A Simulation–based Optimization Approach for Stochastic Yard Crane Scheduling Problem with Crane Mobility Constraints

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Abstract: With the fast-paced growth in containerized trade market the need for effective and efficient operations at container terminals is a critical factor in freight transport. One major contributing factor of terminal efficiency is the productivity of Yard Cranes (YC) resulting from YC scheduling. In this paper, the stochastic YC Scheduling Problem (YCSP) is presented aspiring to provide a new yard cranes analysis through operational attributes of the container handling process. A stochastic mixed integer programming model is proposed, and a simulation-based optimization procedure introduced to build YC schedules that account for the dynamic and uncertainty nature of container handling process in container terminals.

1 INTRODUCTION

Over the past 30 years, freight transportation has rapidly developed, it is now an indicator of the economic growth of countries in global freight operations. Therefore, the effective and efficient management of Container Terminal (CT) is important in the contribution of economic growth. These advancements in freight transportation and information technology have brought new challenges and complications that associate with CT operations. As of 2014, it was estimated that the container flows from largest ports in the world to be 68.4 Million TEU (twenty-foot equivalent unit; a 20 ft. × 8ft× 8.5 ft.). This increase raised a logistic concern all over the most important ports and the world (UNCTAD 2015).

Nowadays, terminal competitiveness in global freight network is directly affected by the storage yard activities (Zhen 2013a). This is due to containerization growth which leads to high vessel turn around time. However, alleviation of vessel turnaround time requires integration between various operations to ensure better performance of terminal operations (Vis and De Koster 2003). Consequently, It is important to decide on the planning of operational activities as well as selecting right handling equipment on storage yard activities to facilitate a seamless flow of containers in the port (Wiese et al. 2010).

A container terminal is an essential node in an open system and dynamic flow of containers materials. Terminals operate under two external interfaces of operations to serve container vessels (Steenken et al. 2005). Moreover, container terminal can be classified into five main areas namely; berth, quay, transport areas, yard storage, and terminal gate. Berth and quay areas considered as the seaside operations, while the yard and gate areas are in the landside operations (Vis and De Koster 2003). For instance, (Lau and Zhao 2008) addressed vessel operations comprise of loading and discharging tasks, where containers are loaded and unloaded to/ from a ship and stacked or retrieved in a storage yard. Furthermore, they explained three types of material handling equipment; Quay Cranes (QCs), Automated guided vehicles (AGVs), and Automatic Stacking Cranes (ASCs) that connect seaside and landside operations.

Fig. 1.Show the schematic diagram of automated container terminal whereas, the storage yard is composed of multiple blocks perpendicular to vessel Each yard block contains an adjacent stretch of slots (40 -60 slots) and each slot denoted as a rectangle in a diagram can store 6 – 9 containers.

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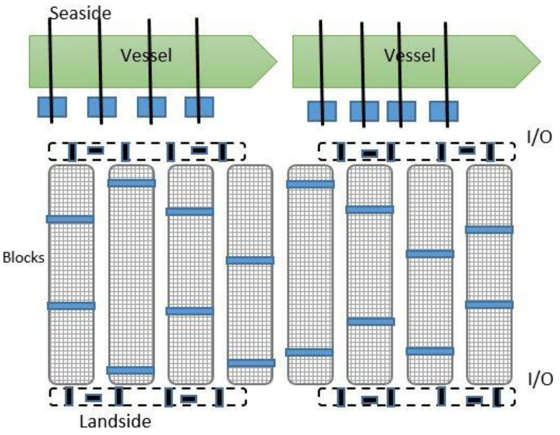

Figure 1: Schematic diagram of an automated container terminal.

In the automated terminal, container handling from/to the transportation trucks is carried at the extremities of the storage blocks. Consider, for example, Hong Kong international terminal is one of the busiest terminals in the world, this terminal received over 10,000 trucks and 15 containers ships a day (Phan and Kim 2016). Fig. 2. Show the trends of the global turnover of the largest seaports.

In this paper, yard crane scheduling problem (YCSP) is presented, and framework approach of a problem based on current research trends is demonstrated. We have established literature review classification following leading attributes that arise in the scheduling of storage equipment in the block; (1) yard layouts, (2) yard crane mobility characteristics, (3) solution methods approach, and (4) Performance measure and uncertainty. These attributes will be more or less in chronological order in our work.

