Berth Allocate Problem with Multi-entry Considering Marine Fish Freshness

Jing Zhu[1(✉)], Wang Yan[2], and Xuehao Feng[3]

[1] School of Management, Zhejiang University, Hangzhou, People's Republic of China
11820014@zju.edu.cn

[2] ZPMC, Shanghai, People's Republic of China
wangyan_wy@zpmc.com

[3] Ocean College, Zhejiang University, Hangzhou, People's Republic of China
fengxuehao@zju.edu.cn

Abstract. In this paper, we analyze the berth allocation problem for vessels calling at fishing ports by considering the current higher consumer demand for seafood freshness in the vast inland areas of China. At first, according to the previous investigation on the site of Zhoushan Fishing Port, we propose a mathematical model to maximize the overall profit with a multiple-entry policy of the vessels. The optimal berth allocation and re-entry of vessels can be obtained. We integrate the vessel's owner, the manager of the port, and the fish market vendor together, regarding the tripartite overall profit as the objective function. Based on this, taking into account the relationship between seafood unloading time and overall income, a mathematical model of mixed-integer linear programming (MILP) is constructed to accurately describe the berth allocation decision framework under which fishing vessels are allowed multiple arrivals.

Keywords: Fish port · Berth allocation · Mathematical programming · Multiple-entry policy

1 Introduction

Berth allocation problem (BAP, also known as the berth scheduling problem) is a well-known NP-complete problem. In this problem, fishing vessels arrive over time and the terminal operator needs to assign them to berths to be served (loading and unloading cargos) as soon as possible. Discrete berth allocation refers to the scenario that the shoreline of the port is artificially divided into multiple different sections [1, 2]. On the contrary, a continuous berth means the shoreline of the port is not divided into different subsections [3, 4].

Some scholars are dealing with uncertainty. A lot of works of literature considered uncertain arrival time [5]). And some preview research focused on the uncertain operation time [6–9], while others aimed at the integrated uncertain factors [10–12].

In this work, we studied a BAP with a multi-entry policy (BAMEP) to maximize the total profit with consideration of the time value of seafood. Although there exists a

Published by Springer Nature Switzerland AG 2021
A. Dolgui et al. (Eds.): APMS 2021, IFIP AICT 634, pp. 149–157, 2021.
https://doi.org/10.1007/978-3-030-85914-5_16

large body of literature in the field of the BAP. Few studies considering Loss of seafood value and multi-entry policy for the berth allocation in fishing ports.

2 Problem Description

The assignment of berth for calling vessels at the port is berth planning. Port has several types of resources, including berth, equipment, and staff. The BAMEP aims at assigning arriving vessels to berth and make full and proper use of the resources mentioned above to get the optimal profit. In each cycle (e.g. one day), vessels arrive at one port at different time points. Each vessel is loaded with at least one type of seafood. We assume the sharing of information under which the port knows the exact amounts of seafood of different types on each vessel. The number of berths in the port is limited, each of which can serve only one vessel at the same time. The unloading process of one vessel can be interrupted by another vessel when the former one finishes the unloading process of one type of seafood. It can wait at a specific area (e.g. anchorage) until one berth becomes available where it can continue to unload the seafood. Some types of seafood can only be unloaded at the specific berth and the efficiency of unloading goods varies according to berths.

As for the fishing port, the fishing goods to transport need to be fresh. Thus, we have to consider freshness when constructing profit formulation. We assume that the prices of the seafood are respectively non-increasing with the time when the seafood is unloaded from the corresponding vessel. Because sailing inbound and out more than one time is permitted, the cost of each time sailing inbound should be taken into account. In terms of further profit, we want to satisfy as many owners of fishing vessels as possible. Thus, we cannot let one vessel waiting for too long. To simplify this problem, making the makespan as early as possible is a proper way. As a consequence, the BAMEP aims to minimize the overall penalty cost resulting from the waiting time and decreasing of the prices.

