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Berth Allocation Problem in Container Terminal TangerMed Morocco

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Abstract

The container terminal industry faces the challenge of efficiently allocating berths for incoming vessels to maximize operational efficiency. The Berth Allocation Problem (BAP) is a fundamental issue that must be addressed, especially in busy ports such as TangerMed in Morocco. To tackle this problem, a real case study was conducted, focusing on optimizing the BAP at TangerMed. The study proposes a simplified linear integer programming model that considers the mooring time and initial berthing location on a single continuous quay at X-Port. This model was implemented using the PuLP Package in Python, and the results were displayed on a time-space diagram. The proposed approach is expected to improve seaport management and enhance the quality of operational services, ultimately leading to increased efficiency and profitability for the terminal.

Keywords
Berth Allocation, Optimization

1. Introduction
The issue of berth allocation involves determining the berthing schedule and location for incoming vessels. The goal of this problem is to optimize the use of limited resources, including berths and equipment, while minimizing the waiting time of vessels and the cost of resource usage. Over the years, the berth allocation problem has become increasingly important in enhancing seaport operations and has thus received significant attention from academia and industry. Several models exist for addressing spatial and temporal variables in port locations, including the berth allocation problem (BAP), the dynamic and discrete berth allocation problem (DDBAP), the quay crane allocation problem (QCAP), and the quay crane scheduling problem (QCSP). These models differ in their constraints regarding time and space. Generally, these constraints limit each vessel's berthing duration and position, while the available space is an internal parameter of the maritime terminal, and the berthing time and space required are specific to the vessel. The BAP aims to schedule vessels at berths by assigning the appropriate berth, vessel size, and time at the maritime terminal. Various researchers have attempted to address the problem from different perspectives, including deterministic and non-deterministic approaches, with exact solution methods and heuristics. However, most models have been developed based on deterministic assumptions, with only a few accounting for variability and uncertainty. Various approaches have been proposed to tackle the BAP, including mathematical programming, heuristic algorithms, and metaheuristics. Mathematical programming models such as integer linear programming (ILP) have been widely used to solve the BAP. For instance, Chen and Chen (2014) proposed an ILP model for the BAP that considers the availability of berths and handling equipment, vessel size and priority, and the order of arrival. The proposed model was tested on a real-world dataset and showed promising results.

Heuristic algorithms are another class of methods commonly used for the BAP. These algorithms aim to quickly generate a feasible solution that may not be optimal but satisfies the constraints of the problem. Zhang et al. (2017)

proposed a hybrid heuristic algorithm for the BAP that combines a genetic algorithm and a local search algorithm. The proposed algorithm was tested on real-world datasets and showed superior performance compared to other existing methods.

Metaheuristics such as simulated annealing, tabu search, and genetic algorithms have also been applied to the BAP. These methods are based on iterative improvement of a solution by exploring the search space and moving towards better solutions. Shi et al. (2018) proposed a hybrid algorithm that combines tabu search and genetic algorithms for the BAP. The proposed algorithm was tested on a real-world dataset and showed significant improvements in solution quality and computational efficiency compared to other existing methods.

Recently, there has been an increasing interest in using machine learning techniques to solve the BAP. For instance, Zhang et al. (2021) proposed a deep reinforcement learning algorithm for the BAP that learns to make berth allocation decisions by maximizing a reward function. The proposed algorithm was tested on a simulation environment and showed promising results.

In conclusion, the BAP is a complex and challenging optimization problem that has attracted significant research attention in recent years. Various mathematical programming, heuristic, metaheuristic, and machine learning techniques have been proposed to solve the problem. Further research is needed to develop more efficient and effective methods to tackle the BAP and to address the practical challenges in seaport operations.

One of the key challenges in the BAP is the dynamic nature of seaport operations, where vessels arrive and depart continuously, and the available resources such as berths and handling equipment may vary over time. To address this challenge, several studies have proposed dynamic models that consider the time-varying nature of the problem. For instance, Li et al. (2019) proposed a dynamic programming model for the BAP that optimizes the allocation of berths and handling equipment over a planning horizon. The proposed model was tested on a real-world dataset and showed significant improvements in solution quality compared to static models.

