RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING VOL. 4 NO. 2 (2023) 29-35

© Universiti Tun Hussein Onn Malaysia Publisher's Office

RPMME

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN: 2773 - 4765

Solving Container Ship Berthing Problem using Heuristics

Mohamad Zharfan Danial Ahmad Nazri[1], Salleh Ahmad Bareduan[1]*

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2023.04.02.004
Received 01 December 2022; Accepted 01 April 2023; Available online 15 December 2023

Abstract: This study analyses total waiting, turnaround, penalty, and Estimated-Time Departure (ETD) of the last vessel leaving the berth to optimise vessel scheduling and berth allocation in port operations. The study compares First Come, First Serve (FCFS), Shortest Processing Time (SPT), and Longest Processing Time (LPT) heuristics for discrete and continuous berth allocation using past research data. The discrete case SPT heuristic has the lowest waiting time of 507.56 hours, turnaround time of 2422.56 hours, and penalty time of 165 hours. In the discrete case, FCFS regulates the final vessel's ETD best, with vessel Passat's earliest ETD observed on January 1, 2017, at 20:00. The comparison emphasises the importance of heuristic selection in berth allocation, requiring consideration of port characteristics, vessel categories, operational limitations, and specific goals for optimal performance.

Keywords: Berth Allocation, Heuristics, Port Operations

1. Introduction

International trade relies on supply chain efficiency. Containerization has transformed international freight transport, enabling economies of scale and cross-modal transport. Port congestion and inefficient berth allocation can delay and disrupt supply chains [1]. This research addresses the berth allocation issue and improves container shipping supply chains. The berth allocation problem optimises ship berths to reduce turnaround time and boost port efficiency. This study examines three heuristics: "first come, first serve," "shortest processing time," and "longest processing time." The objectives of this study are to solve the berth allocation problem using these heuristics, analyse their performance in terms of waiting time, turnaround time, penalty time, and estimated time of departure (ETD) of the last vessel, and determine the most effective heuristic for minimizing delays in the container shipping supply chain. This study addresses the Static Berth Allocation Problem (SBAP) in container ship terminal berthing [2]. The turnaround time, waiting time, penalty time, and ETD of the last vessel leaving the berth will be analysed and compared for the three heuristics. Berth allocation efficiency reduces ship turnaround time, reducing delays, improving shipment reliability, and increasing customer satisfaction. Increased international shipping necessitates container terminal efficiency [3].

*Corresponding author: saleh@uthm.edu.my
2023 UTHM Publisher. All right reserved.

2. Methodology

Methodology plays an essential role in ensuring the efficient and effective execution of research. Typically, a flowchart is used to outline the study's specific steps in order to facilitate planning. First Come, First Serve (FCFS), Shortest Processing Time (SPT), and Longest Processing Time (LPT) were chosen as heuristics, followed by the selection of static and continuous berth cases. On the basis of vessel length and quay length, accurate formulas were then developed to calculate key performance metrics such as waiting time, turnaround time, penalty time, estimated time of arrival (ETA), and estimated time of departure (ETD).

The data used in this study were taken from past research and subjected to extensive analysis and comparison for the purposes of validation [4]. Moreover, existing research papers provided the methodology for evaluating performance indicators for each heuristic. A berth time-space diagram was utilized to visualize the berthing schedule process. Subsequently, each heuristic was separately analyzed, and performance indicator results were compared using the same data. This comparison focused on total waiting time, total turnaround time, total penalty time, and the estimated time of departure (ETD) of the last vessel leaving the berth.

2.1 Data Collection

The essential data required to solve the berth allocation problem includes the number and dimensions of available berths, as well as pertinent information about incoming vessels, including their names, lengths, Estimated Time of Arrival (ETA), and processing times. These data were obtained from a past comprehensive study conducted, which focuses on vessel arrivals at the well-known port of Rades in the western Mediterranean region, specifically in Tunisia [4]. This study's data collection phase began on December 1, 2016. In Table 1, the specific characteristics pertaining to the number and dimensions of berths are described in detail. In addition, Table 2 provides a comprehensive summary of container ships arriving at the port of Rades in December, including their names, arrival dates, lengths, and most importantly, their respective processing times.

