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A SOLUTION OF BERTH ALLOCATION PROBLEM IN INLAND WATERWAY PORTS

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Preliminary notes
This paper explores the impact of berth allocation problem (BAP) solving depending on different options for river port design. Comparing multipurpose and specialized berths layout with port efficiency requirements, based on berth allocation, an optimal design option may be selected. The aim is to achieve an optimal distribution of vessels alongside quay with minimum vessels' time in port and port operator workload. The model set up in this paper is tested on the example of the inland waterway port. The problem solution is attained using the linear mixed integer programming method. Standard assignment problem is adjusted in such a way to achieve the practical results in as low as possible mathematical iterations while not compromising results' precision.

Keywords: *assignment problem, berth allocation, inland waterway, river port design*

Rješenje problema dodjele veza u lukama unutarnjih voda

Prethodno priopćenje
U ovom radu istražuje se utjecaj rezultata problema dodjele veza ovisno o različitim varijantama projekta riječne luke. Uspoređujući postavu višenamjenskih i specijaliziranih vezova na temelju optimalnog pridruživanja vezova plovilima, sa zahtjevima u pogledu efikasnosti luke, moguće je odabrati najbolju varijantu projekta. Cilj je postići optimalni raspored plovila uzduž pristana uz minimalno zadržavanje plovila u luci i minimalni utrošak prekrcajnih resursa. Model osmišljen u ovom radu testiran je na primjeru luke unutarnjih voda. Za rješavanje problema korištena je metoda linearnog programiranja u sklopu koje je posebno razrađen i prilagođen problem asignacije na takav način da se dobiju praktični rezultati u što manje matematičkih iteracija uz prihvatljivu točnost rezultata.

Ključne riječi: *dodjela veza, problem pridruživanja, projektiranje riječnih luka, unutarnji vodni putovi*

1 Introduction

Operational planning in ports includes monthly, weekly and daily planning of various operational procedures that take place in the port. An important task here is the deployment of vessels to berths depending on the characteristics of the vessel, type of cargo and expected time of vessels' arrival in the port. This problem is known as Berth Allocation Problem (BAP).

Traditional approach to the BAP presumes determination of the fixed berthing position that allows docking for certain types of vessels. Berths may be constructed as specialized or multi-purpose depending on the type of cargo and port operations expectation. Multi-purpose berths are considered to be suitable for handling different types of cargo with average performance. Inland waterway vessels have specific characteristics that have to be taken into account in the berth planning process.

Berths' arrangement plan can be either static or dynamic. Static scheduling assumes ad-hoc scheduling of vessels at berths when vessels arrive in port. Depending on the present situation of berth availability, a vessel is sent to the berth or anchorage. In dynamic scheduling, berthing time is planned according to previous notices of vessels' arrivals. In this way it is possible to reduce the total in-port time of vessels.

The arrival of each vessel and/or convoy must be announced 24 hours before scheduled arrival at the port or 48 hours if there is a dangerous cargo on board [1]. Based on this information and data on the quantity and type of cargo it is possible to determine the optimal position and time of mooring in a way that the total time spent in port for all vessels in the system is minimal.

In this paper we present the possibility of solving the problem of dynamic allocation of berths to different types of vessels for different scenarios of berth and terminal design. The aim is to achieve an optimal distribution of vessels alongside quay with minimum in-port stay and overall service cost of the vessels in predefined time horizon. Therefore, better resource utilization and voyage planning is possible through the overall planning process. Costs of vessels' service time, cost of waiting on anchorage and cost of in-time convoy departure may be evaluated and optimized according to common objectives of the stakeholders.

The project of Port of Vukovar – New Port East development is taken as a test example. Problem solving method is based on a linear programming technique that is specifically developed and tailored to the problem of berth assignment.

2 Problem description and previous research introduction

Vessel's stay in port area consists of time spent at anchor (waiting time), in-port manoeuvring time (e.g. approach to the berth, mooring and departure time from the berth) and time spent alongside a terminal for cargo handling operations (Fig. 1). However, for simplicity's, sake, time of approach to the berth, preparation time and manoeuvring time are included in the processing time for cargo handling just like in Fig. 1. Total time vessels spend in the port area should be minimized by optimizing the vessel-berth arrangement considering performance of the berths in servicing different type of vessels and their cargo for a predefined period of time. For this purpose it is necessary to create an operational plan of space-time distribution of vessels in port.