Another important aspect of the BAP is the consideration of multiple objectives, such as minimizing the waiting time of vessels, maximizing the utilization of resources, and reducing the environmental impact of seaport operations. Several studies have proposed multi-objective optimization models for the BAP that consider these objectives simultaneously. For example, Dang et al. (2021) proposed a bi-objective optimization model for the BAP that minimizes the total waiting time of vessels and the total cost of handling equipment usage. The proposed model was tested on a real-world dataset and showed superior performance compared to other existing methods.

In addition to mathematical programming and metaheuristic methods, some studies have proposed game-theoretic approaches to solve the BAP. Game theory provides a framework for modeling the strategic interactions between the seaport operator and the vessels, where each agent seeks to maximize their own objective function. For instance, Wu et al. (2016) proposed a game-theoretic model for the BAP that considers the competition between vessels for berths and the cooperation between vessels and the seaport operator for handling equipment. The proposed model was tested on a simulation environment and showed promising results.

Furthermore, some studies have proposed simulation-based optimization methods for the BAP, where a simulation model is used to evaluate the performance of different berth allocation strategies. For example, Wang et al. (2017) proposed a simulation-based optimization approach for the BAP that combines a discrete-event simulation model and a genetic algorithm. The proposed approach was tested on a real-world dataset and showed significant improvements in solution quality compared to other existing methods.

Overall, the BAP is a complex and dynamic optimization problem that has attracted significant research attention in recent years. Mathematical programming, metaheuristic, game-theoretic, and simulation-based optimization methods have been proposed to solve the problem. Further research is needed to develop more efficient and effective methods to tackle the BAP and to address the practical challenges in seaport operations.

A detailed classification for terminal operations planning and different types of problem according to optimization goals and specific features of problem formulation were given by Bierwirth and Meisel (2010). In some recent papers the focus has slightly been shifted from the allocation problem with operations cost minimization to terminal operations service efficiency and pollution minimization through carbon emission costs minimization. A similar work was initiated by Karam (2020). Armi et al (2021) formulated a mixed-integer linear programming model for the berth allocation and crane assignment problem, and we solved the problem using a rolling-horizon approach.

Heuristics were used extensively in the literature review to tackle the BAP in container terminal, ranging from Bee Colony, Genetic Algorithm, to Tabu Search and other less known algorithms. Yildimir (2020) proposes a decision support system combined with a simulation optimization based on the swarm-based Artificial Bee Colony optimization algorithm for solving the BAP. The proposed methodology was supported by the implementation to the Izmir port in Turkey.

Mnasri and Alrashidi (2021) proposed a solution and a detailed modeling of the discrete and dynamic BAP using a multi-agent methodology. A set of numerical experiments are detailed to prove the performance of the introduced multi-agent strategy that was compared with genetic algorithm and tabu search.

Genetic algorithms in particular, was used to tackle BAP in many situations, the work of Akinowwasi et al. (2021) serves as a good illustration of genetic algorithm application. Alvim. and Ribeiro (2010) introduced a hybrid tabu search algorithm to solve a problem which has, mathematically, the same decision parameters of the BAP. The aim in the two problems is to identify a specific set M of tasks (vessels) to assign to specific number n of machines (berths) having a predefined capacity (makespan).

Kovač (2017) provides an overview of promising and widely used metaheuristic methods in solving different variants of Berth Allocation Problem, with high-quality solutions in reasonable computational time.

Xiang (2021) investigated the berth allocation planning problem at a tactical level considering uncertain operation time. The optimisation model is aimed to minimise the total cost of deviations between the planned and expected berthing time of the vessel. For problem solving, the K-means clustering was first used to construct the uncertainty set. Secondly, a column-and-constraint generation algorithm was used to solve the model.

Rodrigues (2022) discussed the common sources of uncertainty and highlighted the representation of the uncertain parameters. Moreover, he provides an overview of the main methodologies proposed, including stochastic programming, robust optimization, fuzzy programming, and deterministic approaches.

Under the work of Budipriyanto (2015) variability of vessel arrival time and handling time are considered are major causes behind the difference between the schedule planned and actual berthing time. These differences reduce berth productivity due loading and unloading time could not predictable. This situation will influence to operational cost for shipping lines and terminal operators. This paper develops a conceptual model of ship-to-berth allocation considering variability of ship arrival and service time.

