International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 4 No. 3 Nov. 2013, pp. 547-551

http://www.issr-journals.org/ijias/

Mathematical model for Quay Crane Scheduling Problem with spatial constraints

Azza Lajjam, Mohamed El Merouani, Abdellatif Medouri, and Yassine Tabaa

SIT Laboratory, Faculty of Sciences, Abelmalek Essaadi University,
Tetouan, Morocco

ABSTRACT: In the last decades, competition between port container terminals, especially between geographically close one, is rapidly increasing. To improve this competitiveness, terminal managers try to achieve rapid container vessel loading and unloading, that corresponds to a reduction of the time in port for vessels. In this paper, we focus our attention on the operational decision problem related to the seaside area of maritime container terminals. In particular, we study The Quay Crane Scheduling Problem (QCSP) which is considered as a core task of managing maritime container terminals and the optimization of these operations affects significantly the time spent by vessels at berth. The main goal behind this planning problem is to find the optimized sequence of loading and unloading tasks on a set of deployed quay cranes in order to exploit the full performances of port's resources while reducing the berth's total time occupation by vessels. In this paper, we provide a rich model for quay crane scheduling problem that covers important parameters such as ready time and due dates of Quay cranes (QCs), safety margin in order to avoid congestion between QCs and precedence relations among tasks. The proposed model seeks for a more compact mathematical formulation that can be easily solved by a standard optimization solver. Thus, we formulated the Quay Crane Scheduling Problem as a mixed-integer linear model that minimizes the sum of the QCs holding cost and tardiness penalty cost.

KEYWORDS: Transportation, Quay crane, Scheduling, Container terminal, Mixed-integer programming.

1 INTRODUCTION

Container terminals are strongly complex logistics systems because they allow transshipment between various modes of transport. They play an important role in the international logistics. As a consequence, the success of the supply chain depends on how efficient are terminal operations. The productivity of container terminals can be measured in terms of vessel turn time which represent the time spent by a vessel at berth. Many studies have investigated on improving the vessel turn time dealing with berth scheduling, quay crane scheduling, stowage planning and sequencing.

We focus our study on Quay Crane Scheduling Problem (QCSP) which is one of several operational planning problems found at container terminals. We organize the paper as follow. In Section 2, we describe in detail the QCSP. Section 3 presents a survey of previous work on QCSP. In section 4, we formulate the problem as a linear mathematical problem. Finally; we give some conclusions and perspectives in Section 5.

2 PROBLEM DESCRIPTION

As shown in Fig. 1, the container terminal operations can be divided into three main categories, cf. [1]:

- The first includes operations related to loading and unloading of ships and barges that are made in the seaside area.
- The second contains the storage operations and container handling. These operations are performed in the storage area (yard) of the terminal.
- The last category concerns the transfer of containers to ground transportation. These operations take place in the landside area.

In the seaside area, we find three different decisions problems that affect on each other. When a vessel arrives at the port, we have to find a quay space to this vessel. So the first issue treated in the terminal container is berth allocation problem (BAP).It consists of the assignment of incoming vessels to berth positions. Next the containers are transferred from vessel to the quay by using QCs. Hence, the second problem which appears is quay crane assignment problem (QCAP) .It defines how many Quay Cranes (QCs) should be assigned to each berthing ship. Finally, we find the problem that interests our study. It concerns quay crane scheduling problem (QCSP).

