UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN INTEGRATED SCHEDULING MODEL FOR HANDLING EQUIPMENT IN AUTOMATED PORT CONTAINER TERMINALS

SEYED HAMIDREZA SADEGHIAN

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By

SEYED HAMIDREZA SADEGHIAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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DEDICATION

I dedicate this thesis to my wife and my parents

for their love, endless support

and encouragement and to my new born daughter, Viana.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman: Mohd Khairol Anuar Bin Mohd Ariffin, PhD

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Nowadays, the role of the sea port container terminals in national and regional transportation and economy can not be omitted. Massive transportation capacity and lower carrying costs lead different countries to increase throughput of their seaport container terminals. Especially, developing countries have many plans to construct new seaport container terminals or to increase the capacity of their existing ones. To respond enormous and every increasing demand on sea transshipments within the same time frame, terminal managers require more and more efficiency in container terminal performance and operations. Automation of the processes at the quays of the container ports is one the solutions to improve the performance and output of container terminals. For such purpose, using a new generation of vehicles is unavoidable. Automated Lifting Vehicle (ALV) is one of the automatic vehicles that has been introduced during recent years and can be used in container terminals. Using ALVs, due to their ability in lifting a container from the ground by themselves, can decrease the delay of loading and unloading tasks in automatic container terminals. In other side, the integration of various types of handling equipment, is another important way to increase the efficiency of processes and productivity of a container terminal. In this research, a mixed-integer programming model is developed which considers the integration of ALVs, Quay Cranes and Yard Cranes at automated container terminals with unlimited buffer spaces. This model minimizes the delay time of the QC operations, the total traveling time of ALVs, and the total traveling time of AYCs within the storage blocks.

To evaluate the performance of the developed model and solving method, numerical experiments are designed and the obtained results are reported and analyzed in this research.

The results show that the application of the ALV with integrated scheduling, decreases the total travel time of vehicles, delay of quay cranes and operation time of yard cranes by 7.3% and in some cases even up to 9.3%.

As the integrated scheduling of handling equipment is a “non-deterministic polynomial-time hard” (NP-hard) problem and also the computation time and ease of application are so important for real practices of the scheduling methods, So a meta-heuristic algorithm based on Genetic Algorithm is developed, in which, new operators create solutions

considering the constraints of the problem and also a heuristic rule proposed which assigns the ALVs to the tasks. The results obtained from the designed test cases, show that the “Priority Based assignment” (PBA) has the best performance in this problem.
In addition, results proved that the modified meta-heuristic algorithm is able to find near optimal solutions and on average, the solutions found by the GA algorithm are only 0.2% worse than the optimal solutions and in the worst case in the test cases this difference is 2.3% which is acceptable.

Finally, sensitivity analysis shows that as the number of ALVs increases, the objective function decreases. Also, it is illustrated that by increasing the uncertainty in QCs' operational time, the objective function of the problem decreases slightly.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL PENJADUALAN BERSEPADU PENGGUNAAN PERALATAN DI TERMINAL-TERMINAL PELABUHAN KONTENA

Oleh

SEYED HAMIDREZA SADEGHIAN

Dec 2014

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Hari ini, peranan sesebuah terminal kontena pelabuhan laut dalam pengangkutan bagi ekonomi negara dan kawasan serantau tidak lagi diabaikan. Kapasiti pengangkutan besar-besaran dan kos yang lebih rendah menyebabkan sesebuah negara itu, meningkatkan daya pemprosesan di setiap terminal kontena pelabuhan mereka. Terutamanya, di negara-negara membangun yang mempunyai banyak rancangan untuk pembinaan terminal kontena pelabuhan laut yang baru mahupun meningkatkan keluasan yang sedia ada. Disebabkan tindak balas terhadap permintaan yang besar dan pada masa yang sama peningkatan untuk keperluan pengankutan, pengurus terminal memerlukan lebih banyak tenaga dan kecekapan dalam mengurus prestasi terminal kontena dan operasi. Operasi system secara otomatik di pelabuhan kontena adalah salah satu cara untuk meningkatkan mutu dan prestasi di terminal kontena. Untuk tujuan ini, penggunaan pengankutan moden adalah penting. Kenderaan pengangkut otomatick (ALV) adalah salah satu pengankutan yang telah diperkenalkan sejak beberapa tahun kebelakangan ini dan boleh digunakan di terminal kontena. Penggunaan ALV adalah disebabkan kerana keupayaannya dalam mengangkat beban yang berat yang mana boleh mempercepatkan tugas-tugas pemindahan barang secara otomatik di terminal kontena. Dalam erti kata yang lain, integrasi pengendalian peralatan pelbagai jenis ini merupakan satu lagi cara yang penting dalam meningkatkan kecekapan proses dan produktivit di terminal kontena. Di dalam kajian ini, model pengaturcaraan campuran maklumat, yang berpendapat bahawa, integrasi ALVs, Quay Cranes dan Yard kren diterminal kontena otomatik dengan ruang yang terhad, dibangunkan. Jenis model ini telah mengurangkan kelewatan masa dalam operasi QC, serta jumlah penggunaan masa ke ALVs dan AYCs di dalam blok-blok simpanan.

Untuk menilai kecekapan model dan penyelesaian kaedah yang dicadangkan, ujikaji berangka direka dan keputusan yang telah diperolehi dilaporkan dan dianalisis dalam kajian ini.

