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Investigating transportation system in container terminals and developing a yard crane scheduling model

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A B S T R A C T

The world trade has tremendous growth in marine transportation. This paper studies yard crane scheduling problem between different blocks in container terminal. Its purpose is to minimize total travel time of cranes between blocks and total delayed workload in blocks at different periods. In this way the problem is formulated as a mixed integer programming (MIP) model. The block pairs between which yard cranes will be transferred, during the various periods, is determined by this model. Afterwards the model is coded in LINGO software, which benefits from branch and bound algorithm to solve. Computational results determine the yard cranes movement sequence among blocks to achieve minimum total travel time for cranes and minimum total delayed workload in blocks at different planning periods. Also the results show capability and adequacy of the developed model.

1. Introduction

According to information provided by United Nation Conference on Trade and Development, containerized trade is predicted to grow by an average annual rate of 5.32 percent between 2003 and 2025 (Legato et al., 2009). Today the majority of international cargoes are containerized through major seaports. Recently, growing competition among container terminals, especially those in Asia and Europe, has put pressure on the seaports to make facilities more efficient to deal with this dynamic challenge and consider service quality improvement, service cost reduction and throughput increase. The container transportation system is capital intensive and so controlling the turn-around time of vessels at container terminals to decrease total cost is important for marine companies. The issue that has important role in turn-around time is loading and unloading time of vessels (Huang et al., 2009; Lee & Lee., 2010). Some cranes along the quay perform vessels loading and unloading operations. Every vessel is served by several quay cranes that many yard cranes support them (Javanshir, SeyedAlizadeh Ganji, 2010). Fig.1 depicts typical flow of containers in a container terminal. When a vessel arrives at the terminal, quay crane discharges containers from the vessel and

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then yard cranes unload containers and locate them at various locations in the yard for storage. In the loading operation, export containers are loaded onto trucks by yard cranes and then containers are off-loaded at the yard and finally quay cranes load them to vessels (Ng, Mak, 2005).

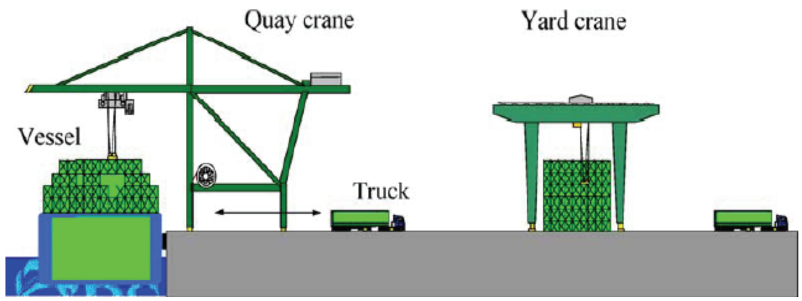


Fig.1. Typical flow of containers in a container terminal

Usually rail mounted gantry crane, rubber tyred gantry crane, straddle carrier and forklift are used for moving containers in yard blocks at container terminals. Therefore there are two types of yard cranes as follows: rail mounted gantry crane and rubber tyred gantry crane. A rail mounted gantry crane moves along a rail in a block whereas rubber tyred gantry crane moves on rubber wheel and this kind of yard crane can move among blocks. As shown in Fig. 2, a block has 6 lanes or rows that one of them is for trucks and the rests are for storing containers. Usually each lane has five containers in height called tiers. In addition, there are 20 or more containers in length in every lane. A vertical section of a block (for example, 5 tiers×6 lanes) is usually indicated as a bay (Legato et al., 2009).