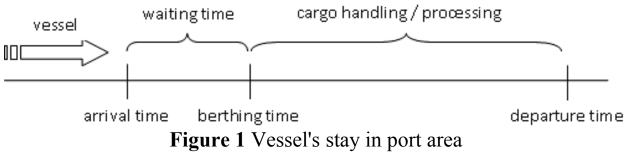


Figure 1 Vessel's stay in port area

Every vessel i that comes into the port should be assigned a berthing position s depending on the length of the vessel l, type of cargo c, expected time of arrival a and estimated time of cargo handling operations p.

There are a range of vessel types in inland navigation. The most significant differences are in cargo transport technology applied: single motor vessels have own propulsion and cargo holds and lighters (barges) have no propulsion so they must be coupled with pushers (tugs). Vessels are coupled in so-called formation f creating one single navigation entity – convoy. Upon arrival on port anchorage, vessels may be decoupled to dock alongside the quay when scheduled to berth. Therefore, each unit of formation is considered as single vessel during cargo handling process. When the cargo operations are completed, vessels are ready to leave the berth and the port. Convoy is ready to leave the port when the last vessel to be coupled finishes handling operations. Departure times both for vessels and convoys are marked with d.

In the following example the quay 450 m long consisting of 5 fixed berths for accepting various cargoes and vessel types is considered. These berths may be designed as single purpose berths, for one type of cargo, or multipurpose berths for different types of cargo. However, a multipurpose berth, together with adjacent terminal area, may be designed as of primary or secondary purpose depending on terminal process design, warehouse facility allocation and technology applied.

Primary and secondary berths may be distinguished according to cargo handling performance for certain type of cargo, where standard production rate is applied as performance reference. Secondary berths have less performance than primary berths with the same resources level, as their efficiency η is lower. We presume that, in the particular case (Tab. 1), the production rate for loading operations may be reduced by 20 % (700 t/shift and 560 t/shift, respectively) for dry bulk cargo and up to 40 % for general cargo (300 t/shift and 180 t/shift, respectively) when secondary berths are used. The same applies for unloading operation where handling rates may be slightly different.

Therefore, default production rate and estimated handling time for secondary berths could be achieved against the cost of additional resources engaged (e.g. mobile cranes, man-power, loaders, forklifts, etc.), or in other words with higher intensity μ. Estimated handling time p for each vessel may be determined on the basis of the port production rate survey tables for certain types of cargo and operation mode (loading/unloading).

We consider berth optimization in relation with flexibility of multipurpose berths/terminals to fulfil default handling process in required timeframe. Utilization and intensity rate values for berth/terminal design are based on performance measurement data from the river port of Vukovar and shown in Tab. 1.

Table 1 Berths arrangement and performance design

Berth No.	Production rate efficiency η				Intensity required $\mu = 1/\eta$				Purpose ●primary ○ secondary			
	C	DB	G	H	C	DB	G	H	C	DB	G	H
1	1	0	0	0	1	-	-	-	●			
2	0,8	1	0,6	0	1,25	1	1,67	-	○	●	○	
3	0	1	1	0	-	1	1	-		●	●	
4	0	0,8	1	0	-	1,25	1	-		○	●	
5	0	0	0,7	1	-	-	1,43	1			○	●

Note: C – cereals terminal, DB – dry bulk terminal, G – general cargo terminal, H – heavy goods terminal

The problem of optimizing berths' allocation at the port is discussed in many papers that are mainly related to the container terminals. Lim, A. [2] considers berths as a continuous space instead of fixed length moorings in order to reduce unused space alongside quay. The optimal arrangement of vessels alongside quay is made with respect to a predetermined and unchanging time of vessels' arrivals by the method of graphs. Nishimura, E., Imai, and A. Papadimitriou, S. [3] take into account the dynamic changes in the arrival times of vessels, positions of berths are fixed. Optimization of the berths allocation with respect to the common spatial-time component is studied in the paper of Kim, H. and Moon, K. [4]. The problem is formulated as a "mixed-integer linear-programming" model, noting that in the case of multiple units in a system, the solution search requires solving of complex mathematical calculations.