Table 1: Length of berth [4]

Berths	Berth length, l_i (meters)
1	150
2	150
3	180

Table 2: Ship allocation planning to berth [4]

No of Vessel	Name of Vessel	Length of Vessel, L_i(meter)	ETA_i	Processing Time P_i (hours)
1	KARINA	122	2/12/2016 17:30	50
2	REECON EMRE	141	3/12/2016 00:40	184
3	PASSAT	125	03/12/2016 15:00	140
4	AVERA	125	05/12/2016 07:00	263
5	HEINZ SCHEPPERS	96	07/12/2016 07:00	45
6	NICOLA	122	07/12/2016 22:00	134
7	ALLEGRO	125	08/12/2016 07:00	193
8	MAX CAVALIER	141	13/12/2016 15:40	140

9	GRAND	126	14/12/2016 00:40	211
10	JSR CAPILA	130	15/12/2016 13 :00	32
11	JSP SLIDUR	125	20/12/2016 16:00	129
12	PASSAT	125	21/12/16 08:00	258
13	HEINZ SCHEPPERS	96	21/12/16 11:06	44
14	MANDO	142	23/12/2016 00:40	92

2.2 Model assumption

The development of a model to address the berth allocation problem necessitates the establishment of specific assumptions that shape the formulation and resolution of the problem. These assumptions serve as a framework to comprehend and tackle the complexities associated with allocating berths to incoming vessels, streamlining the problem by focusing on crucial factors and variables that influence the allocation process. This study model has the following assumptions: The berth allocation problem is static, the number of cranes is equal to the number of berths, the type of berth is discrete and continuous, the estimated time of arrival (ETA) should be necessarily known for each vessel in the planning horizon, the depth of the seawater remains constant, approaching, preparation, clearance, and manoeuvring time is ignored, each berth can serve just one ship at a time for discrete cases, there are only three berths, the clearance between adjacent vessels is 10m for vessels below 130m in length for continuous case, for a vessel that has waiting time, the ETD of the previous vessel is the berthing time for the new vessel ranking prioritization allocation of berths starting from berth one, berth two, and lastly, berth three, for continuous cases, the arrangement of the vessel is allocated approaching 0m from quay length, the clearance distance between vessels for continuous case is minimum. All the assumption of for this study model except for the last three is taken from past research.

2.3 Model Development

Berth time space was explicitly utilized for this research's discrete and continuous types of berth cases. Thus, overlap between each other can be prevented. The Y axis is the quay length, and the length of each berth is different, whereas the X axis is the time allocated for the vessel. For discrete cases, only one ship can berth at a time. Whereas, for continuous cases, the ship can be berth along the quay as long there is enough space or clearance distance between the vessels.

Turnaround time refers to the total duration taken for a vessel to complete its berthing process, including the time from arrival at the berth to its departure. It encompasses various activities such as unloading or loading cargo, refuelling, maintenance, and other necessary operations. Several equations from [5] can be generated as follows:

$$Turnaround\ Time = Waiting\ time + Processing\ time \qquad \text{Eq.1}$$

$$ETD = Arrival\ Time + Turnaround\ Time \qquad \text{Eq.2}$$

$$Waiting\ time = Berthing\ Time - Arrival\ Time \qquad \text{Eq.3}$$

2.4 Clearance distance for Continuous Case

This study's berth allocation problem emphasises the significance of considering the continuous case, which requires taking vessel separation into account. Effective berthing requires careful consideration of the distance between adjacent ships. The minimum clearance distance between any two ships in the port of Kaohsiung is dependent on the length of the later-arriving vessel. Specifically, vessels longer than 130 metres must maintain clearance distances of at least 10% of their length, whereas vessels shorter than 130 metres must maintain a clearance distance of at least 10 metres. Therefore, the formula can be deduced as follows:

$$Clearance\ Distance = \frac{10}{100} \text{ x Length of second ship berth} \qquad \text{Eq.4}$$