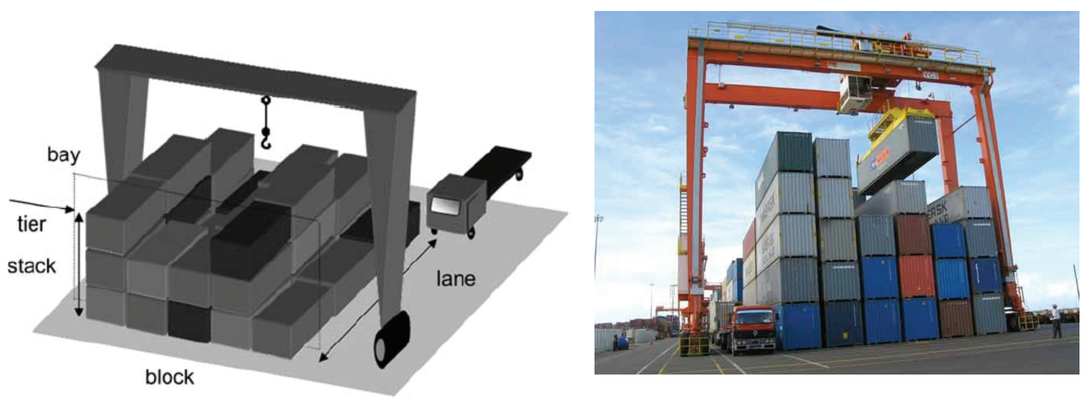


Fig.2. Real and schematic illustration of a block and yard crane in a container terminal

In details, the diverse operational services of yard cranes are presented as follows (He et al., 2010):

1. Lifting inbound containers from the internal trucks and storing them at storage blocks;
2. Lifting outbound containers from the external trucks and storing them at storage blocks;
3. Retrieving inbound containers from yard and putting them to external trucks for customers;
4. Retrieving outbound containers from yard and putting them to internal trucks for exit;
5. Rearranging containers in yard.

Yard cranes are most desirable equipments for loading and unloading containers in container terminals. However, these equipments move slowly, which increase waiting time for trucks. As a result, quay cranes become idle and their efficiency are reduced by this sort of delay. Hence logical yard cranes scheduling plays important role in improving container terminals efficiency and decreasing operational cost (Seyedalizadeh Ganji, 2009, 2010).

Resource allocation and facilities scheduling are fundamental problems in both loading and unloading operations. When a handling job is started by quay cranes, subsequently, trucks and yard cranes are employed to finish this movement. In addition, yard cranes reshuffle and retrieve containers among the blocks (Amin & Golchubian, 2009).

Many researchers are interested in yard cranes scheduling. In this respect, Kim and Kim (1999) minimized the sum of the set up time and the travel time of cranes in a container storage block by modeling the process as a mixed integer program (MIP). In the same case, Kim and Kim (2003) also employed heuristic algorithms. Zhang et al. (2002) employed a mixed integer programming (MIP) model to find the times and routes of crane movements among blocks so that the total delayed workload in the yard is minimized. Then they solved the problem by Lagrangean relaxation. Linn et al. (2003) proposed a mixed integer programming (MIP) model to find the minimum total delay workload in blocks. Kim et al. (2003) suggested a dynamic programming model for determining the sequence of yard crane jobs. They suggested several heuristic rules to solve the model and finally a simulation study is performed to compare the performances of the suggested approaches.

Ng and Mak (2005) studied the yard crane scheduling problem with the aim of minimizing sum of jobs waiting times. They modeled the problem as an integer programming and proposed a branch and bound algorithm to solve the scheduling problem optimally. Ng (2005) investigated yard crane scheduling among adjacent blocks. He formulated the scheduling problem as an integer programming with the aim of minimizing the total completion time of jobs. Then the model was solved by a dynamic programming-based heuristic method. Jung and Kim (2006) proposed a model for loading operation scheduling that considered several yard cranes in a block.

Chen et al. (2007) investigated a problem with two yard cranes to minimize total loading time in stacks. Then they solved the problem by Tabu search method. Lee et al. (2007) discussed the scheduling problem of two-transtainer systems, which serve the loading operations of one quay crane at two different container blocks. The goal is to minimize the total loading time at stack area. A mathematical model was set to formulate the problem and a simulated annealing (SA) algorithm was developed to solve the proposed model.

Legato et al. (2009) suggested an integer programming to deal with yard crane scheduling problem between several blocks. Their purpose was to determine the block pairs between which yard cranes will be transferred during the periods in order to satisfy the crane capacity requirements and minimize the total cost for block matching and crane activation. In addition, Lee and Kim (2009) compared and evaluated various cycle-time models for yard cranes in container terminals. They calculated trucks waiting time under various sequence rules and they introduced calculation formula to determine yard cranes cycle time in every sequence rule. Huang et al. (2009) comprehensively studied various issues in the route planning for container loading and unloading in the automated container terminal. They used a multi objective mathematical model considering the factors including length, smooth degree and safety distance to determine the yard cranes optimum rout. To solve the model, an optimum route method was developed based on genetic algorithm.