Guan, Y. and Cheung, K. [5] study the dynamic berth allocation problem. The authors grouped vessels into a common group with respect to the estimated time of arrival in order to simplify the problem. There are two mathematical models recommended whose parts are partially used in this study. Following the idea by Imai et al. [6] they apply a weight coefficient to each vessel. They develop a tree procedure and a heuristic that combines the tree procedure with the heuristic in Guan et al. [7]. Unlike Lim [2], Imai et al. [6], Brown et al. [8] and Lai and Shi [9], Park and Kim [10] consider the continuous BAP (*berth allocation problem*) with the objective of estimating the berthing time and location by minimizing the total waiting and service time and the deviation from the preferred berthing location. Park and Kim [10] extend their previous work to combine the BAP with consideration of quay crane capacities. Their study determines the optimal start times of vessel services and associated mooring locations while at the same time determines the optimal assignment of quay cranes to vessels. The handling time was considered independent from the berthing location of the vessel. Lee et al. [11], following the work of Park and Kim [10] presented a method for scheduling berth and quay cranes, which are critical resources in container ports.

All the mentioned papers refer to examples of major container ports (hub ports) where the proposed mathematical models are solved by simplified heuristic and simulation methods.

Radmilović Z. [12] explores the problem of allocation of berths for vessels in inland waterways. The proposed model requires an optimal scheduling plan for vessel moorings on the basis of technical characteristics and types of vessels being moored. The goal is to make such an arrangement by which the processing time of vessels at the port is kept to minimum. The method is not suitable for operational problem solving because the time and the dynamics of arrivals of vessels in port are not used as criteria.

Ports in inland navigation cannot be compared with the large container sea ports in respect to physical characteristics or the vessels' traffic or cargo volume handled, but when it comes to optimization of berths allocation, similarities can be drawn with seaports.

3 Optimization model for finding the minimum of vessels port service time

It is assumed that the BAP can be solved by linear programming methods, using the task to-resources assignment method. The objective is to find the best berthing scenario for a specific planning horizon.

Table 1 Model notations

Input parameters	
l_i	length of the vessel expressed in the number of fixed berth segments required
s	berth segments alongside the quay
a_i, a_f	vessel /convoy arrival time
c_i	type of cargo class of the vessel i
p_i	estimate handling operations duration of the vessel i
μ_{sc}	intensity of resource required at berth s for cargo type c
$\mu_{\max}$	maximum level of intensity potential
Q_{ic}	binary parameter if cargo class c is loaded at vessel i
M	large integer constant
C_1, C_2, C_3	cost coefficients set up relation between cost of resources, waiting costs and in-time convoy departure costs/savings
Output variables	
X_{ist}	binary decision variable indicates that vessel i is assigned to berth s at time window t
Y_{ijk}	binary variable indicates that headmost space j and time k segments are associated with vessel i
d_i, d_f	vessel /convoy departure time
w_i	berthing waiting time for vessel i

Assignment problem is a special case of linear programming where the resources are allocated to specific tasks. Resources can be workers, machinery, vehicles, units of time, and so on. Mathematical model of the assignment problem has the following form [13]:

$$\min Z = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} x_{ij}, \tag{1}$$

with constraints:

$$\sum_{j=1}^{n} x_{ij} = 1, \quad i = 1,...,n$$

(each resource can be allocated to only 1 task)

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 1,...,n$$

(each task can be executed by only 1 resource) and condition:

$$x_{ij} \geq 0, \forall i, j.$$

From the above constraints and condition, it follows that the variable x_{ij} is of a binary form that can be represented as follows:

$$x_{ij} = \begin{cases} 1, & \text{if the resource } i \text{ is assigned to task } j \\ 0, & \text{otherwise} \end{cases}$$

In this paper, berths are defined as resources and vessels are defined as tasks. If the length of the vessel is greater than the length of the berth, such vessel shall occupy two adjacent berths. It is not allowed that two vessels reside on a single berth at the same time (vessel to vessel mooring alongside a quay), since such possibility is prohibited by Croatian legislation [1].