3 Mathematic Model

3.1 The Assumptions

When we are dealing with problems, we have to make some assumptions as the reality is so changeable and unpredictable.

The fishing vessels are allowed to arrive at the port any time but their arriving time is deterministic. And the prices of seafood are non-increasing with the time when they are unloaded at the port, respectively.

We care about neither the length of the berth nor the length of the vessel. For the reason that we are aiming at dealing with the problem in the fishing port, the fishing boats are almost of equal size. Accordingly, we regard all the sizes as the same length and make our problem easier and clearer. Moreover, no crossing constraints and safety space between berths must be obeyed.

A berth may not have the capacity to serve all categories of fishing goods. Consequently, the capacity of the berth can constrain the berth allocating.

The vessels are permitted to sail into the berth more than once until all the goods have been unloaded. In this paper, we let it possible for the vessels to sail into the berth more than once. The operation of one vessel can be interrupted only when all seafood of one type on that vessel is unloaded.

In this model, we regard a certain berth each time been arranged like a box. Under that consequence, if a certain berth has been arranged for n times, then we have n boxes here. With this assumption, we transfer the original problem to the problem to arrange the vessel to the berth's box, not merely the berth itself.

For a certain box of a berth, there is an independent start service time and ending service time. Relatively, for every kind of seafood in any vessel, there is an independent start service time and ending service time, too.

3.2 The Mathematical Formulation for the Model

As we have assumed, the work we have to do is to arrange each box of berth properly. The approach MILP is proposed, so a basic formulation deciding the arrangement to get the optimal objective is presented here. But before that, the following notation should be introduced first. And the variables and parameters notation is shown in Table A1 in the Table 1.

Table A1. Notations in the formulation

Parameters	
w_{ij}	The amount of jth goods in the ith vessel
c_{mj}	1, for the mth berth can serve the jth goods; 0, otherwise
v_i	The number of times that the vessel i can sail in the berth and out
R^A	The penalty parameter of the price reduced to the freshness decreasing
R^T	The transforming parameter to convert the ending time to the value
R^I	The cost parameter the vessel sailing inbound one time
T_i	The arrival time of the ith vessel
p_j	The price of the jth goods when totally fresh
E_m	The efficiency of unloading goods in the mth berth
M	A large enough number
s_{ij}	1 for there is jth goods in the ith vessel; 0, otherwise
m_1	The proportion parameter of the profit in the objection formulation
m_2	The proportion parameter of the maximize of the ending time in the objection formulation
N_{berth}	The total number of all the berths in the port
N_{goods}	The total number of the kinds of all the fishing goods
N_{vessel}	The total number of all the vessels to be arranged
N_{order}	The maximum number of the times which the berth can be arranged
Variables	
t^s_{mk}	The start time, the time when the mth berth starts to be used in the kth time
t^e_{mk}	The ending time, the time when the mth berth has been used in the kth time
T^s_{ij}	The start time, the time when the jth kind of seafood of the ith vessel starts to be unloaded
T^e_{ij}	The ending time, the time when all of the jth goods of the ith vessel unloaded
x_{ijmk}	1 for the mth berth is used for ith vessel at the kth order to unload the jth goods; 0, otherwise
y_{ijl}	1 means that in terms of the ith vessel, the jth kind of seafood is unloaded right followed by the lth goods
z_{mk}	1 for the mth berth has been arranged for k times,0, otherwise
π_{ijmk}	1 for before the mth berth is used for ith vessel at the kth order to unload the jth goods, the vessel should sail into the berth; 0, otherwise
τ_i	The number of times that the vessel i truly sail in the berth and out

The object function can be formulated as below.

$$Minimize : m_1 \sum_i \sum_j R^A w_{ij} p_j T^e_{ij} + m_2 \left(R^T \times \max_{i,j}(T^e_{ij}) \right) + R^I \sum_i \tau_i \tag{1}$$