He et al. proposed (2010) a dynamic yard cranes scheduling model using objective programming, which is based on rolling-horizon approach. The aim was to minimize the total delayed workload among all blocks and minimize the total times that yard cranes move from one to another block at each planning horizon. To solve the problem, they developed a hybrid algorithm, which employed heuristic rules and parallel genetic algorithm (PGA). Park et al. (2010) proposed heuristic-based and local-search-based real-time scheduling methods for twin rail-mounted gantry (RMG) cranes working in a block at an automated container terminal. The methods reschedule the cranes in real time for a given fixed-length look-ahead horizon whenever an RMG finishes a job. They claimed if two RMGCes cooperate in a block, the truck waiting times would be reduced, significantly.

In this paper yard cranes scheduling problem is formulated as a mixed integer programming based on Legato's model (2009). In the rest of the paper, a detailed problem description and mathematical model are given in Section 2. A numerical study is presented in Section 3. In this section, the proposed model is tested by Lingo software. Section 4 concludes the paper and recommends some suggestion for future studies.

2. Yard crane scheduling model

2.1. Problem description

A large-scale stacking yard may be divided in to a number of large parts called zones. Every zone includes several rectangular shapes named blocks. Containers are stored in these blocks temporarily side by side and one on top of the other until they are picked up by trucks or loaded onto vessels. In each zone, stacking and shuffling the containers are carried out by yard cranes. In the other words within a zone, a yard crane can move freely to carry out all movement operations generated by different vessels. The physical handling rate of a yard crane is usually about half of a quay crane. The container flow in a container terminal is bottlenecked because of the slow yard crane movement. Hence, a good yard crane scheduling can augment a terminal efficiency rate by increasing the container flow to and from vessels as a result of reducing the truck waiting time.

Decision making about how many yard cranes can work in a block and which of them is allocated to that block depends on the predicted daily workload and total required capacity. Our modeling efforts are referred to overcome the workload imbalance among the blocks while a yard crane needs to move from one to another block for the complete utilization. These movements can occur between both adjacent and non-adjacent blocks. In this case, allocation and movement of yard cranes between blocks are called yard crane scheduling. As shown in Fig. 3, if two blocks, e.g. blocks 11 and 22, are not adjacent, a yard crane needs to turn around for moving. Therefore, this sort of movement takes longer time than the straight movement that occurs among adjacent blocks, e.g. blocks 11 and 12.

Yard cranes occupy truly big road space during long operation time because of their slow movement and bulky body. In the other words, these characteristics generate some sort of obstruction among blocks and delay for other terminal operations. In addition, inefficient block-to-block movements will cause losses of crane productivity. Up to now, yard crane scheduling has been generally planned by port supervisors based on their experience. They send idle yard cranes to other blocks to release the workload when congestion occurs.

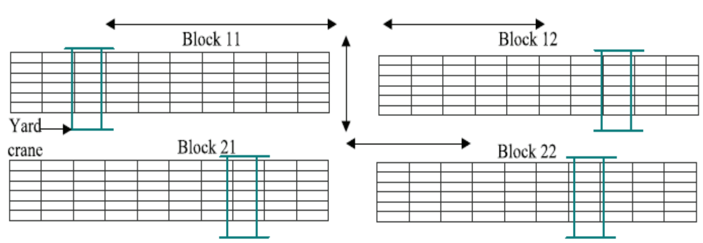


Fig.3. Illustration of yard crane scheduling

This paper studies yard crane scheduling problem among blocks and it is formulated as a mixed integer programming based on Legato's model (2009). Following issues are considered for the proposed model to be more practical:

1. The objective function is based on time. This is due to complication of cost estimation at cost based problems. Hence, the proposed model determines the sequence of yard cranes movement, considering the total required time for finishing left workload and total travel time of yard cranes among the blocks. In addition, the yard cranes movement time is the key parameter, which controls the transportation cost and also it significantly affects on the turnaround vessels time.

2. Minimizing the total delayed workload is concerned to raise the container handling efficiency.

3. Multiple planning periods are assumed in this paper so that the system is studied as dynamic. This matter is useful under some uncertain conditions, because of randomly occurring events and random duration of logistic activities in such a situation. In this way more detailed and more accurate yard crane scheduling can be implemented. Therefore, we settle on a planning horizon of 1 day, divid them into six 4-h periods as follows: 00:00–4:00, 4:00–8:00, 8:00–12:00, 12:00–16:00, 16:00–20:00, and 20:00–24:00. Every evening, the forecasted workloads in the block for the following day are assembled. Then operating plan of yard cranes is determined for each of the six planning periods.