Each vessel is assigned an index $i(1, 2,\ldots, N)$ where N is the total number of vessels in the system. MCPV+PL vessels' formation (*Motor Cargo Pushing Vessel* in formation with *Pushed Lighter* - barge) can be viewed as a single vessel moored alongside without decoupling the formation while PMV+PL (*Pushing Motor Vessel* in formation with *Pushed Lighters*– barges) can be viewed as formation of vessels $f(1, 2,\ldots, F)$ or a convoy. The set containing vessel-to-convoy assignment $G(i,f)$ is defined according to vessels' arrival data.

The quay is divided into 5 berths. Each berth is a segment of the quay 90 m long labelled with index $s(1, 2,\ldots, S)$. The selected length is sufficient to accommodate the majority of vessels that appear in the port of Vukovar. The length of the berth includes a safety distance between the vessels which is due to the technical characteristics of vessels and the port being significantly lower compared to the seaports. The length of the vessel l is expressed by the number of berths that are occupied by the vessel, in most cases that is 1. If the vessel is longer than the anticipated length of the berth, she occupies two sections that are marked with the index j.

The dynamic environment of the process requires a solution that takes into account the different times of arrival a_i, a_f and departure d_i, d_f of single vessels and convoys. Time axis is divided into discrete time windows that can attain values $t(1, 2,\ldots, T)$ where T is the total number of time windows for an arbitrary period. Time window for a specific vessel i is marked by the index $k(1, 2,\ldots, T)$ and depends on the anticipated stay of vessel at berth.

Application of assignment method requires definition of a three-dimensional binary variables X and Y that determine the relationship between vessel, vessel's position and time segment in which the berth is occupied by the vessel:

X_{ist} – binary variable which indicates that the vessel i is moored alongside the berth s, at time window t and can attain values:

$$X_{ist}=\begin{cases}1, & \text{if the vessel } i \text{ is berthed at berth } s \text{ in time } t\\ 0, & \text{otherwise}\end{cases}$$

Y_{ijk} – binary variable that indicates the headmost space and time segment of the vessel and can attain values:

$$Y_{ijk}=\begin{cases}1, & \text{if space and time segments } j,\, k \text{ are}\\ & \text{associated with the vessel } i\\ 0, & \text{otherwise}\end{cases}$$

Objective function minimizes vessels make span and trans-shipment workload at port and reads:

$$\min Z=C_1\sum_{i\in V}\sum_{s\in S}\sum_{t\in T}\sum_{c\in B}X_{ist}Q_{ic}\mu_{sc}l_i^{-1}+C_2\sum_{i\in V}d_i+C_3\sum_{f\in F}d_f\,, \quad (2)$$

where:
Q_{ic}– type of cargo on board, input binary parameter from data table
μ_{sc}– intensity of resources required depending on type of cargo and berth class, from data table
d_i – departure time of the vessel, decision variable
d_f – departure time of the convoy, decision variable
l_i – length of the vessel expressed in number of berths occupied by the vessel
C_1, C_2, C_3 – cost related coefficients.

4 Setting the limits of the objective function

The objective function (2) minimizes the vessel makespan - total time in port during the given time horizon, as well as port operator workload by optimizing the assignment of vessels to berths according to their cargo and berth/terminal preferences for certain type of cargo.

In order to find a practical solution, the following constraints should be added:

$$d_i=a_i+p_i+w_i\,,\quad \forall i\in\{1,\dots,N\} \quad (3)$$

$$d_i\le d_f\,,\quad \forall (i,f)\in G \quad (4)$$

$$\sum_{i=1}^{N}X_{ist}\le 1\,,\quad \forall s\in\{1,\dots,S\},\,\forall t\in\{1,\dots,T\} \quad (5)$$

$$\sum_{s=1}^{S}\sum_{t=1}^{T}X_{ist}-l_ip_i=0,\quad \forall i\in\{1,\dots,N\} \quad (6)$$

$$\sum_{i=1}^{N}\sum_{s=1}^{S}\sum_{c=1}^{B}X_{ist}Q_{ic}\mu_{sc}\le\mu_{\max}\,,\quad \forall t\in\{1,\dots,T\} \quad (7)$$

Constraint (3) establishes the relationship between time of arrival at the port and time of departure. Difference between these two depends on handling process time – p_i and waiting time for free berth – w_i. Convoy departure time is defined by the constraint (4) as ready time of last processed vessel in the formation. Constraint (5) prevents that the same berth and time segments are assigned to more than one vessel. The exact number of berths and time segments, which can be taken by a single vessel considering its length and handling time, is regulated by constraint (6). Since the resources are not unlimited we include constraint (7), which inhibits increase of intensity above maximum value allowed.