The set of constraints is given below.

$$\sum_m \sum_k x_{ijmk} = s_{ij},\ \forall i,\ \forall j \tag{2}$$

$$z_{mk} = \sum_i \sum_j x_{ijmk},\ \forall m, \forall k \tag{3}$$

$$z_{mk} \leq 1,\ \forall m, \forall k \tag{4}$$

$$z_{mk} \leq z_{mk-1},\ \forall m,\ \forall k, k \neq 1 \tag{5}$$

$$\sum_i \sum_k x_{ijmk} \leq M \times c_{mj},\ \forall m,\ \forall j \tag{6}$$

$$t^s_{mk} \geq t^e_{mk-1},\ \forall m,\ \forall k, k \neq 1 \tag{7}$$

$$t^e_{mk} = t^s_{mk} + \sum_i \sum_j x_{ijmk} \times \frac{w_{ij}}{E_m},\ \forall m,\ \forall k \tag{8}$$

$$t^s_{mk} \geq \sum_i \left(\sum_j x_{ijmk} \times T_i \right),\ \forall m,\ \forall k \tag{9}$$

$$T^s_{ij} \geq \left(x_{ijmk} - 1 \right) \times M + t^s_{mk},\ \forall i, \forall j,\ \forall m,\ \forall k \tag{10}$$

$$T^s_{ij} \leq \left(1 - x_{ijmk} \right) \times M + t^s_{mk},\ \forall i,\ \forall j,\ \forall m,\ \forall k \tag{11}$$

$$T^e_{ij} \geq \left(x_{ijmk} - 1 \right) \times M + t^e_{mk},\ \forall i,\ \forall j,\ \forall m,\ \forall k \tag{12}$$

$$T^e_{ij} \leq \left(1 - x_{ijmk} \right) \times M + t^e_{mk},\ \forall i,\ \forall j,\ \forall m,\ \forall k \tag{13}$$

$$T^s_{ij} \leq s_{ij} \times M,\ \forall i,\ \forall j \tag{14}$$

$$T^e_{ij} \leq s_{ij} \times M,\ \forall i,\ \forall j \tag{15}$$

$$\sum_{j=0}^{N_{goods}} \left(y_{ijl} \times s_{ij} s_{il} \right) = 1,\ \forall i,\ \forall l, l \neq j \tag{16}$$

$$\sum_{j=0}^{N_{goods}} y_{ijl} = 1,\ \forall i,\ \forall l, l \neq j \tag{17}$$

$$\sum_{l=1}^{N_{goods}+1} \left(y_{ijl} \times s_{ij}s_{il}\right) = 1,\ \forall i,\ \forall j, l \neq j \tag{18}$$

$$\sum_{l=1}^{N_{goods}+1} y_{ijl} = 1,\ \forall i,\ \forall j, l \neq j \tag{19}$$

$$T^e_{ij} \leq T^s_{il} + \left(1 - y_{ijl}\right) \times M,\ \forall i,\ \forall j,\ \forall l, l \neq j \tag{20}$$

$$T^s_{ij} \geq T^e_{il} + \left(y_{ilj} - 1\right) \times M,\ \forall i,\ \forall j,\ \forall l, l \neq j \tag{21}$$

$$\pi_{ijm1} = x_{ijm1},\ \forall i,\ \forall j,\ \forall m \tag{22}$$

$$\pi_{ijmk} \leq x_{ijmk},\ \forall i,\ \forall j,\ \forall m,\ \forall k, k > 1 \tag{23}$$

$$\pi_{ijmk} \leq \left(1 - x_{ijmk}\right) - \left(\sum_{l,l \neq j} x_{ilmk-1} - 1\right),\ \forall i,\ \forall j,\ \forall m, \forall k, k > 1 \tag{24}$$