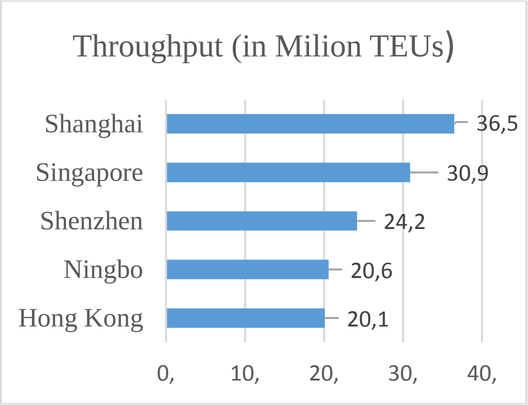

Figure 2: World turnover of largest seaport (IHS 2016).

The remainder of the paper is organized as follows, in section 2 of the paper detailed description of the storage yard crane problem followed by yard storage analysis in section 3 and section 4, simulation framework of the YCSP. In section. Five conclusions and the future prospect are summarized.

2 PROBLEM DESCRIPTION

In this section, yard crane scheduling problem (YCSP) is modeled as an integer program. We seek to develop a mathematical model describing the attributes of yard crane schedule to sequence the stacking and retrieving of containers in a block. Based on two main factor, mobility rules and uncertainty, some important assumption for the formulation have been constructed.

a) The planning horizon is apportioned into T small time periods (weeks, beginning t = 1)

b) The volume of a particular task group should not exceed the capacity of the YC given that all tasks in a single bay should be a group of one task.

c) The YC movements are within a block and should be non-crossing with a safety distance between cranes.

d) All job in a block are assumed as discrete operations, and the task will be grouped in a different segment of the block whereas arriving vessels and external truck represent the tasks to be handled.

e) At the beginning of rolling horizon, all yard cranes are available, the estimated time of operation and start time of processing of tasks are known.

f) Each yard crane has same productivity.

Parameter

I	set of all jobs I = {1, 2…n} to be handled
K	set of identical yard cranes K= {1, 2}
Rt_i	ready time of job i
L_i	location of job i
Tt_{ij}	time required for yard cranes to travel from L_i to L_j
h	time required by a yard crane to handle one job.

Decision variables

Z_i	(U_i, V_i) the handling time window for job I
U_i	the time at which the yard crane assigned to handle job i
V_i	completion time of job i
t_i	arrival time of the yard crane assigned to job i
Θ	completion time of the yard crane k
X_{ij}^{k}	1 if yard crane k handle job i before job j

0 otherwise.

Y_i YC assigned to handle job i

The model follows below

$$\text{Min} \sum_{k=1}^{m} \theta \tag{1}$$

$$\sum_{j=1}^{n} X_{0j}^{k} = 1, \qquad k = 1 \dots m \tag{2}$$

$$\sum_{i=1}^{n} X_{iT}^{k} = 1, \qquad k = 1 \dots m \tag{3}$$

$$\sum_{k=1}^{m} \sum_{i=0}^{n} X_{ij}^{k} = 1, j = 1 \dots n \tag{4}$$

$$\sum_{j=1}^{n} X_{ij}^{k} - \sum_{j=1}^{n} X_{ij}^{k} = 0, k = 1 \dots m \tag{5}$$

$$V_i = U_i + h, \qquad i = 1 \dots n \tag{6}$$

$$U_i = \max \{Rt_i, t_i\}, \qquad i = 1 \dots n \tag{7}$$

$$V_j - V_i \geq Tt_{ij} + h - (1 - X_{ij}^{k})M, i, j = 1 \dots n \; | i \neq j \tag{8}$$

$$(Y_i - Y_j)(L_i - L_j) > 0 \text{ if } \bigcap_{i \neq j} Zi \cap Zj \neq \emptyset \quad i, j = 1 \dots, n \,|\, i \neq j \tag{10}$$

$$V_j + Tt_{iT} - \Theta \leq M(1 - X_{ij}^{k}), \; j = 1 \dots n, k = 1..\text{m} \tag{11}$$