Furthermore it is also necessary to ensure that the time segments are assigned sequentially one after another to ensure the homogeneity of the vessel-berth assignment. The algorithm determines the initial space-time segments in which the vessel will be berthed, that is, variable Y assignment together with the constraints (8), (9) and (10), according to Guan, Y. and Cheung, K. [5]. Constraint (8) guarantees that there is only one initial space-time segment assigned to the vessel in the feasible space and time range according to vessel's length and estimated time of arrival. Constraint (9) is needed for consecutive assignment of space-time segments, one after another in order to assure a reliable solution. In case that, for a particular vessel, initial segment Y_{ijk} does not overlap with the assigned one X_{ist}, that is, when Y_{ijk}=0, constraint is released due to large integer constant M. Constraint (10) determines departure time for the vessel. The expression $\sum_{j=1}^{S-l_i+1}\sum_{k=a_i}^{T-p_i+1}kY_{ijk}$ defines berthing/handling start up time of the vessel where index k is time segment that corresponds to the berthing time. Terms of binary variables are set in (11):

$$\sum_{j=1}^{S-l_i+1}\sum_{k=a_i}^{T-p_i+1}Y_{ijk}=1\,,\quad \forall i\in\{1,\dots,N\} \quad (8)$$

$$\sum_{S=j}^{j+l_i-1}\sum_{t=k}^{k+p_i-1}X_{ist}\ge l_ip_i+M(Y_{ijk}-1),$$
$$\forall i\in\{1,\dots,N\},\,\forall j\in\{1,\dots,S\},\,\forall k\,|k\ge a_i \quad (9)$$

$$\sum_{j=1}^{S-l_i+1}\sum_{k=a_i}^{T-p_i+1}kY_{ijk}+p_i=d_i\,,\forall i\in\{1,\dots,N\} \quad (10)$$

$$X_{ist}\in\{0,1\}\ \ \forall i,s,t;\ \ Y_{ijk}\in\{0,1\}\ \ \forall i,j,k \quad (11)$$

5 Solution search and model testing

Testing of the model is made on the example of the real expected arrivals of vessels in the port of Vukovar. Four cargo groups and two different terminal design options are taken into consideration.

The first option is represented by the proposed optimization model focusing on primary and secondary purpose berths, while the second option assumes that the berths are strictly of specific purpose.

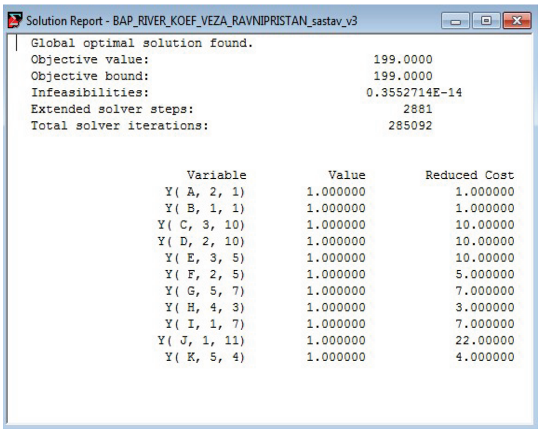
Input data for function optimization are based on the related terminal design and berth production efficiency (Tab. 1) and vessels' data from arrival schedule (Tab. 2). The mathematical model has been translated into program code and solved by LINGO, linear programming tool. The results obtained for the first option, multipurpose berths with preferred cargo class terminal design, are shown in Tab. 2 and in solution reports (Fig. 2 and Fig. 3).