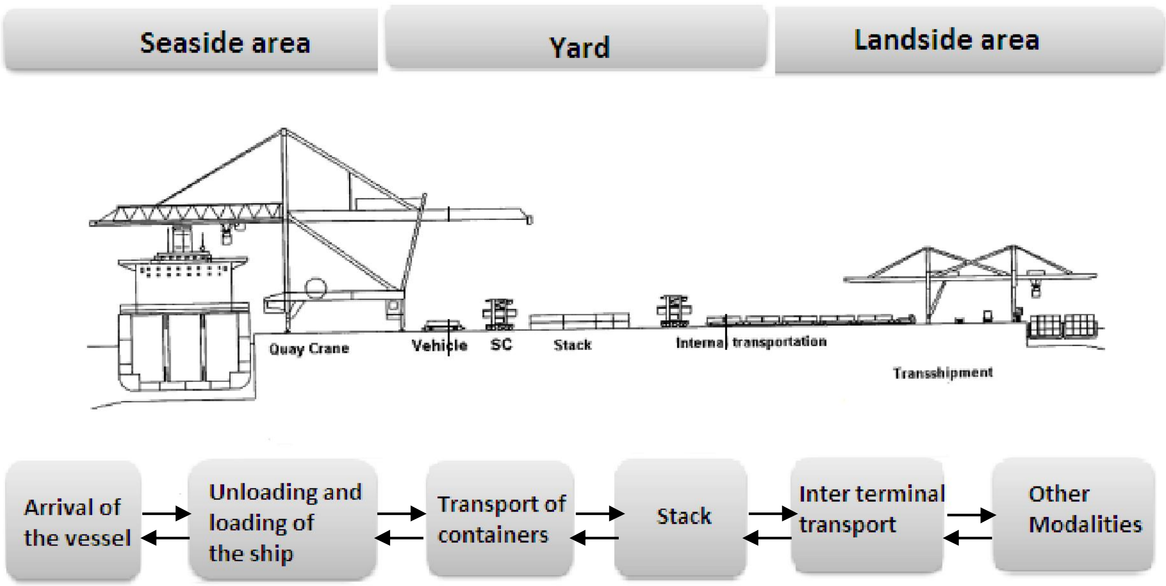

Fig. 1. Processes at a container terminal

This paper discusses the problem of scheduling quay cranes (QCs) which are considered as the most important equipment in port terminals. QCs are used at the seaside of a terminal for loading and unloading containers into and from vessels. They have direct impact on the throughput of container terminal. As a result, the efficient use of these equipments lead to short vessel turn time. Therefore, the scheduling of QCs is one of the most significant issues treated in container terminal. It consists of finding the sequence of charging and discharging containers such that the overall handling time is minimized.

According to Meisel and Bierwirth [2], there are five different classes of QCSP problem. QCSP of bay areas, QCSP of complete bays, QCSP of stack, QCSP of container groups and QCSP of container. The first category, QCSP of bay areas, consider a task as the workload of different bays. Whereas, in the QCSP of complete bays, tasks refer to the loading and unloading operations in a single bay. It means that every bay is served exclusively by one QC. The third category concern the QCSP of stack .It means that the tasks refer to the transshipment of all containers in a stack .The fourth category, QCSP of container groups, defines tasks as loading and unloading operations for a group of container that are stored in adjacent slots of a bay. Finally, in the QCSP of container, tasks refer to the handling of one container.

In practice, the scheduling target is often to complete all the jobs with respect to certain criteria. In our problem, these criteria can be measured according to the completion time of tasks, the makespan of a schedule which corresponds to the maximum completion time among all tasks and the throughput of cranes. Like any scheduling problem, QCSP must satisfy some constraints. The first one concerns interference constraints which mean that the QC scheduling models respect that the cranes cannot cross each other. Because they are mounted on a single rail track alongside the quay. Thus, to ensure the non-crossing constraint, we have to take into consideration a safety margin which has to be kept between adjacent cranes at all time. The second constraint deals with precedence relations among tasks. It allows ensuring that unloading precedes loading for the tasks in the same ship bay and to represent stacking of containers as defined by stowage plan. When unloading operations are performed in a ship bay, tasks on a deck must be performed before tasks in the hold.Conversely, for the loading operation, tasks in the hold must be fulfilled before tasks on the deck.

3 SURVEY OF QCSP

The quay crane scheduling problem for container terminals was first highlighted by Daganzo [3]. He studied the static quay crane scheduling problem with the objective of minimizing the aggregate cost of ship delay with berth length limitations. Furthermore, Peterkofsky and Daganzo [4] developed a branch and bound solution method for the static quay crane scheduling problem. Nevertheless, both of them did not consider non-crossing constraints, which did not reflect the practical cases. Kim and Park [5] defined a QCSP with container groups. They considered a non-crossing and precedence constraints and formulated the problem as MIP model. Additionally, they provided a branch and bound method to resolve the problem.Bierwirth and Meisel [2] gave a classification scheme for QCSP, and outlined a comprehensive review of this problem.