2.2. Assumptions

We make the following assumptions to develop our yard crane scheduling model.

- The capacity of a yard crane is measured in minutes and all cranes have the same capacity of 240 min in each 4-h planning period. Similarly, the workload, lack of crane capacity and additional crane capacity in blocks can be forecasted and measured in minutes.
- Because of the limitation of block size and the potential events of crane interference, at most two yard cranes are permitted to serve a block, simultaneously.
- At the end of each planning period, the delayed workload is overflowed to the next period. So the workload of a block must be calculated as a summation of the workload of the current period and the overflowed workload from the previous planning period.

The ultimate aim of this developed model is to minimize the total travel time of cranes between blocks and the total delayed workload in blocks at different periods.

2.3. Notations

i: Index of blocks with additional crane capacity;

j: Index of blocks with insufficient crane capacity;

t: Index of time periods;

M: Number of blocks with additional crane capacity;

N: Number of blocks with insufficient crane capacity;

k: Maximum number of cranes allowed simultaneously in the same block;

C: The capacity of one crane within a planning period;

a_{it}: Amount of crane capacity available in block i during planning period t (expressed in time units);

b_{jt}: Amount of crane capacity requested by block j during planning period t (expressed in time units);

t_{ij}: The time required for transferring yard crane from block i to block j;

2.4. Decision variables

X_{ijt}: It is equal to 1, if crane move from block i to block j during planning period t and otherwise it is equal to 0.

W_{jt}: Delayed workload in block j during planning period t.

2.5. Mathematical model

The purpose of the developed model is to minimize the total travel time of cranes between blocks and the total delayed workload in blocks during different planning periods. The developed mixed integer programming (MIP) model is as follows:

$$\min \sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{t=1}^{T} t_{ij} \times X_{ijt} + \sum_{j=1}^{N}\sum_{t=1}^{T} W_{jt} \tag{1}$$

Subject to:

$$\sum_{i=1}^{M} a_{it} \times X_{ijt} \geq b_{jt} \qquad j=1,\ldots,N \qquad t=1,\ldots,T \tag{2}$$

$$\sum_{i=1}^{M} X_{ijt} \leq k \qquad j=1,\ldots,N \qquad t=1,\ldots,T \tag{3}$$

$$W_{j(t-1)} + b_{jt} - \sum_{i=1}^{M} a_{it} \times X_{ijt} - W_{jt} = 0 \qquad j=1,\ldots,N \qquad t=1,\ldots,T \tag{4}$$

$$a_{it} \leq C - t_{ij} \times X_{ijt} \qquad i=1,\ldots,M \qquad j=1,\ldots,N \qquad t=1,\ldots,T \tag{5}$$

$$X_{ijt} \in \{0,1\} \tag{6}$$

$$W_{jt} \geq 0 \tag{7}$$

Constraints set (2) specifies that the crane capacity transferred from block i to block j in planning period t must satisfy the crane capacity requested in block j in period t. Constraints set (3) guarantees that the number of cranes working simultaneously in block j in period t cannot exceed k. Constraints set (4) maintains the balance between the workload that should be finished ($W_{i(t-1)}+b_{jt}$) and the workload that can be finished ($\Sigma a_{it} \times X_{ijt}$) in each block using slack variable W_{it}. Constraints set (5) ensures that the additional crane capacity in block i in the planning period t cannot exceed its total net crane capacity. Constraints sets (6) and (7) are non-negative and integer constraints.

3. Numerical experiment

This section employs the branch and bound method to solve the MIP model using Lingo software. The capability and applicability of developed model are evaluated by conducting the following numerical experiment. In this experiment we have totally 13 blocks where 5 have additional crane capacity(a_{it}), and 8 do not have crane capacity (b_{it}). They are obtained by Uniform distribution (10,80) and (10,60), respectively. In addition, the time required to move from block i to j (t_{ij}) is achieved by Uniform distribution (40,100) and total planning time period is set to 6. Therefore, available total time for a yard crane would be 240 min in each period. In this example, variable k (maximum number of cranes that can work simultaneously in a block) is equal to 2. Table 1 gives summarizes the results of the proposed model solved by Lingo.

