verification of Results

In this section, the verification of the results in detail, compared to the actual situation. This section also reviews the effectiveness of additional number of berths by increasing the draft of 5, 6 and the RORO berth and adding quay cranes.

Table 1. Actual versus predicted average waiting time comparison.

Month	**Awt for Actual Data (H×10)**	**Awt for 4 units of Cranes**	**Awt for 5 units of Cranes**	**Awt for 6 units of Cranes**	**Awt for 7 units of Cranes**
Jan.	26.18	19.63	15.71	13.09	11.22
Feb.	21.75	16.31	13.05	10.88	9.32
Mar.	20.40	15.30	12.24	10.20	8.74

Table 1 show the comparison of results in terms of the average waiting time between actual data and the proposed simulation model. The number of cranes and berths was increased in the proposed model. The average waiting time was varied accordingly. The actual data had 4 berths and 3 to 4 cranes for cargo handling process, compared to the predicated average waiting time having up to 7 units and 5 berths. The average waiting time was varied over the first quarter of 2020 based on the number of ships call at port. The increase of number of cranes up to 7 units seems practical in order to ensure the results within the acceptable ranges.

The increase of number of berths is directly proportional to the extension of quay length at port; but, for the case of Mu'alla port the number of berths can't be extended due to the port boundary, the only extension that could be done is to increase the draft of berth of 5 and 6 from 6.7 m to 11 m, in this way berths from 1 to 6 can be used in a continues mode and this will significantly reduce waiting time.

The key point to improve the port performance is the cargo handling processes, followed by services rendered to cater the ever-increasing ship numbers entering the port. Technological advancement of service can also ease the process of cargo handling at port [23]. Efficient services offered will become a strong attraction to ship operators to select the port as their hub or service provider.

Table 2 shows the predicted average waiting time in case of draft increased for berths 6 and 7 and total qual length will be 1000 m instead of only 750 m and this will impact the average waiting time; as, the increase number of berths will extend the wharf length at port. Most of the results produced are between the acceptable ranges, which are less than 80 hours.

Table 2: Comparison between actual data with the increment of berths and cranes.

Month	Average Waiting Time (H) from Actual Data (H)	Number of berths	Number of cranes	Average Waiting Time (H×10)
Jan.	26.18	5	4	11.13
Feb.	21.75	6	5	8.70
Mar.	20.40	7	6	7.77

With additional numbers of cranes and berth, there will be systematic drop of annual average waiting time [23]. Additional numbers of berth can be done gradually based on the number of vessels calls. Normally, high vessel calls for a certain period of time will not affect cargo throughput for that particular port. This is the best approach to avoid port congestion to occur.

The key point to improve the port performance is the cargo handling processes, followed by services rendered to cater the ever-increasing vessel numbers entering the port. Technological advancement of services can also ease the process of cargo handling at port. Efficient services offered will become a strong attraction to vessel operators to select the port as their hub or service provider.

IX. CONCLUSION AND FUTURE WORK

The paper estimated the optimum number of berths and cranes required in order to minimize vessels queuing time. The optimization strategies are based on the hypothesis that the increment number of berths and cranes can reduce the average waiting time at port.

The Queuing theory has been made as a main reference to determine the best selection of parameters in the mathematical model. The use of mathematical model is the best fundamental for simulation analysis. The best selection of variables in the mathematical model will improve waiting time. The developed mathematical model can be used for existing and new port, for through simulation.

Most of the simulation results show the average waiting time of less than 8 hours, the best average waiting time is 70.7 hours, by using 7 berths and 6 units of crane.

In future work, we will extend our statistics data to cover wider range of vessel calls to port during normal and peak seasons considering uncertainties; in addition, based on this study we will implement artificial intelligence algorithm for better results and problem solving.

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