$$X_{ij}^{k} \in \{0, 1\}, \quad i, j = 1 \dots n, k = 1 \dots m \tag{12}$$

$$V_i, U_i, t_i, \Theta \geq 0, \quad i = 1 \dots n, k = 1 \dots m \tag{13}$$

$$Y_i \in \{1, 2 \dots\} \qquad i = 1 \dots n \tag{14}$$

The objective is to minimize the completion time of the yard crane operation by constraint (1). *Carrying out all group task sequence*: constraints (2) -(4), to ensure the completion of all workgroup by yard crane. Each task should be carried out by single YC and should follow after the last task group handled by YC. Constraint (5) ensure the balance flow of cranes during travels. *Handling time requests constraints* (6) – (7), to make sure that the start time of the task group to be later than its estimated time, also the start time of task group should be later than YC completion time. *Movement of yard crane constraints* (8) – (9) define the move time for each yard crane from the current location to the next one. Then, ensure mobility integration (non-crossing) of yard crane in the block. Constraint (10) ensure that the completion time for each yard crane is defined. X_{ij}^{k} Binary variable by constraint (11). Non-negative integer variables in constraints (12) and (14)

This study has considered, deviation of process time and start time of handling a task simultaneously. These deviance factors arise due to the lateness arrival of the vessel or external truck that leads to work delays.

3 YARD STORAGE OPERATION

This section discusses yard storage operations and introduces cranes as primary equipment in yard block. The cranes perform stacking and retrieving operations of the containers while integrating with quay cranes and transport vehicles (Zhen 2013a). In the various practical and theoretical studies, yard crane scheduling problem has been presented in two categories; Rail Mounted Gantry Crane (RMGC) and Rubber Tire Gantry Crane (RTGC). The two types operate in different rules. RMGCs are automated and work in intra-block operation. On contrary RTGCs are manually operated, and work on various zones in the yard storage (Gharehgozli et al. 2014).

3.1 Yard Storage Layout

A typical yard storage layout determines the containers placement and a network of operations; each block has material handling equipment (yard crane) serving a block or multiple blocks. A standard block is made of several rows each with bays so that container can be stored in several tiers depending on the capability of equipment used to stack them (Liu et al. 2004). There are two types of yard layout configurations; (1). Non-automated (2) Automated yard layout. The main differences observed in their design is the position of the input/output point (container exchange position of yard vehicle and cranes), the level of automation used and the block position to quay; horizontal/vertical (Lee and Kim 2013).

Conventional yard layout configuration mostly used in container terminals in the world. It has blocks arranged parallel/horizontal to the quay. Fig.3. Show the schematic diagram of the typical configuration of conventional yard storage layout. Usually, one or more rows in each block are reserved for internal and external transfer vehicles as truck lanes. In this configuration, cranes travel in vehicle lanes for stacking and retrieving tasks. Each yard block contains adjacent slots and each slot denoted as rectangle in a diagram can store 6 – 9 containers. On contrary automated yard layout mostly employed in Europe and few Asia ports, blocks are perpendicular/ vertical to the quay. Input and output points are located at both ends of the storage block where automatic guided vehicle pick up containers at seaside and external truck at land.

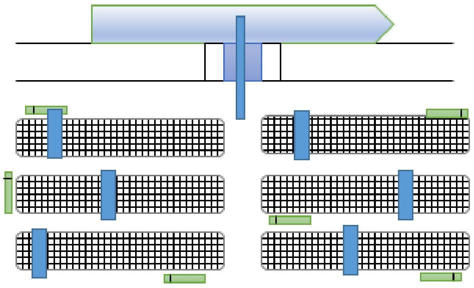

Figure 3: Schematic diagram of conventional terminal layout.

3.2 Crane Mobility Characteristics

Dispatching standards and setting of yard cranes routes indicate the operational mobility attributes employed in the storage area. Yard crane follow the dispatching rule in the block finding the optimal paths. (Narasimhan and Palekar 2002) studied yard operation by considering a single YC which retrieves and stack container in a single block. Some of the articles have also addressed retrieval and stacking requests operation simultaneously. (Zhang et al. 2002) formulated a mixed integer programming model for YC problem under a given workload in multiple blocks. Their objective was to minimize the unfinished workload defined as either retrieval or stacking.