Table 2 Vessels' input data and results

Vessel	Input data			Optimized output (design option 1) min $Z = 199$			Optimized output (design option 2) min $Z = 208$		
	c_i	a_i	p_i	w_i	d_i	d_f	w_i	d_i	d_f
A (single)	C	1	4	0	5	-	0	5	-
B (single)	C	1	4	0	5	-	4	9	-
C (single)	DB	5	5	5	15	-	5	15	-
D (single)	DB	5	5	5	15	-	5	15	-
E (formation 2)	DB	5	5	0	10	10	0	10	10
F (formation 2)	DB	5	5	0	10		0	10	
G (single)	G	4	7	3	14	-	6	17	-
H (single)	G	3	7	0	10	-	0	10	-
I (formation 1)	C	7	4	0	11	15	2	13	17
J (formation 1)	C	7	4	4	15		6	17	
K (single)	H	4	3	0	7	-	0	7	-

The results show that all vessels except A and G are docked at primary berths. Upon arrival, vessel A is bound to berth no. 2 rather than berth no. 1 which is occupied by the vessel B. Therefore, additional resource is needed for finishing cargo operations in requested time. Its value corresponds to reduced cost value (Fig. 3) which is 1,25, that means 25 % more power is required. In case of vessel G she has to wait 3 time units and use secondary berth for general cargo operations, thus needs 43 % more resources for handling operations.

Results presented in Fig. 2 show initial positions and berthing times of the vessels. Moreover, from the same report, according to the different reduced cost values, we can read impact of the particular vessel assignment to overall solution result. In this case the biggest impact has the vessel J (or I-J formation).


Solution Report - BAP_RIVER_KOEF_VEZA_RAVNIPRISTAN_sastav_v3

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Global optimal solution found.
Objective value:                 199.0000
Objective bound:                 199.0000
Infeasibilities:                 0.3552714E-14
Extended solver steps:           2881
Total solver iterations:         285092