2.5 Penalty Time

Penalty time refers to the delay encountered by a vessel as a result of factors such as congestion, and inefficiency. Typically, penalty time is associated with increased costs, decreased productivity, and possible disruptions to the supply chain [6]. During the waiting period, vessels anchorage is allowed. Thus, anchorage fees are assessed at all main ports in an effort to reduce pre-berthing delay and, consequently, vessel turnaround time. This will aid in streamlining vessel scheduling for customers and result in efficient port anchorage utilisation. research follows the berthing policy. During the waiting period, no anchorage fees are to be assessed by the port. Free waiting time in the anchorage should not surpass 48 hours [7]. Hence, a formulation can be generated as follows:

$$Penalty\ Time = Waiting\ time - 48\ hours \qquad \text{Eq.5}$$

2.6 Time Gap between first vessel arrive

The time gap between the first vessel's arrival is essential to make the graph correctly, and the first vessel's arrival is Karina. Thus, it will be the reference date for all the other vessels of the graph.

$$Time\ Gap\ = ETA\ of\ vessel - Date\ of\ first\ vessel\ arrive \qquad \text{Eq.6}$$

2.7 Data Analysis

The validation of this research depends on the data from past research, from the ETA, berth allocation, and processing time [4]. The outcome of the berth time-space diagram, total waiting time, total turnaround time, and the ETD of the last vessel leaving the berth was determined and compared. The percentage error was then calculated for validation of this study. The percentage error is shown below:

$$Error = \left|\frac{Measured\ Value - True\ Value}{True\ Value}\right| \times 100\% \qquad \text{Eq.7}$$

Next, the berth time-space diagram was done for the first come, first serve, shortest processing time, and longest processing time heuristics for the discrete and continuous cases to analyse their performance. The performance for each heuristic for both cases were analysed by referring to their performance indicator as follows: Total waiting time, Total turnaround time, Total penalty time and ETD of the last vessel leave the berth. Each heuristic was analysed and compared in the form of a bar graph. The process of identifying patterns in bar graphs was essential in order to acquire a deeper understanding and uncover the meaning behind them.

3. Results and Discussion

Studies need results and discussion to evaluate and interpret methodology. The most valuable chapter discusses the study's findings, implications, and potential benefits. This chapter reviews field research.

3.1 Model Validation

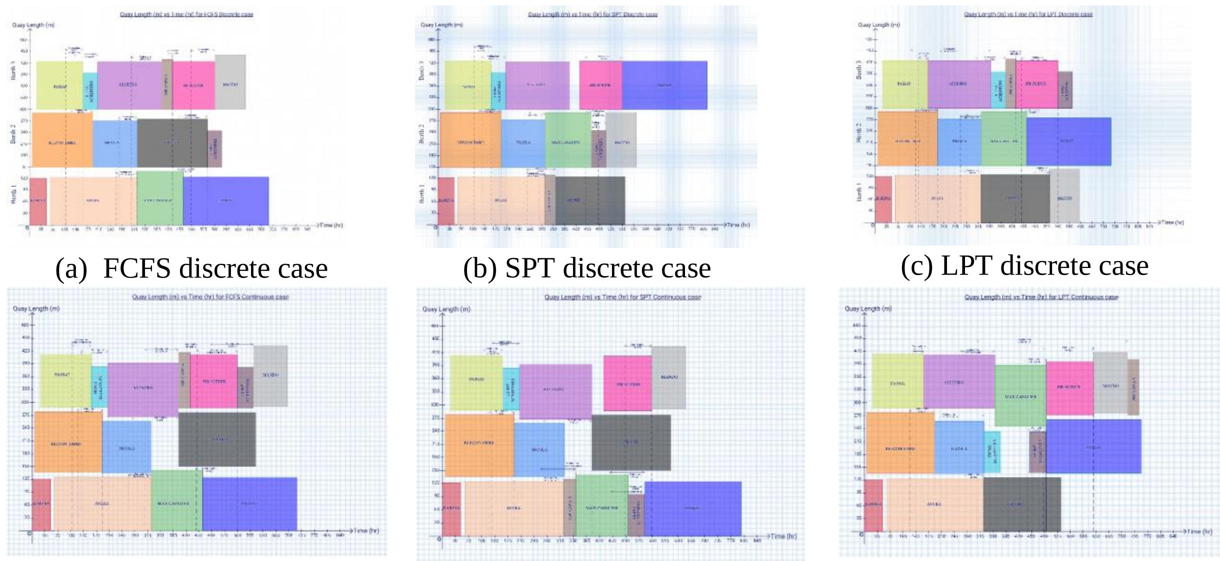
By comparing the results from past research from [4] to the data set of the departure date of the ship from the berth of Model G, the last vessel leaves the berth is Passat, and this research also found Passat on December 3, 2016, at 14:00 as shown in Table 3. The cumulative waiting time is 763.57 hours, matching previous research [4]. The total turnaround time remains 2678.57 hours. The methodology chapter formula is accurate and validated. Total turnaround time is constant, so the percentage error is zero. This research approach is more credible and valid with a zero percent difference.