2. Problem Statement

The capacity of terminals is continually increasing as manufacturing industry and logistics operations expands leading to extensive cargo operations. With the significant increase in cargo shipping volumes, shipping lines and container terminals are under pressure to improve their operational loading and unloading processes and increase overall efficiency. In addition, container terminals are facing greater constraints in terms of providing high-quality services and reducing vessel waiting times. Therefore, enhancing operational efficiency has become a critical concern for container terminals.

The berth allocation problem (BAP) is typically modeled in two-dimensional space, and a time-space diagram can be used to visualize the problem. The quay is represented as a horizontal line with a predetermined length, while the vessel is represented as a rectangle:

The length of the rectangle represents the time unit, which includes mooring, processing, and completion time, while the vertical axis represents the berth position.

The vessels are illustrated as rectangles with a length equal to the process time and a width that corresponds to the vessel's size. To solve the BAP, it is crucial to position these rectangles in the available space without overlapping (Figure 1).

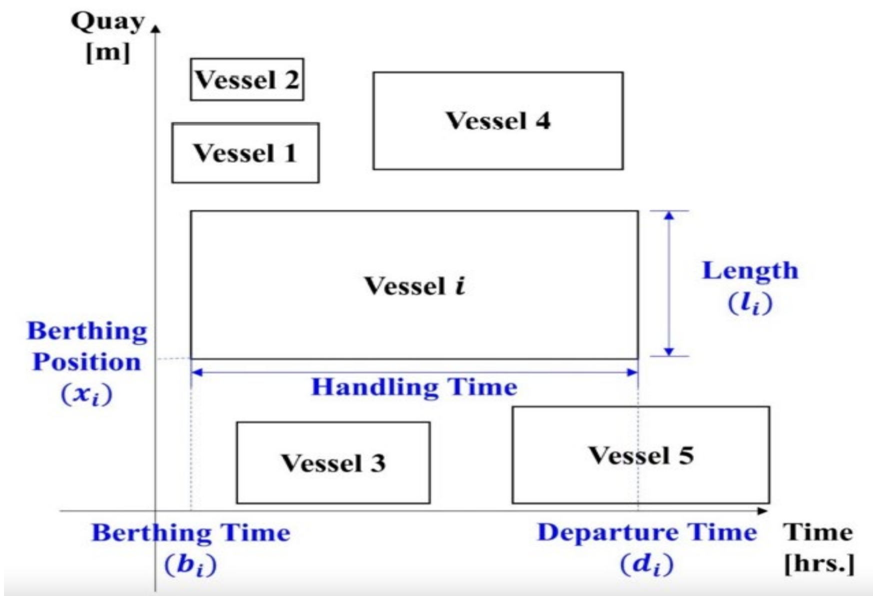

Figure 1. Vessel- Berth Allocation with two-dimensional space (time and space)

3. Methodology

The formulated berth allocation mathematical model is developed based on the following assumptions:

- The expected arrival / departure time of all the vessels is known beforehand.
- Each vessel can be occupied by only one quay crane.
- Crane can handle 20 moves / hour.
- Sets:
    - V : the number of vessels
- Parameters:
    - LVi : The length of vessel i
    - LQ : The quay space length
    - LPH : The planning horizon length
    - Pi : Expected processing time for vessel i
    - Ni : The Number of Moves in Vessel i
    - Ai : Arrival time for vessel i Di : Departure time for vessel i
    - Cb : The cost for the delayed berthing of vessel i
    - Cd : The cost for the delayed departure of vessel i

- Decision variables
    - Mi: The mooring time for vessel i.
    - Ci : Completion time of vessel i.
    - Bi : The first berthing position for vessel i

- Binary variables:
    - xij : if processing time is overlapped between vessel i and vessel j => xij = 1; Otherwise xij = 0
    - yij : if the berthing position is overlapped between vessel i and vessel j => yij = 1; Otherwise yij =0

The objective function of our mathematical model is to minimize the total cost of staying at the port. The first cost that we have is a penalty cost resulting from the delayed berthing where the arrival time of vessel i is before the mooring time of the same vessel. The other cost is another penalty cost that result from the delayed departure when the completion time of the vessel is after the departure time already expected. The following formula is the objective function