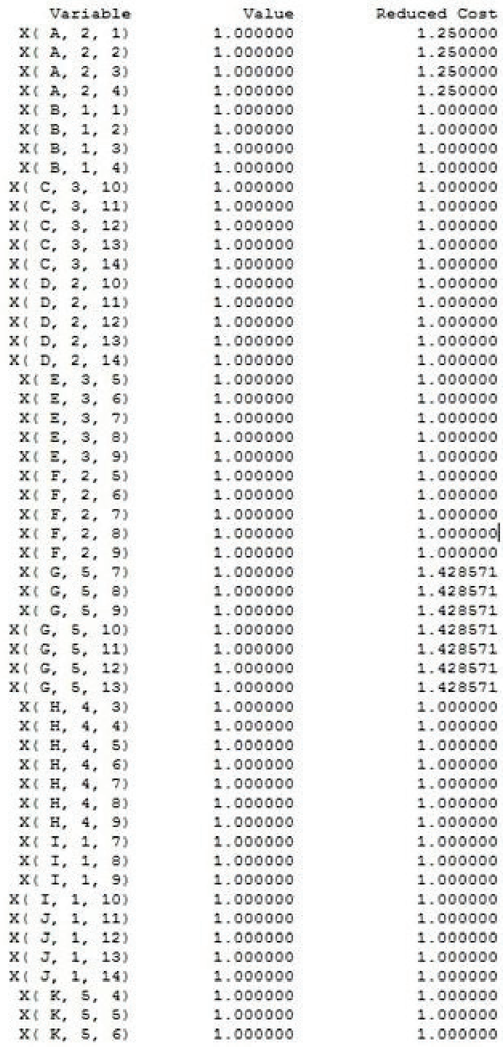
      Variable          Value        Reduced Cost
    Y( A, 2, 1)       1.000000          1.000000
    Y( B, 1, 1)       1.000000          1.000000
   Y( C, 3, 10)       1.000000          10.00000
   Y( D, 2, 10)       1.000000          10.00000
    Y( E, 3, 5)       1.000000          10.00000
    Y( F, 2, 5)       1.000000          5.000000
    Y( G, 5, 7)       1.000000          7.000000
    Y( H, 4, 3)       1.000000          3.000000
    Y( I, 1, 7)       1.000000          7.000000
   Y( J, 1, 11)       1.000000          22.00000
    Y( K, 5, 4)       1.000000          4.000000
```

Figure 2 Optimal solution found from the design option 1

As the vessel J is pushed lighter (PL) forming the formation with vessel I, her waiting time and finishing time influence the convoy departure time. So, although the vessel I has finished earlier she needs to wait until vessel J finishes handling operations to be coupled together and leave the port. Space-time arrangement of vessels is shown in Fig. 4.

The second option gives worse results, with more waiting times for vessels, because there is no option for alternative berthing available. Comparing waiting times there are 17 time units in option 1, contrary to 28 time units in option 2. However, there is no need for additional resources for cargo processing to be provided by the port operator.

From Fig. 2 the berthing position and time of berthing can be read according to value of variable Y, (Y_{ijk}=1). Reduced cost for the variable Y shows level of its influence on objective solution. The largest values of reduced cost have the vessels that need to wait for a free berth (C, D and J). Theoretically, if it would be possible to reduce time for waiting, the better optimal solution could be possible. Of course it is not possible because quay length limits the number of berths.



Variable	Value	Reduced Cost
X(A, 2, 1)	1.000000	1.250000
X(A, 2, 2)	1.000000	1.250000
X(A, 2, 3)	1.000000	1.250000
X(A, 2, 4)	1.000000	1.250000
X(B, 1, 1)	1.000000	1.000000
X(B, 1, 2)	1.000000	1.000000
X(B, 1, 3)	1.000000	1.000000
X(B, 1, 4)	1.000000	1.000000
X(C, 3, 10)	1.000000	1.000000
X(C, 3, 11)	1.000000	1.000000
X(C, 3, 12)	1.000000	1.000000
X(C, 3, 13)	1.000000	1.000000
X(C, 3, 14)	1.000000	1.000000
X(D, 2, 10)	1.000000	1.000000
X(D, 2, 11)	1.000000	1.000000
X(D, 2, 12)	1.000000	1.000000
X(D, 2, 13)	1.000000	1.000000
X(D, 2, 14)	1.000000	1.000000
X(E, 3, 5)	1.000000	1.000000
X(E, 3, 6)	1.000000	1.000000
X(E, 3, 7)	1.000000	1.000000
X(E, 3, 8)	1.000000	1.000000
X(E, 3, 9)	1.000000	1.000000
X(F, 2, 5)	1.000000	1.000000
X(F, 2, 6)	1.000000	1.000000
X(F, 2, 7)	1.000000	1.000000
X(F, 2, 8)	1.000000	1.000000
X(F, 2, 9)	1.000000	1.000000
X(G, 5, 7)	1.000000	1.428571
X(G, 5, 8)	1.000000	1.428571
X(G, 5, 9)	1.000000	1.428571
X(G, 5, 10)	1.000000	1.428571
X(G, 5, 11)	1.000000	1.428571
X(G, 5, 12)	1.000000	1.428571
X(G, 5, 13)	1.000000	1.428571
X(H, 4, 3)	1.000000	1.000000
X(H, 4, 4)	1.000000	1.000000
X(H, 4, 5)	1.000000	1.000000
X(H, 4, 6)	1.000000	1.000000
X(H, 4, 7)	1.000000	1.000000
X(H, 4, 8)	1.000000	1.000000
X(H, 4, 9)	1.000000	1.000000
X(I, 1, 7)	1.000000	1.000000
X(I, 1, 8)	1.000000	1.000000
X(I, 1, 9)	1.000000	1.000000
X(I, 1, 10)	1.000000	1.000000
X(J, 1, 11)	1.000000	1.000000
X(J, 1, 12)	1.000000	1.000000
X(J, 1, 13)	1.000000	1.000000
X(J, 1, 14)	1.000000	1.000000
X(K, 5, 4)	1.000000	1.000000
X(K, 5, 5)	1.000000	1.000000