In term of interference constraints, they are taken into consideration in many studies. Thus, Lee et al [6] studied QCSP with interference constraints and proposed a genetic algorithm. Evenly, Choo et al [7] investigated the QCSP with specific constraints to prevent congestion in the yard. They proposed MIP as a model to the problem and resolve it with heuristic algorithm based on lagrangian relaxation.Lim et al [8] further considered the non-crossing spatial constraint for QC.

Regarding criteria, Lim et al [8] considered the latest completion time for all jobs, which is widely used in practice. Also Kim et park [5] had as a goal the minimization of the weighted sum of the makespan of the container vessel and the total completion time of all quay cranes. Recently, Kaveshgar et al [9] has studied the quay crane scheduling problem based on the model of Kim and Park [5] and they proposed the use of GA to solve the proposed problem.

4 MATHEMATICAL FORMULATION

This section proposes a mathematical formulation for the QC scheduling problem. This model must satisfy the constraints below:

- A task is defined as the handling operations of one bay.
- Only one quay crane can work on a ship bay at a time until it completes the ship bay.
- Each QC can operate after its earliest available time.

We use the following notations for the mathematical formulation.

4.1 INDICES

i,j Tasks indices which are ordered in an increasing order according to their locations on the ship-bay.

k QCs where k=1,…,K. QCs are also ordered in an increasing order of their relative locations in the direction of increasing ship-bay numbers.

4.2 PROBLEM DATA

P_i^k Processing time of task i on QC k.

β_k Fixed cost of using QC k.

α_k Variable cost of using QC k.

w_j Tardiness cost of task j.

d_j Due date of task j.

r_k Release time of QC k.

l_i Bay position of task i.

t_{ij} The travel time of a QC from bay position l_i of task i to bay position l_j of task j.

M A sufficiently large constant.

4.3 SETS OF INDICES

Ω The set of all tasks.

ψ The set of pairs of tasks that cannot be performed simultaneously. When tasks i and j cannot be performs simultaneously, $(i,j) \in \psi$.

ϕ The set of ordered pairs of tasks between which there is a precedence relationship. When task i must precede task j , $(i,j) \in \phi$.

4.4 DECISIONS VARIABLES

X_{ij}^{k} 1, if task j immediately follows task i on QC k; 0, otherwise. Tasks 0 and T will be considered to be the initial and final states of each QC, respectively.Thus when task j is the first task of QC k, $X_{0j}^{k} = 1$. Also, when task j is the last of QC k , $X_{jT}^{k} = 1$.

Y_{ij} 1, if task j start later than the completion time of task i; 0, otherwise.

Z_k 1, if QC k is selected; 0, otherwise.

Q_k Completion time of QC k.

C_i Completion time of task i.

$C_{\max}$ Makespan.

The QC scheduling problem can be formulated as follows:

Minimize $$\sum_{k=1}^{K}\left(\alpha_k Q_k + \beta_k Z_k\right) + \sum_{i=1}^{N} w_i \max\left\{0, C_i - d_i\right\} \qquad (1)$$

Subject to

$$C_k \le C_{\max} \qquad \forall k = 1,\ldots,\mathrm{K} \qquad (2)$$

$$\sum_{j\in\Omega} X_{0j}^{k} = 1 \qquad \forall k = 1,\ldots,\mathrm{K} \qquad (3)$$

$$\sum_{i\in\Omega} X_{iT}^{k} = 1 \qquad \forall k = 1,\ldots,\mathrm{K} \qquad (4)$$

$$\sum_{k}\sum_{i\in\Omega} X_{ij}^{k} = 1 \qquad \forall j \in \Omega \qquad (5)$$

