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STUDY OF THE IMPACT OF QUAY CRANE PRODUCTIVITY RATE ON BERTH AND QUAY CRANE ASSIGNMENT AND SCHEDULING

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ABSTRACT: *The integrated berth allocation and quay crane assignment and allocation is among the most addressed problems in the maritime related literature. The accuracy of this problem solutions depends on the precision of the resource's capacity estimation. Accordingly, in this paper, we investigate how the estimation error impacts the problem solutions. We focus on the quay cranes as being the main resources involved in serving the port customers vessels. We modelled the problem and tested different estimation errors scenarios for a dataset of instances. Computational results illustrated clearly the variation pattern of the problem solutions error over the capacity estimation error.*

KEYWORDS: *Berth allocation, quay crane assignment, quay crane scheduling, quay crane capacity.*

1 INTRODUCTION

Maritime logistics topic is set to become a widely investigated area in the literature due its very noticeable impact on the international trade (UNCTAD, 2018). Improving the port performance brings about various problems to be investigated especially the berth allocation, quay crane assignment and scheduling problems. The quality of this problem solutions depends mainly on how accurate the estimated resources capacities are. In this paper, we focus on the quay crane resources and we propose a model for this integrated problem inspired from a similar one in the literature. Then,

we investigate how the quay cranes capacity estimation error influences the quality of the problem solutions. We conduct an experimental study to illustrate the impact of several estimation error values on the model objective value over a set of real based instances.

The remainder of this paper is as follows. Section 2 reports the most related past works regarding the topic addressed in this paper. A mathematical formulation of the studied problem is presented in Section 3. In Section 4, we report the results of the conducted experiments, then the paper ends with a conclusion and some potential lines for future work.

2 LITERATURE REVIEW

The berth allocation and quay crane assignment and scheduling problems were widely addressed in the literature and different formulation and algorithms were proposed to solve them (Bierwirth and Meisel, 2015; Li et al., 2015, Fu and Diabat, 2015; He et al., 2019). Recently, many contributions tended to integrate those problems in one single formulation due to the cost savings induced by that (Agra and Oliveira, 2018; Chen et al., 2013; Correcher and Alvarez-Valdes, 2017; Meisel and Bierwirth, 2012; Unsal and Oguz, 2013, Chargui et al., 2019). In most of past work, the performance rate of quay cranes was considered fix even though its estimation is subject to potential error. In fact, the capacity of a quay crane, which is expressed in terms of the number of containers moved per time period, is variant and dependent on many factors such as the characteristics of containers to be handled (Linn et al., 2013).

In the light of that, we investigate empirically the impact of the quay crane estimation error on the solution of the berth allocation and the quay crane assignment and scheduling integrated problem. For this, we modelled the problem based on the formulation proposed by Chargui et al. (2019) and conducted a set of experiments to highlight the variation.

3 MATHEMATICAL MODEL

3.1 Problem data

V	Number of vessels.
P	Number of bay sections across the quay.
T	Number of time periods in the planning horizon.
C	Number of quay cranes.
M	Sufficiently large positive number.
r	Processing rate of quay cranes.
D_{vp}	Number of containers to handle on the bay

p of vessel v .

J_v	Arrival time of vessel v .
E_v	Right berth position of vessel v .
F_v	Left berth position of vessel v .

3.2 Decision variables

Q_{vt}^{pc}	1: if crane c is handling the bay p of vessel v at time period t . 0: otherwise.
y_v	Service starting time of vessel v .
m_{tp}	Performance rate of the quay crane on bay p at time period t .
H_{vtp}	Number of containers remained to handle from bay p of vessel v at the beginning of time period t .
Z_{vtp}	Number of containers remained on vessel v at bay p from time period $t-1$.
X_{vtp}	Number of containers handled on vessel v at bay p at time period $t-1$.
s_{vt}	1: if vessel v is being served at time period t . 0: otherwise
I_v	Total time needed to serve the vessel v .

3.3 Objective function

The objective of the model consists in minimizing the sum of vessels serving times. It's expressed as in equation (1).

$$\text{Minimize } \sum_{v=1}^V I_v \quad (1)$$

3.4 Constraints

$$\sum_{p=1}^P \sum_{v=1}^V Q_{vt}^{pc} \leq 1 \quad (\forall t = 1..T, c = 1..C) \quad (2)$$

Constraints (2) ensure that at each time period a quay crane is at most assigned to one bay and one vessel.

$$\sum_{c=1}^C \sum_{v=1}^V Q_{vt}^{pc} \leq 1 \quad (\forall t = 1..T, p = 1..P) \quad (3)$$