X(K, 5, 6)	1.000000	1.000000

Figure 3 Optimal solution found from the model represents berth positions and time windows assigned to vessels (option 1)

On the other side, Fig. 3 shows the values for decision variable X, where the assignment (X_{ijk}=1) includes all time window intervals occupied by the vessel i as well as possible cases where more than 1 berth position is occupied by the vessel i. In this arrangement reduced cost for the variable X provides information on resource intensity needed or "pressure" on resources. Again, it is a case for those vessels that are docked at berths that are not primarily aimed for handling their type of cargo. If one decides that is not acceptable, those vessels will have to wait for the free space on the preferable berth position (where reduced cost equals 1). However, that is a question of efficiency and operational planning strategy, whether to dock a vessel upon arrival on less suitable place or whether to put her on anchorage and wait for the free berth.

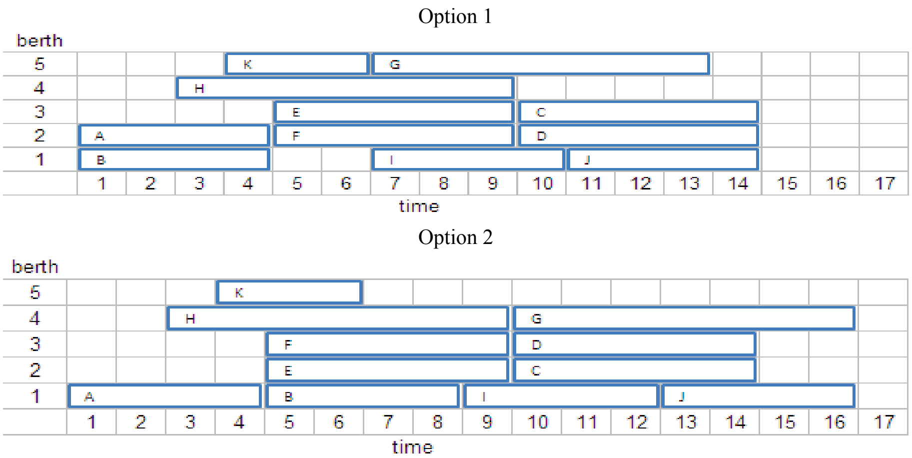


Figure 4 Representation of optimal solution found for different berth/terminal design

6 Conclusion

The distribution of vessels alongside quays is a daily operating procedure of port management. In this paper, based on the known dynamics of the arrivals of vessels in port for a certain period of time, the optimization model is set with the goal to minimize the total time of vessels' stay in port and transhipment operations workload.

The fundamental limitation of the proposed model or any other model is the "default" production rate effect where the time of handling operations is normalized and represents a functional requirement that the port must meet. The question is to what extent the individual berths can meet these requirements and what terminal design should best suit the user requirements.

Specific multipurpose approach, based on different terminal design with variable intensity of cargo processing and dual berth functionality, proposed in this paper, allows more flexibility in port operations planning.

Objective function that minimizes vessels makespan and transhipment workload, gives appropriate results regardless of the transport technology and type of vessels expected in the port. Therefore, it can be successfully implemented both to single vessels and vessel formations, frequently used transport technology in inland navigation.

The results obtained by the linear programming method with adapted assignment problem satisfy the requirements of optimization in inland navigation ports, for the related problem scale, and justify specific multipurpose approach in berth/terminal design.

Limitation of the model grows for large scales of units but that is out of scope of river ports concern. However, the linear model assumes discrete time-window interval. Certain limitation and inaccuracy may apply if this interval is too long. Reliability and applicability of the model strongly depends on fixed processing time beforehand calculation. Therefore, further research could aim to incorporate variable processing time and handling rates in the model to validate across different terminal designs.

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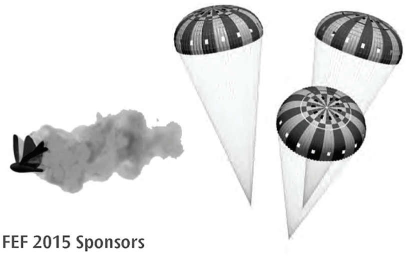

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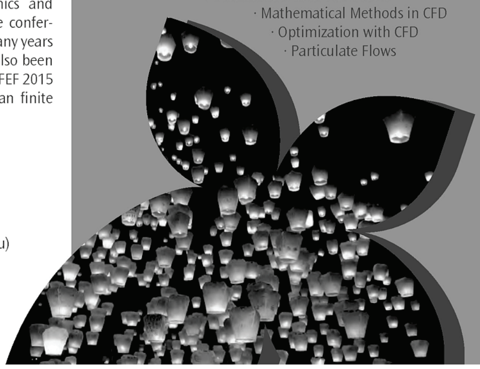

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