$$\pi_{ijmk} \geq x_{ijmk} - \sum_{l,l \neq j} x_{ilmk-1},\ \forall i,\ \forall j,\ \forall m,\ \forall k, k > 1 \tag{25}$$

$$\sum_j \sum_m \sum_k \pi_{ijmk} = \tau_i,\ \forall i \tag{26}$$

$$\tau_i \leq v_i,\ \forall i \tag{27}$$

$$T^e_{ij} \geq 0,\ \forall i,\ \forall j \tag{28}$$

$$T^s_{ij} \geq 0,\ \forall i,\ \forall j \tag{29}$$

$$t^e_{mk} \geq 0,\ \forall m,\ \forall k \tag{30}$$

$$t^s_{mk} \geq 0,\ \forall m,\ \forall k \tag{31}$$

$$y_{ijl} \in \{0, 1\},\ \forall i,\ \forall j,\ \forall l, j \neq l \tag{32}$$

$$x_{ijmk} \in \{0, 1\},\ \forall i,\ \forall j,\ \forall m,\ \forall k \tag{33}$$

$$z_{mk} \in \{0, 1\},\ \forall m,\ \forall k \tag{34}$$

$$\pi_{ijmk} \in \{0, 1\},\ \forall i,\ \forall j,\ \forall m,\ \forall k \tag{35}$$

Accordingly, we are aiming at making it a win-win situation for each aspect. We regard them all as a whole and care about the overall interest including the vessels arriving and unloading the goods, and the goods selling from the port to the market. However, sometimes we not only care about the profit we have but also the waiting time the vessels spend. In terms of the long-term profit, the manager of the port will never let one of the fishing vessels wait for too long. In the above, the objective function (1) minimizes the integration of the sum of the profit, the max of the ending time, and the times for all the vessels sailing inbound and out.

Constraint (2) is a usual constraint which only if the kind of seafood is on the vessel, we will assign it. Constraint (4) is a bind that one box of a berth cannot be arranged twice or even more. Constraint (5) lets the arrangement of the berth be ordered, which means you cannot arrange a box before the smaller numbered box has been arranged. Constraint (6) enforces the seafood can only be unloaded if the berth has the capacity.

Constraint (9) requires that the starting time of service should be larger equal than the arriving time of the vessel which is common sense. Constraints (10) to (13) define the variables T^s_{ij} and T^e_{ij} by using the relationship with t^e_{mk} and t^s_{mk}. Constraints (14) and (15) also uses big M constraints to require that the variables T^s_{ij} and T^e_{ij} should be zero if there's no seafood here. Constraints (16) to (21), the variable y_{ijl} is been introduced to let us get the unloading sequence of different seafood of the same vessels. We use the virtual start point seafood with the index 0, and the virtual ending point seafood with the index $N_{goods} + 1$.

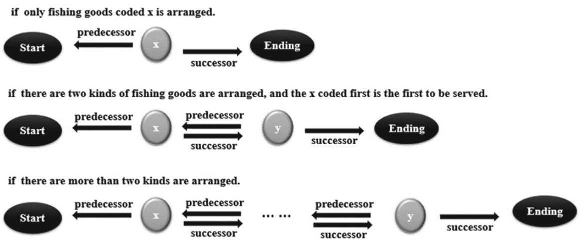

Fig. 1. The berth plan on the timeline

With the virtual start point and ending point, every point from 1 to N_{goods}, which means every kind of goods on a certain vessel, will have a predecessor and a successor. Some examples are shown in Fig. 1.

We also want to control the times that every vessel sails into the berth and out. To let the model closer to reality, the times that the vessel sails in and out can be limitless. Accordingly, a new binary variable π_{ijmk} is been introduced to show whether Seafood j on the Vessel i is unloaded at Berth m in the order of k or not.

Constraints (23) to (25) defines the variable π_{ijmk} when the index k larger than one. We can use some mathematical techniques to define π_{ijmk} with the comparison to x_{ijmk} and x_{ijmk}. We use a new variable τ_i to record the times that Vessel i sail into the berth in total, which is Constraint (25). Constraint (26) requires that the times that every vessel in and out to the berth should less equal than the parameter v_i.