Constraints (3) guarantee that at each time period a bay is allocated at most one quay crane and one vessel.

$$m_{tp} \leq \sum_{c=1}^C \sum_{v=1}^V Q_{vt}^{pc} r \quad (\forall t = 1..T, p = 1..P) \quad (4)$$

Constraints (4) determine the performance rate of the quay crane assigned to each bay at every time period. It's null if no quay crane is assigned to that bay at that time period.

$$\sum_{c=1}^C Q_{vt}^{pc} \leq H_{vtp} M \quad (\forall t = 1..T, p = 1..P, v = 1..V) \quad (5)$$

Constraints (5) ensure that, at each time period, if the remaining workload on each bay and every vessel is null, no quay crane will be assigned that bay.

$$H_{vtp} = 0 \quad (\forall t = 1..T: t \leq J_v, p = 1..P, v = 1..V) \quad (6)$$

Constraints (6) ensure that the remaining workload at every bay of a vessel is null before the arrival of that vessel.

$$H_{vtp} \leq D_{vp}(t = y_v) + Z_{vtp} - X_{vtp} \quad (\forall t = 1..T: t \leq J_v, p = 1..P, v = 1..V) \quad (7)$$

Constraints (7) is used the calculate the handled amount at each time period.

$$\sum_{t=1}^T X_{vtp} \geq D_{vp} \quad (\forall p = 1..P, v = 1..V) \quad (8)$$

Constraints (8) ensure that the workload on each bay of a given vessel must be handled during the planning horizon.

$$X_{vtp} \leq M \quad (\forall t = 1..T: t \leq J_v, p = 1..P, v = 1..V) \quad (9)$$

Constraints (9) guarantee that the number of containers handled on bay of a vessel at a given time period is null in case no crane was assigned that bay before.

$$X_{vtp} \leq m_{t-1,p} \quad (\forall t = 2..T: t \geq J_v, p = 1..P, v = 1..V) \quad (10)$$

$$X_{vtp} \geq m_{t-1,p} - M \quad (\forall t = 1..T: t \leq J_v, p = 1..P, v = 1..V) \quad (11)$$

Constraints (10) and (11) are used to calculate the number of containers handled during a time period that must be after the starting time to serve the vessel.

$$Z_{vtp} \leq M(t \geq y_v + 1) \quad (\forall t = 2..T: t \geq J_v, p = 1..P, v = 1..V) \quad (12)$$

$$Z_{vtp} \leq H_{v,t-1,p} \quad (\forall t = 2..T: t \geq J_v, p = 1..P, v = 1..V) \quad (13)$$

$$Z_{vtp} \leq H_{v,t-1,p} - M(1 - (t \geq y_v + 1)) \quad (\forall t = 2..T: t \geq J_v, p = 1..P, v = 1..V) \quad (14)$$

Constraints (12), (13) and (14) are used to calculate the remaining workload from each time period.

$$\sum_{c1=1, c1 < c}^C \sum_{p1=1, p1 > p}^P Q_{vt}^{p1c1} r \leq M(1 - Q_{vt}^{pc} r) \quad (\forall t = 1..T, p = 1..P, v = 1..V, c = 1..C) \quad (15)$$

Constraints (15) are added to avoid the interference between quay cranes.

$$I_v \geq \max_{t=1}^T (t(s_{vt} = 1)) - J_v + 1 \quad (\forall v = 1..V) \quad (16)$$

Constraints (16) define the port stay of a vessel as the time interval between its arrival time and the last time period it was being served.

$$\sum_{p=1}^P H_{vtp} \leq s_{vt} M \quad (\forall t = 1..T, v = 1..V) \quad (17)$$

$$s_{vt} \leq \sum_{p=1}^P H_{vtp} \quad (\forall t = 1..T, v = 1..V) \quad (18)$$

Constraints (17) and (18) ensure that the remaining workload of a vessel bay is null if it hasn't started being served yet.

$$s_{v1t} \leq M \quad (\forall v1 = 1..V, v2 = 1..V: v1 \neq v2, t = 1..T: t \geq J_v) \quad (19)$$

Constraints (18) are added to prevent physical contact of vessels.

$$Z_{v1p} = 0 \quad (\forall p = 1..P, v = 1..V) \quad (20)$$

5 CONCLUSION

As the accuracy of the integrated berth allocation and quay crane assignment and scheduling problem solutions depends on the capacity estimation quality, we modeled the problem and conducted an experimental study to highlight the influence of the estimation error on the objective function values obtained using different scenarios of errors. The results showed that there is a significant impact of the error value on the optimal solution found for every instance. This work could be extended by proposing some methods to control the estimation error in order to reduce its impact on the planning solutions.

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