$$C_i + t_{ij} + p_j - C_j \le M(1 - X_{ij}^{k}) \qquad \forall i,j \in \Omega,\ \forall k = 1,\ldots,\mathrm{K} \qquad (6)$$

$$C_i + P_j \le C_j \qquad \forall (i,j) \in \phi \qquad (7)$$

$$C_j + t_{jT}^{k} - Q_k \le M(1 - X_{jT}^{k}) \qquad \forall i \in \Omega,\ \forall k = 1,\ldots,\mathrm{K} \qquad (8)$$

$$r_k - C_j + t_{0j}^{k} + p_j \le M(1 - X_{0j}^{k}) \qquad \forall i \in \Omega,\ \forall k = 1,\ldots,\mathrm{K} \qquad (9)$$

$$X_{ij}^{k} = 0 \ or \ 1 \qquad \forall i,j \in \Omega,\ \forall k = 1,\ldots,\mathrm{K} \qquad (10)$$

$$Q_k, C_i \ge 0 \qquad \forall i \in \Omega,\ \forall k = 1,\ldots,\mathrm{K} \qquad (11)$$

In this model, the objective function is composed of two terms. The first term is the QC holding cost and the second term is the total cost of tardiness penalties. This objective function reflects the balance between the system cost and the cost related to the job tardiness penalties. Constraint (2) determines the makespan which corresponds to the completion time of all tasks. Constraints (3) and (4) define the first and the last tasks for each QC, respectively. Constraint (5) ensures that every task must be completed by exactly one crane. Constraint (6) determines the completion time for each task. Constraint (12) defines the completion time of each QC. Constraint (13) ensures that the first task of a crane is not started before the crane is ready. Finally, (14) and (15) define the domains of the decision variables.

5 CONCLUSION

Our study has been focused on the QCs scheduling problem, which is an important problem in the operation of port container terminal. Thus, we proposed a mixed-integer programming model that minimize the cost of tardiness penalties and the cost of using QCs as criterion and take into account constraints of precedence between tasks and non-crossing constraint. As perspective, we are looking forward to resolve this problem with the Genetic Algorithm method. And compare between the optimal solutions found by the LINGO and the proposed algorithm based on Genetic Algorithm in term of the objective function value.

REFERENCES

[1] R. Steenken, S. Voß and R. Stahlbock , "Container terminal operation and operations research - a classification and literature review," *OR Spectrum*, vol. 26 , no. 1, pp. 3-49, 2004.

[2] C. Bierwirth and F. Meisel , "A survey of berth allocation and quay crane scheduling problems in container terminals," *European Journal of Operational Researc*h, vol. 202, no. 3, pp. 615-627, 2009.

[3] C. F. Daganzo, "The crane scheduling problem," *Transportation Research -Part B,* vol. 23, no. 3, pp. 159-175, 1989.

[4] R. I. Peterkofsky and C.F Daganzo, "A branch and bound solution method for the crane scheduling problem," *Transportation Research - Part B*, vol. 24 , no. 3, pp. 159-172, 1990.

[5] K. H. Kim and Y. M. Park, "A crane scheduling method for port container terminals," *European Journal of Operational Research*, vol. 156, no. 3, pp. 752-768, 2004.

[6] D. H. Lee, H. Q. Wang and L. Miao, "Quay crane scheduling with non-interference constraints in port container terminals," *Transportation Research Part E*, vol. 44, no. 1, pp. 124-135, 2008.

[7] S. Choo, D. Klabjan and D. Simchi-Levi, "Multiship crane sequencing with yard congestion constraints," *Transportation Science*, vol. 44, no. 1, pp. 98-115, 2010.

[8] A. Lim, B. Rodriguez and F. Xiao, Y. Zhu, "Crane scheduling with spatial constraints," *Naval Research Logistics*, vol. 51, no. 3, pp. 386-406, 2004.

[9] N. Kaveshgar, N. Huynh and S. K. Rahimian, "An efficient genetic algorithm for solving the quay crane scheduling problem," *Expert Systems with Applications*, vol. 39, no. 18, pp. 108-117, 2012.