4 Experimental Results and Analysis

In this section, we conducted comprehensive numerical experiments to illustrate the optimal solution and how it is influenced by parameters. The solution is obtained using ILOG CPLEX 12.9 optimizer coded with JAVA. The computational experiments were conducted on a computer with Core™ i5-630HQ CPU with 2.30 GHz processors and 8.00 GB RAM.

We assume that there are 10 fishing vessels to arrange with four categories of seafood, assumed to be lobster, salmon, octopus, and fish, and coded from 1 to 4 in order. At first, a sensitivity analysis on capacity is introduced below. Types of berth in different scenarios are shown in Table 1.

Table 1. The experiments about the berth.

No.	Scenario	Efficiency			Profit ($)	Time used (quarter-hour)
		Berth 1	Berth 2	Berth 3		
		General	Lobster	Octopus		
1	1A	1	9	9	53401.50	247.11
2		5	9	9	54417.42	76.80
3		6	9	9	54441.62	64
4		9	9	9	54519.59	64
5	2 (three berth are general)	1	9	9	54518.17	64
6		5	9	9	54527.27	64
7		9	9	9	54542.71	64
8	3	1	9	9	52750.67	276.44
9		5	9	9	54417.85	84.36
10		9	9	9	54513.97	64
11	4	1	9	9	52768.57	399.11
12		5	9	9	54323.39	97.51
13		9	9	9	54485.79	64
14	5	1	9	9	52693.67	520.89
15		5	9	9	54099.59	109.69
16		9	9	9	54441.62	64
17	1B	5	9	8	54452.56	78.7
18		5	9	9	54460.52	76.80
19		5	9	10	54465.59	75.18
20		5	9	11	54472.03	74.03

In terms of the five scenarios, we conduct three experiments each with the efficiency of Berth 1 changing. We set the efficiency of the Berth 1 in the three experiments respectively as low efficiency, medium efficiency, and high efficiency with the numbers 1, 5, and 9. Using the arrangement data, the objective profit and the total working time can be calculated. Conclusions can be easily found in the scatter plot.

As shown in and Table 1, we can find that when we improve the efficiency of the general berth from low efficiency to medium efficiency, the profit has relatively significant growth. There is still a growth between high efficiency and a medium one. As expected, general berths are more valuable to profits when berths have the same efficiency. However, as we have mentioned that too many general berths are easy to cause waste. Besides, a unique berth always has a relatively higher efficiency than the general berth. Thus, choose a proper unique berth is of high importance. Comparing Scenarios 3, 4, and 5, we can find that the right combination of unique berths can help maximize profits. In a real port assignment, the number of the berth is limitless and much lower than the number of fishing goods. Thus, by no means we can have each fishing goods a unique berth. Choosing the right combination of the unique berth can be a valuable problem for the management of the port company. Furthermore, Compare Scenario 1B with Scenario 1A, the results imply that the effect of improving the efficiency of general berths is better than that of improving the efficiency of private berths. Considering that the costs of them are different, so further work could be done when deciding the efficiency of which berth to improve.

What kind of berth should be constructed, the general one or the unique one can be a valuable question for the management of the port to dealing with. We also conducted the experiments by adding a berth.

Table. 2. The experiments about adding a berth.