Minimize total costs of delayed berthing and delayed departure:
Cb*(Mi-Ai) +Cd (Ci-Di)

Bj – (Bi + LVi) – (xij -1) LQ >= 0 (1)
When the service time overlaps, this constraint guarantees that the berthing locations of vessels i and j are not interfered

Mj - (Mi + Pi) – (yij -1) Lph >= 0 (2)
The ai here is to guarantee that the operation periods of vessels I and j are not disrupted when their berthing locations coincide.

yij + yji + xij+xji>= 1 (3)
yij +yji <= 1 (4)
xij + xji <=1 (5)
These constraints sure that the operating times or berthing locations of vessels i and j do not overlap in the time-space diagram.

Ci = Mi + Pi (6)
This constrain specifies the time at which each vessel departs

Ai <= Mi <= Lph -Pi (7)
Bi <= LQ – LVi (8)
The objective is to establish the top limit for each vessel's berthing duration and berthing position respectively

4. Data and Application

A case study was used for the application of the model and a linear program was formulated with the data gathered from the TangerMed port for two days from several clients coming with different vessels sizes (Small & Medium (Table 1 and Table 2).

Table 1. Vessel Data- Day 1

Vessel ID	Vessel Length	Vessel Moves	Arrival expected Time	Processing Time	Departure Expected Time
1	134	220	12	11	20
2	110	200	5	10	11
3	125	240	10	12	17
4	140	220	7	11	25
5	138	200	17	10	15

Table 2. Vessel Data- Day 2

Vessel ID	Vessel Length	Vessel Moves	Arrival expected Time	Processing Time	Departure Expected Time
1	175	200	5	10	14
2	155	260	10	13	19
3	142	180	7	9	13
4	120	160	6	8	15

5. Results and Discussion

From the results we got in Day 1, we can clearly see that for vessel 2, vessel 3, and vessel 4 the mooring time is exactly the same as the expected arrival time already given to the terminal operator because the berthing positions were already free at the time of arriving. In this case, a reservation for these clients will be made by respecting the exact mooring time and berthing position given. However, the mooring time of vessel 1 is 15 while the arrival given time is 12; Also, the mooring time of vessel 5 is 18 while the expected time of arriving is 17 which means the mooring time of the two vessels are after the expected arrival time. This can be explained by the non-availability of the adequate berthing positions in the time horizon given by the clients of the two vessels. In this case, those clients will be informed beforehand about their mooring time and exact berthing positions; therefore, they will not have to speed up and consume more fuel in order to get to the port terminal before other vessels. Also, they will not get to the port while other vessels are served and be obliged to wait for berths to get free, the thing that will exempt them from paying the taxes and penalty cost for a delayed berthing/ departure. Similarly, we can see from the results of Day 2 that vessel 1, vessel 3, and vessel 4 are having the mooring time equals to their expected arrival time. Yet, the mooring time of vessel 2 exceeds the time of arrival where it is expected to be at the port container terminal at 10; however, the given mooring time is at 14. As already discussed, the clients will receive a reservation at the adequate berthing with the right mooring time. The thing that will ensure them having their spot waiting for them upon their arrival without any delay. From the interpretation results and more specifically the time-space diagrams, there is no overlapping in terms of the processing time or the berthing positions. Also, as already mentioned, the company 40 has three quay cranes, and the policy of X-Port emphasizes that each incoming vessel should be served by only one crane that has the ability to make 20 moves per hour. Since the length of the quay is 500m, the maximum number of vessels that can be along the quay at the same service time is 3 which means that the quay cranes available are sufficient. See Figure 2 for Time-space Diagram in Day 1.