Table 3: Comparison results of Model G

Model G Parameter	[4]	This research
Last Vessel Leave the Berth	Passat	Passat
ETD of the Last Vessel Leave the Berth (Date)	3/1/2017 20:00	3/1/2017 20:00
Total Turnaround Time (hour)	2678.57	2678.57
Percentage Error (%)	0	

3.2 Comparison of Discrete and Continuous Berth Case for Port

Comparing discrete and continuous port berth allocation methods helps understand their effects. Berth allocation is based on vessel arrival and departure times, berth capacities, and penalty time. Figure 1 shows the results of berth allocation in the form of berth time space diagram. The discrete case SPT reduced waiting time to 507.56 hours shown in Figure 2. Shorter wait times boost supply chain efficiency. Ships spend less time at port, improving supply chain efficiency. This ensures timely deliveries and supply chain reliability. This study confirms past research finding that SPT solves the berth allocation problem better than FCFS [8].



(a) FCFS discrete case (b) SPT discrete case (c) LPT discrete case

(d) FCFS Continuous Case (d) SPT Continuous Case (d) LPT Continuous Case

Figure 1: Graph of Quay length versus Time

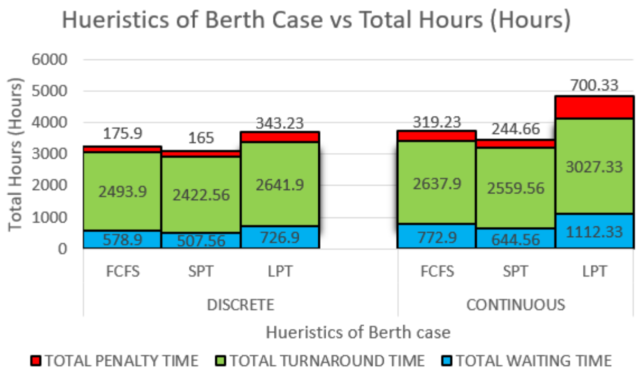


Figure 2: Summary of Bar Chart for Heuristics of Berth Case versus Total Hours

Lower wait times boost port efficiency. Shorter wait times allow more vessels to be handled. Figure 2 showed discrete case SPT heuristics had the lowest value of 2422.56 hours. By attracting more shipping lines, reducing ship turnaround time increases port productivity, capacity utilisation, and competitiveness. The discrete case SPT heuristic has the lowest penalty time at 165 hours. Supply chain businesses can lose money from demurrage fees and late delivery fines. Shorter suspension periods reduce financial losses. Reducing waiting time reduces turnaround time and penalty time. Continuous and discrete berth allocation problems have different heuristic hours. Continuous cases wait 843.26 hours, while discrete cases wait 604.45 hours. Continuous is more flexible than discrete. In continuous vessel allocation, clearance distance optimises berth space. Each discrete berth can hold one vessel, causing constraints and inefficiencies.

To standardise vessel-berth allocation in continuous, all heuristics set the clearance distance to its minimum. Thus, continuous case berth allocation ports should use the shortest processing time heuristic. This heuristic optimises continuous berth allocation by minimising total waiting, turnaround, and penalty times. Vessel length affects continuous cases. More can enter the berth faster with shorter vessels or longer quays. The discrete case has much higher values than the continuous case using specific data and quay length and the clearance distance rule. From Table 4, the discrete FCFS heuristics case on January 1, 2017, at 20:00 has the earliest ETD. FCFS beats SPT and LPT in vessel departures but not total waiting, turnaround, or penalty time. In continuous case, FCFS releases vessels early, 40 minutes apart.