No.	Scenario	Efficiency	The maximum order				Obj ($)	Time used (quarter-hour)
			Berth 1	Berth 2	Berth 3	Berth 4		
1	1	5	3	3	7	2	54489.23	84.08
2		6	1	6	4	4	54497.07	82.92
3		7	1	5	6	3	54500.37	80.62
4		8	2	6	2	5	54509.65	75.00
5		9	3	5	1	6	54522.79	72.78
6	2	9	3	5	4	3	54514.71	73.68
7	3	9	0	6	3	3	54508.79	73.42
8	4	9	4	7	1	3	54486.96	77.67
9	5	9	3	7	3	2	54485.79	77.56

As Table 2 implies, the following messages can be found. When a unique berth is added, the high the price of the kind of seafood aimed at, the more the profit is. The significant trend is shown in Column 6 to Colum 9 of Table 2. However, the gap is not simply related to price. Other factors such as the amount of each kind of fishing goods and the conditions of other berths may influence the profit as well. Besides, the rise of efficiency of berth helps the increase of profit. Adding the cost of construction of berth of different efficiency can make the problem clearer. And proper kinds of unique berth (Experiment 7 and Experiment 6) works better than general berth with not high enough efficiency (Experiment 1, Experiment 2, and Experiment 3). Thus, building multi-functional berths is not necessarily better than unique berths. We also found from

Table 2 that the maximum order in the results of some experiments varies in a relatively large gap. It means that some berths are overworking while some are idle. So it is not rational to make all the berth multifunctional.

5 Conclusion and Future Research

This paper introduces a berth allocation problem to solve the fishing port berth arrangement for fishing vessels. Some activities including inbound, outbound, transshipment and fishing goods selling in the market are taken into consideration. To maximize the total profit to get a win-win situation is our objective. Besides, the decision we make can get the industrial development and benefit fishermen and consumers as well.

Acknowledgements. This work was supported by the by National Natural Science Foundation of China (no. 71801191).

References

1. Imai, A., Nishimura, E., Papadimitrou, S.: The dynamic berth allocation problem for a container port. Transp. Res. Part B Methodol. **35**(4), 401–417 (2001)
2. Cordeau, J.F., Laporte, G., Legato, P., et al.: Models and tabu search heuristics for the berth-allocation problem. Transp. Sci. **39**(4), 526–538 (2005)
3. Park, K.T., Kim, K.H.: Berth scheduling for container terminals by using a sub-gradient optimization technique. J. Oper. Res. Soc. **53**(9), 1054–1062 (2002)
4. Lee, D.-H., Wang, H., Miao, L.: Quay crane scheduling with non-interference constraint in port container terminals. Transp. Res. Part E Logist. Transp. Rev. **44**(1), 124–135 (2008)
5. Umang, N., Bierlaire, M., Vacca, I.: Exact and heuristic methods to solve the berth allocation problem in bulk ports. Transp. Res. Part E Logist. Transp. Rev. **54**, 14–31 (2013)
6. Hendriks, M., Laumanns, M., Lefeber, E., Udding, J.T.: Robust cyclic berth planning of container vessels. OR Spectr. **32**(3), 501–517 (2010)
7. Golias, M.M.: A bi-objective berth allocation formulation to account for vessel handling time uncertainty. Marit. Econ. Logist. **13**(4), 419–441 (2011)
8. Karafa, J., Golias, M.M., Ivey, S., Saharidis, G.K., Leonardos, N.: The berth allocation problem with stochasti c vessel handling times. Int. J. Adv. Manuf. Technol. **65**, 1–12 (2013). https://doi.org/10.1007/s00170-012-4186-0
9. Ursavas, E., Zhu, S.X.: Optimal policies for the berth allocation problem under stochastic nature. Eur. J. Oper. Res. **225**, 380–387 (2016)
10. Han, X., Lu, Z., Xi, L.: A proactive approach for simultaneous berth and quay crane scheduling problem with stochastic arrival and handling time. Eur. J. Oper. Res. **207**, 1327–1340 (2010)
11. Zhen, L., Chang, D.: A bi-objective model for robust berth allocation scheduling. Comput. Ind. Eng. **63**, 262–273 (2012)
12. Xu, Y., Chen, Q., Quan, X.: Robust berth scheduling with uncertain vessel delay and handling time. Ann. Oper. Res. **192**(1), 123–140 (2012)