(Ng et al. 2005) studied multiple crane scheduling problem for non-crossing cranes in a single block. They developed a branch and bound algorithm for a large size problem to minimize the total delay time for all requests. (Lee et al. 2006) presented loading sequence requirements in the schedule considering two non-crossing yard crane in separate blocks. The authors developed a genetic algorithm to find the solution. Likewise, (Li et al. 2009) introduced a discrete time model for automatic stacking cranes to minimize the earliness and lateness combination of all request in their due course. They proposed a dynamic rolling horizon algorithm, to ensure the real-time update of the schedule for all tasks. (Vis and Carlo 2010) formulated the same setting. However, the stacking cranes can pass through one another, but they cannot work in the same bay. the request of all activities has neither due times nor sequence. They developed a mathematical model to minimize makespan for both cranes and applied simulated annealing-based heuristic to solve the large instance of the problem; the authors concluded that numerical solution based on heuristic solutions are within 2% of the large instance and 6% for a small instance of the problem.

3.3 Solution Method Approaches

Most of the research papers in yard cranes scheduling problem in literature are described in mathematical modeling. Such as; linear, nonlinear, and mixed integer programming models. Due to the computational complexity of solving these models to optimality, advanced techniques such as heuristics, meta-heuristic, and algorithms used to address the problem to approximate solution. Therefore, we categorize these into two branches; exact solution methods and approximate solution methods.

3.3.1 Exact Solution Methods

Exact solutions are widely used in formulating mathematical models for the purpose of developing adjusted patterns in some parameter to get exact solutions.(Cheung et al. 2002) formulate a mixed integer program of the YC scheduling problem to minimize the total workload of tasks. Numerical experiment results, concluded the solution approach was effective and efficient for large-sized problems. Moreover, (Lee et al. 2007) developed a mathematical model for scheduling of two transtainer systems. The objective was to reduce total loading time on two-yard crane moving in the separate blocks. They used simulated annealing (SA) to solve the proposed model. Numerical experiment results concluded that the completion time of SA introduced was 10% above lower bound and performance of the algorithm is extraneous to some of the containers loaded. In some cases YC problems use combination exact and approximate solutions in finding a result, for instance (Cao et al. 2008) formulated a mixed integer program to provide an efficient operation strategy for loading outbound container. Using a dual rail mounted gantry crane they developed a greedy heuristic algorithm and simulated annealing algorithm to solve the problem. (Wiese et al. 2010) formulated integer linear program for container layouts in yard operations, they expressed restricted model to a square storage yard and added a Variable Neighbourhood Descent (VND) heuristic for solving yard operations' problems with an arbitrary shape. Their study shows that the VND heuristic provides the trade-off of time and solution quality by economic results for 43% of the instances.

3.3.2 Approximate Solution Methods

Due to the compound nature of YC scheduling problems, research studies use approximate solutions to achieve a near optimal results in solving large instances of the problems. In their paper (Kozan and

Preston 1999) introduced genetic algorithms for the optimization of container transfer in maritime terminals. The goal was to find the optimal storage strategy and schedule for handling container in a yard. (Chen et al. 2004) addressed yard storage optimization in Singapore port, to minimize space allocation of cargo in a designated yard and satisfy space requirement. They used the combinatory heuristic method to solve the problem. Results concluded that a traditional heuristic approach achieves relatively better results in a short time by 10% above margin.

(Dell'Olmo and Lulli 2004) considered container as a network of complex substructures or platform to address resource allocation problem to minimize the total delay time in the overall system and on the time horizon. They introduced a dynamic programming approach tackling large size problem and conclude that the percent is 6.3% above the lower bound of the solution. In recent years (Burke et al. 2012) proposed an empirical analysis on comparing Monte Carlo based hyper-heuristics for solving capacitated timetabling problems in the automated terminals. They applied a simulated annealing to accompany the hyper-heuristic on finding the approximate solution. Their proposed approach claims to prove the new precisely technique to schedule automated cranes.