Table 1
The general results for numerical experiment

Model class	Mixed integer programming
Solver type	Branch and bound
Number of variables	288
Number of iterations	90
Solving time duration	5 second
Best objective function value	4891
Total travel time of cranes between blocks	3103
Total delayed workload in blocks	1788

The results show that the best objective function value is equal to 4891, the total travel time of cranes between blocks is 3103 and the total delayed workload in blocks during different planning periods is 1788. The maximum portion of objective function value is associated with the movement time of cranes between blocks. This long transferring time of cranes is due to yard cranes slow motion and large scale. In addition, the results show sequence of yard cranes movement between the blocks to achieve the minimum total cranes travel time and total delayed workload. Fig. 4 depicts a typical layout of container terminal that illustrates movements of the yard cranes among blocks in period 1 (by arrows). In this figure blocks with the additional crane capacity have gray color and the blocks with no crane capacity have white color. Cranes with additional capacity move to blocks with no crane capacity while more than two cranes are not allowed to cooperate in one block, simultaneously. As an example, the additional crane capacity of block 1 moves to blocks 4 and 10, because in this period they do not have crane capacity. Similarly, the other arrows indicate crane capacity movement between the other blocks and this sort of diagram can be drawn for the rest of planning periods.

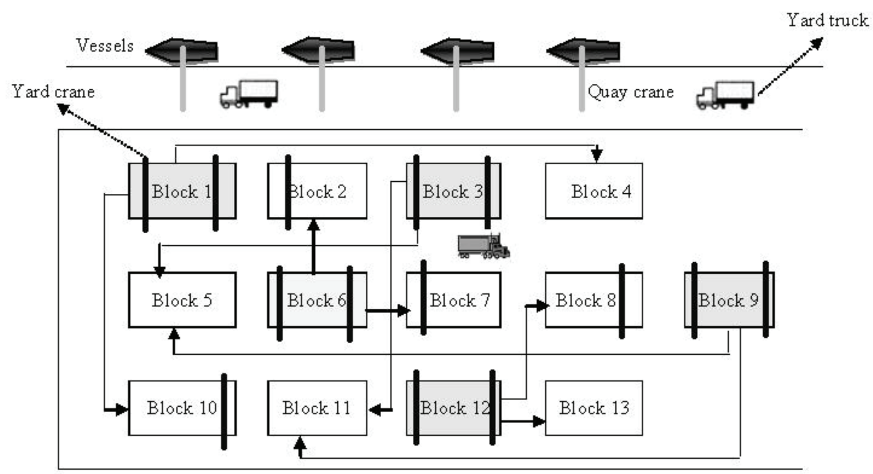


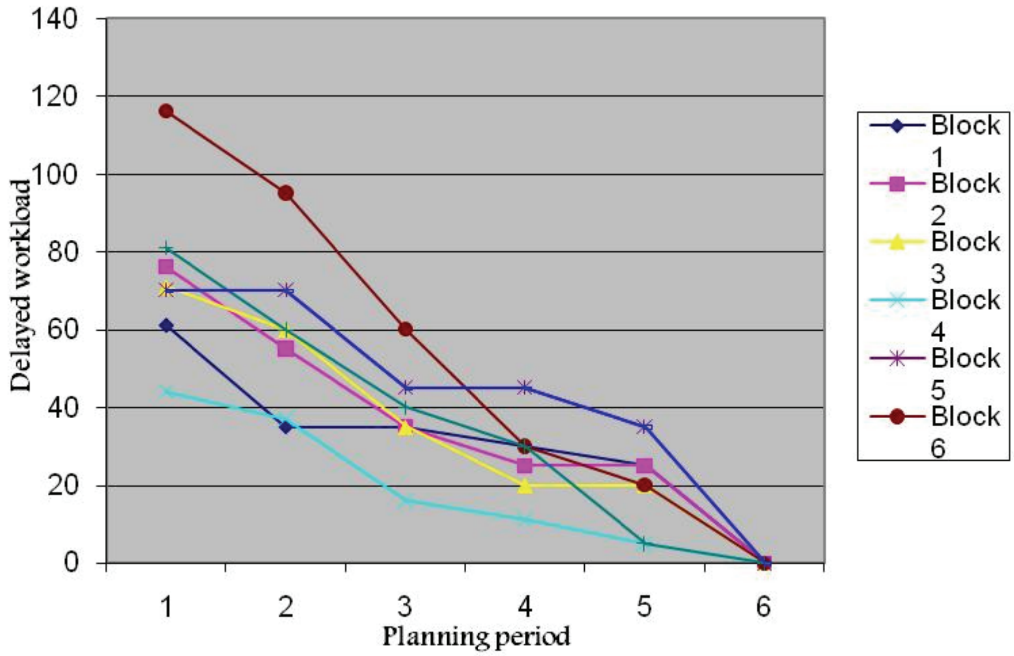
Fig.4. Cranes movements in period 1

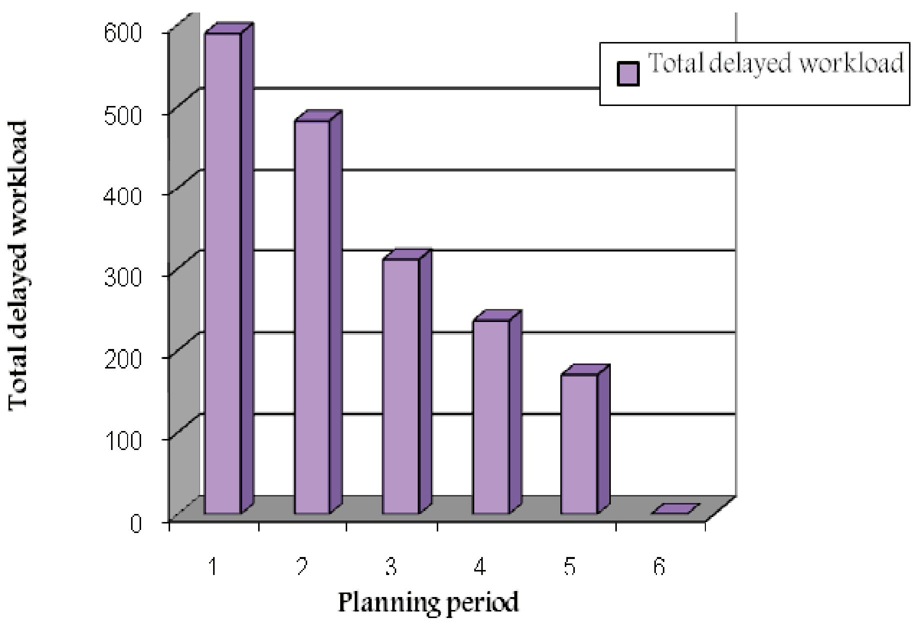
Table 2 shows delayed workload in blocks during different planning periods. In the other word, proposed model yields the solutions with optimum cranes movements to achieve minimum unfinished workload and to cover the total lack of crane capacity at the end of planning periods.

Table 2
Delayed workload in blocks with crane capacity at different planning period

	Blocks with crane capacity							
Planning period	1	2	3	4	5	6	7	8
1	61	76	71	44	70	116	81	70
2	35	55	60	37	70	95	60	70
3	35	35	35	16	45	60	40	45
4	30	25	20	11	45	30	30	45
5	25	25	20	5	35	20	5	35