Table 4: ETD of last vessel leave the berth for discrete and continuous case

Case	Discrete			Continuous		
Heuristics Parameter	FCFS	SPT	LPT	FCFS	SPT	LPT
Vessel	Passat	Passat	Passat	Passat	Passat	Passat
ETD	01/01/17 20:00	05/01/17 19:00	01/01/17 20:40	01/01/17 20:40	05/01/17 00:00	03/01/17 07:00

The comparison of the FCFS, SPT, and LPT heuristics for total waiting times, turnaround times, penalty time, and ETD of the last vessel leaving the berth can help port management and planning. The discrete or continuous instance of the berth allocation problem depends on its requirements. This research's performance indicator helps port authorities assess equity, efficiency, and berth utilisation conflicts. The trade-offs between total waiting time and other factors, as shown by the difference for this data set only, can help them choose the best heuristic.

4. Conclusion

This study solved the container ship berthing problem using FCFS, SPT, and LPT heuristics. The second objective was met by evaluating these heuristics using key metrics like total waiting time, total turnaround time, total penalty time, and the ETD of the last vessel to leave the berth for discrete and continuous cases. The results show FCFS balances vessel arrivals. It promotes equity and reduces biases in allocation. It may not outperform SPT in wait time and productivity. However, FCFS for the discrete case is the best heuristic for regulating the ETD of the final vessel leaving the berth, with the earliest ETD on January 1, 2017, at 20:00 for vessel Passat.

SPT and LPT rank vessels by processing time. SPT has the lowest waiting times, turnaround time enhancements, and penalty time. LPT has the longest wait times, but prioritizing larger vessels or complex operations may maximize resource use. The discrete case follows the continuous case but with higher value, with SPT reducing vessel time at the port the most, followed by FCFS and LPT. Finally, rigorous analysis and comparison showed that SPT is the best heuristic for reducing berth allocation delays. This research achieved all three goals.

Acknowledgement

The authors wish to thank to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity. The authors would also like to thank the Ministry of Higher Education Malaysia for supporting this research under Fundamental Research Grant Scheme Vot No. FRGS/1/2018/TK03/UTHM/02/9 and partially sponsored by Universiti Tun Hussein Onn Malaysia.

References

[1] C. A. Ouedraogo, A. Montarnal, D. Gourc, and C. Ouedraogo, "Multimodal Container Ttransportation Ttraceability and Supply Chain Risk Management: A Review of Methods and Solutions Cheik Aboubakar Ouedraogo, Aurelie Montarnal, Didier Gourc. Multimodal Container Ttransporta-tion Ttraceability and Supply Chain Risk Management: A Review of Methods and Solutions Multimodal Container Ttransportation Ttraceability and Supply Chain Risk Management: A Review of Methods and Solutions," *International Journal of Supply and Operations Management IJSOM 2022*, no. 2, pp. xx–xx, 2022, doi: 10.22034/ij.

[2] J. Wawrzyniak, M. Drozdowski, and É. Sanlaville, "Selecting algorithms for large berth allocation problems," *Eur J Oper Res*, vol. 283, no. 3, pp. 844–862, Jun. 2020, doi: 10.1016/j.ejor.2019.11.055.

[3] D. Song, "A Literature Review, Container Shipping Supply Chain: Planning Problems and Research Opportunities," *Logistics*, vol. 5, no. 2, p. 41, Jun. 2021, doi: 10.3390/logistics5020041.

[4] L. Kallel, E. Benaissa, H. Kamoun, and M. Benaissa, "Berth allocation problem: Formulation and a Tunisian case study," *Archives of Transport*, vol. 51, no. 3, pp. 85–100, 2019, doi: 10.5604/01.3001.0013.6165.

[5] K. Buhrkal, S. Zuglian, S. Ropke, J. Larsen, and R. Lusby, "Models for the Discrete Berth Allocation Problem: A Computational Comparison," 2009.

[6] F. N. Atencio and D. M. Casseres, "A comparative analysis of metaheuristics for berth allocation in bulk ports: A real world application," Elsevier B.V., Jan. 2018, pp. 1281–1286. doi: 10.1016/j.ifacol.2018.08.356.

[7] "BERTHING POLICY FOR DRY BULK CARGO FOR MAJOR PORTS 2," 2016.

[8] K. K. Lai and K. Shih, "A study of container berth allocation," *J Adv Transp*, vol. 26, no. 1, pp. 45–60, 1992, doi: 10.1002/atr.5670260105.