3.4 Performance Measure and Uncertainty

Dynamic operations that subsist during loading and unloading of the container may affect the performance of cranes operations if overlooked. The effects may occur due to the failure of equipment, delay of vessel/truck arrival time, incorrect information of vehicles or ship and human errors.

3.4.1 Uncertainties

The arrival time of ships/external trucks may affect the performance of the terminal, for example, (Zhen et al. 2011) proposed an optimization model for berth allocation problem under uncertainty of vessel arrival time and handling time to obtain a robust schedule. However, the same settings were used in (Zhen and Chang 2012) to formulate a mathematical model under two objectives on stochastic consideration of vessel arrival and operation time. (Zhen 2013b) presented the decision support system (DSS) that replaced the traditional system of operation. By introducing real-life events of uncertainty in yard allocation problem. This decision support system enabled port operators to cope with the adjustable volume of arriving containers.

(Golias et al. 2014) proposed a berth scheduling problem. The schedule minimizes the total service times for serving all vessels, they formulated a discrete mathematical model and used a heuristic to find a robust schedule.Furthermore, (Jun-Liang et al. 2016) addressed yard crane scheduling where, handling time, vessel and truck arrival were assumed to be dynamic with different service priorities. They developed mixed integer programming, and simulation based genetic algorithm search was applied to develop a robust YC schedule.

3.4.2 Performance Measure

Performance metrics such as crane makespan, crane utilization, and vessel turnaround time indicate the level of efficiency achieved by the terminals during processes. For instance, (Petering and Murty 2009) considered a restriction on the system would prevent the system from being disturbed by outside factors such as trucks/vessel arrival, they developed performance measures using the rule-based control system that deploys cranes among blocks on the same zone of operation. (Borgman et al. 2010) investigated the effect of vessel departure time and stacking point of container on the overall performance of container terminal. The discrete-event simulation tool was developed for analysis, and it was found that minimizing departure time proved to be significant on reshuffle and performance of container terminals. Furthermore (Bortfeldt and Forster 2012) proposed a heuristic tree search procedure for container relocation problem taking into account effect of the height of stacks in the overall performance of the stacking operations. They compared their method with.

3.4.3 Emerging Issues

The performance of the container terminal is measured on the capacity to accustom a large number of vessels and minimum vessel turnaround time. However, handling capacity increase with an increase in the size of the terminal. Recently large operating terminals have considered a direct impact of handling equipment on the cost of energy consumption. In (Xin et al. 2014) addressed the energy-aware control in scheduling automated terminal by considering the behavior of the terminal under two operating level; higher level and lower level represented by discrete event dynamics and continuous dynamics respectively. They further elaborated latter level obtained of minimal value to achieve minimum energy consumption while maintaining operational time constraints. Also, (He et al. 2014) addressed the pollutants generated from the yard activities mentioning carbon dioxide as a threat to the environment. They developed mixed integer programming model and solved the problem in a vehicle routing procedures. To account for the total energy associated in yard crane.

4 SIMULATION FRAMEWORK OF STOCHASTIC YARD CRANE SCHEDULING PROBLEM

A proposed framework seek to develop a yard crane schedule considering the effects of mobility and capture realistic environment. This framework put together an optimization program and a simulation model of a yard crane operations. The objective is to minimize the total yard crane completion time and penalty costs that are associated with operational uncertainties. The optimization program will generate an initial feasible solution to be used into the simulation model as initial input data. Initially, the simulation model will evaluate the current and total costs based on the positional values of crane and efficiency measures (such as speed, start time and recovery time of operation, when there is equipment failure or late arrival of ship/trucks). Then model outputs will be returned to the optimization program checking the optimality. Consequently, this simulation-based optimization is an optimization on the basis of the simulation results to capture the dynamic nature of operations and the uncertainties. As it can be seen in fig.4 simulation model of yard crane is the core component, while the optimization is the central program for evaluation.