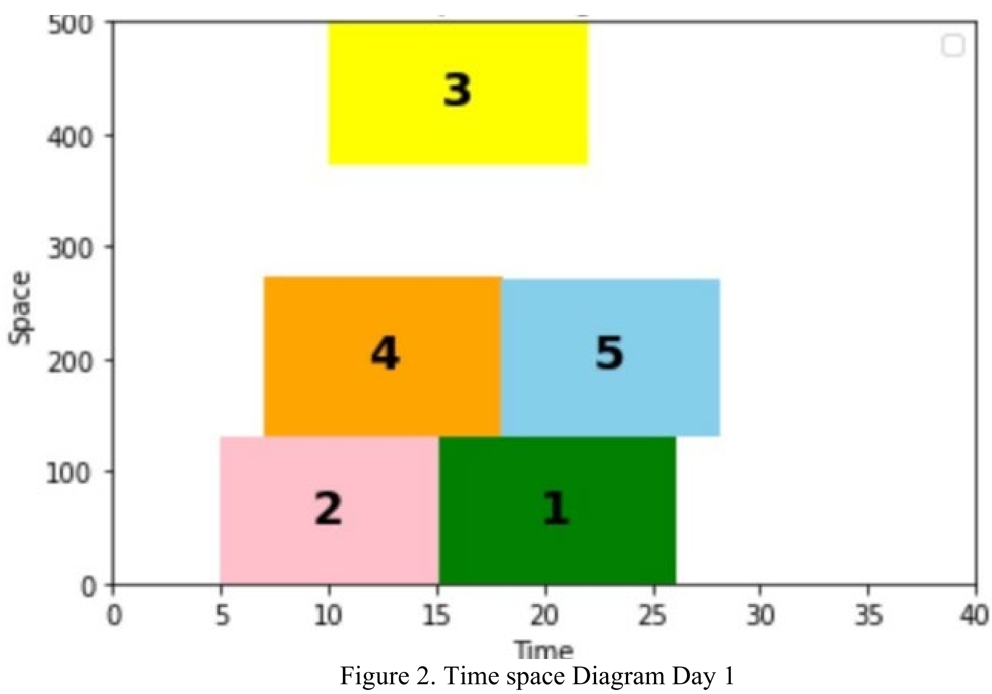

Figure 2. Time space Diagram Day 1

6. Conclusion

Berth allocation problem (BAP) is a fundamental optimization problem in the field of maritime logistics, which aims to allocate berths to incoming vessels arriving at a seaport. Berthing operations are considered one of the most crucial seaport operations. They have a great impact both on vessels' service time and service quality. The various layouts of seaport terminals lead to a wide range of methods for solving logistics problems. This research has addressed a simplified optimization method for the fundamental berth allocation problem (BAP) at TangerMed container terminal in Morocco. To address this challenge, this study proposed a simplified integer linear programming model, solved in Python using the PuLP Package, to calculate the mooring time and initial berthing location on a single continuous quay at X-Port container terminal. The time-space diagram presents the output of the Python program. Implementing this method can aid in improving the management of the seaport and enhancing the operational quality of service at the port. It enables better decision-making in the allocation of resources within the cargo terminal, ultimately leading to more efficient and effective operations.

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Biographies

Ilham Kissani, is a professor in the School of Science and Engineering since spring 2010. She received her Bachelor degree in Operations Research with Honors from the Engineering School INSEA in Rabat and both Master and Ph.D. degrees from Laval University in Canada. She is an expert in logistics and management science and has worked on the implementation of optimization models using various Decision Support Systems (Supply Chain Studio, Promodel, Supply Chain Guru…), for companies having critical needs for redesigning their supply chain following a situation of merger, expansion, or cost minimization. One of the consulting mandates, with AXIA, was related to the redesign of Natura supply chain, a cosmetic Brazilian firm to match some expansion needs. Her teaching interests include production and operations management and management science topics. She has been the recipient of numerous awards and nominations (FORAC, NSERC). Her research interests include Green and Lean aspects in supply chain and logistics. She has done significant research work and published over top quality international conferences.

RabieZine, received the bachelor's degree in Mathematics and Applications, the master's degree in Applied Mathematics in 2008 and the Ph.D. degree in Operations Research & Optimization in 2011, from Faculty of Sciences, University Moulay Ismaïl, Meknes, Morocco. Between 2008 and 2012, he worked as a project manager in two electrical network installation companies in Morocco. In 2013, he joined Prince Sattam bin Abdulaziz University in Saudi Arabia as assistant Professor. He has been promoted to Associate Professor in 2018. He is part of the Reviewer Boards and Scientific committee in some Journals and International Conferences. His main interests are in optimization, optimal control, electrical power distribution and its applications.

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