6	0	0	0	0	0	0	0	0

As Table 2 indicates, the delayed workload at initial periods is more than that at ending planning periods. This means that with increase in the planning periods, lack of cranes capacity decreases gradually and finally it tends to zero at period 6. Fig. 5 shows this decreasing trend for different planning periods. In addition, Fig. 6 depicts the decreasing trend of total delayed workload for all blocks in six planning periods. As we can observe from figure, yard cranes are deployed in an optimal manner where the total unfinished works for all blocks tend to zero at period six.





4. Conclusions and future study

This paper focused on investigating and planning yard crane operations in container terminals. In this paper, yard crane scheduling problem was formulated as mixed integer programming and it was implemented for a sample problem to indicate the model efficiency. Objective function was based on the time and the ultimate aim was to minimize the total movement time and delayed workload. In other words, yard cranes move among the blocks in a way to reduce the total delayed workload at per block to zero. In addition, the multiple times were considered in the model. Generally, the following issues could be extracted from the current paper:

- Mixed integer programming model is eligible and efficient tool to solve yard crane scheduling problems at container terminals. In addition, Lingo software and branch and bound method are appropriate tools to solve such a model.
- Proposed model determines the block pairs between which yard cranes are transferred during different periods, in order to satisfy the crane capacity requirements and minimize the total delayed work load and total cranes travel time between blocks.
- The developed model calculates the lack of capacity of the blocks with delayed work load. As it is shown in a numerical experiment, with increase in the planning periods in each block the lack of crane capacity decreases until this value tends to zero at the last period.
- The model determines sequences of the cranes movements between blocks in every planning period.

The model could be developed by studying the efficiency of yard cranes. Investigation in this field is recommended as a topic to marine transportation researchers.

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