Optimization Program: the program constitutes of mathematical model built with mixed integer programming, and it will follow the following steps;

- Initial data generation of the yard activities this will include block characteristics, the number of cranes, handling efficiency and the distribution of crane service time also berth and gate features which include vessel/truck size and their probabilities of arrival and the distribution of inter-arrival time between successive vessel/truck.
- Simulation initiation: The optimization program transfer the initial data into the simulation, and activates evaluation process in the simulation program to get vessel/truck waiting times and the berth utilization ratio.
- Objective function assessment: After the simulation is complete, the program returns the results to the optimization program, and the optimization program evaluates the total time and costs.
- Decision: optimization program assesses the initial solution from the simulation by comparing the total costs. If the designed total cost is minimal, the system stops and outputs the optimal design and schedule and the corresponding decision. Otherwise, it returns to data generation stage and go on to the next iterative operation

Simulation Model: This involves submodule for vessel/truck arrival and handling operation module. To help capture the realistic part of the yard operation especially in a block, berth, and gate. To be able to incorporate the effect of crane utilization on the schedule that will reduce unnecessary penalty cost that may occur during the process.

5 CONCLUSIONS

This paper conducted analysis and introduced a new classification of the stochastic yard crane scheduling problem. Although, few articles have addressed the stochastic nature of the problem, yet the majority of research paper have overlooked its effects in scheduling cranes. A mathematical model was developed, and simulation-based optimization framework is proposed for solving these new attributes of the problem. Hence, based on the analysis of literature introduced, no study has addressed the integration of uncertainty factors and mobility settings in scheduling yard cranes. This confirms a gap for future work which will focus on the generation of optimal solutions results and improvements that would allow considering larger instances of the problem.

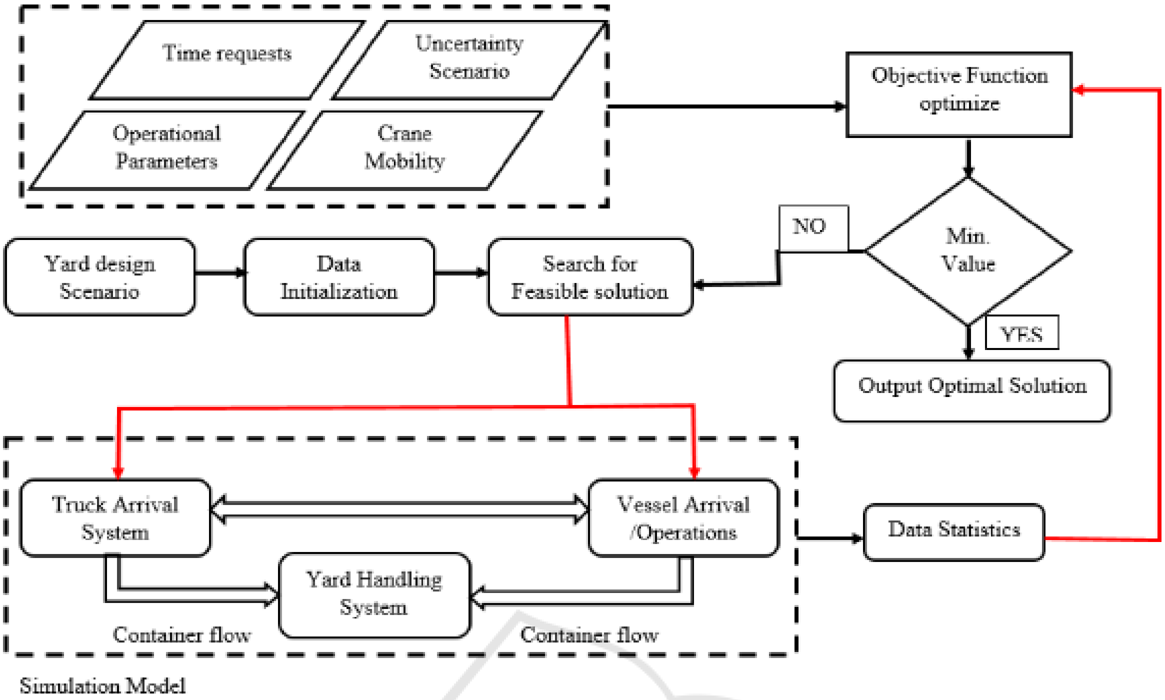

Figure 4: Simulation-based optimization flowchart for YCSP.

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