Berdasarkan keputusan yang diperolehi menunjukkan bahawa pendekatan ALV dengan jadual bersepadu, boleh mengurangkan penggunaan tempoh perjalanan kenderaan-kenderaan tersebut, kelewatan kren jeti dan masa operasi kren bermeter secara

umumnya sebanyak 7.3% dan boleh mencecah sehingga ke 9.3% dalam beberapa kes lain.

Penjadualan bersepadu pengendalian peralatan adalah masalah " non-deterministic polynomial-time hard " (NP-hard) dan juga pengiraan masa serta memudahkan penggunaan yang begitu penting untuk amalan sebenar daripada kaedah penjadualan. Jadi algoritma meta-heuristik berdasarkan Algoritma Genetik diwujudkan, di mana, terciptanya pengendalian baru sebagai langkah penyelesaian terhadap kekangan masalah. Dalam teras algoritma yang dicadangkan itu, satu peraturan heuristik dicipta terhadap tugasan kenderaan tersebut. Keputusan menunjukkan bahawa "Keutamaan Berdasarkan Tugasan", mempunyai prestasi yang baik dalam menyelesaikan masalah ini.

Tambahan pula, keputusan yang diperolehi membuktikan bahawa cadangan Algoritma meta-heuristik mampu memperolehi penyelesaian yang purata dan optimum, penyelesaian yang ditemui oleh algoritma GA hanyalah 0.2% lebih teruk daripada penyelesaian yang optimum dan berkemungkinan perbezaan hanya mencecah sehingga 2.3% sahaja.

Akhir sekali, analisis kepekaan menunjukkan bahawa bilangan ALVs meningkat, manakala fungsi objektif berkurangan. Selain itu, ia digambarkan bahawa dengan peningkatan ketidaktentuan dalam waktu operasi QCS ', manakala fungsi objektif pada masalah tersebut berkurangan sedikit.

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Your nice help, I would never forget.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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α	The travel cost per unit time of an ALV.
β	The penalty cost per unit delay time of a QC.
γ	The travel cost per unit time of an AYC.
ϕ_{ki}^{lj}	The decision variable which becomes 1 if jth container of QC_l be carried directly after ith container of QC_k by the same AYC.
a_i^k	The event that an ALV transfers the ith container of QC_k. When the ith operation of QC_k is a loading operation, an event a_i^k corresponds to the release of the ith container by ALV into the buffer at QC_k. When the ith operation of QC_k is an unloading operation, it corresponds to the pick up of the ith container by an ALV from the buffer at QC_k.
a_j^0	The starting event of ALV_j , $j \in V$.
a_j^F	The stopping event of ALV_j , $j \in V$.
ACT	Automated Container Terminal
AGV	Automated Guided Vehicle
ALV	Automated Lifting Vehicle
AQC	Automated Quay Crane
AS/RS	Automated Storage/Retrieval System
AYC	Automated Yard Cranes
B&B	Branch and Bound method
BAP	Berth Allocation Problem
c_{ki}^{lj}	The travel time between QC_k and QC_l including all required time for the ALV to be ready for completes transferring the jth container of QC_l after it experiences ith container of QC_k .
clv_{ki}^{lj}	The time required for an ALV to be ready for a_j^l after it experienced the a_i^k.
cyc_{ki}^{lj}	The required time for an AYC to be ready for o_j^l after it experienced the o_i^k .
D	The set of $a_j^F, j \in V$.
FCFS	First-Come-First-Served
FMS	Flexible Manufacturing System
GA	Genetic Algorithm
GAPM	Genetic Algorithm Plus Maximum matching
K	The set of QCs.
K'	$\{D\} \cup K$.

$K^{"}$	$\{S\} \cup K$.
L^k	The set of loading tasks for QC_k , $k \in K$.
$l(a_i^k)$	The location where the event a_i^k occurs.
$l(a_i^0)$	The initial location of ALV_j.
$l(a_i^F)$	The location where an ALV completes its journey.
$l(o_i^k)$	The location where the event o_i^k occurs.
L/U	Load/ Unload
M	A big positive number.
m_k	The number of tasks for QC_k , $k \in K$.
m_l	The number of tasks determined for ALV_l , $l \in V$.
MIP	Mixed Integer Programming
MLGA	Multi-Layer Genetic Algorithm
NP-hard	Non-deterministic Polynomial-time hard
NV	Nearest Vehicles
o_i^k	The event that a specific AYC transfer the ith container of QC_k. o_i^k corresponds to the release of the ith container by AYC into the buffer, when the ith operation of QC_k is a loading operation. When the ith operation of QC_k is an unloading operation, it corresponds to the pick up of the ith container by an AYC from the buffer.
OQ	The operational time of quay cranes.
PBA	Priority Based Assignment
P/D	Pick up/ Delivery point
q_i^k	The ith operation of QC_k.
Q	The set of AYCs.
QC	Quay Crane
QC_k	The QC number k in quayside, $k \in K$.
QCAP	QC Assignment Problem
QCSP	QC Scheduling Problem
RA	Random Assignment
RMG	Rail Mounted Gantry
RTG	Rubber Tired Gantry
S	The set of $a_j^0, j \in V$.
s_i^k	The earliest possible completion time of q_i^k.
SA	Simulated Annealing
SC	Straddle Carrier
sw_{ki}^{lj}	The switching time between a_i^k and o_j^l.
T	The set of a_i^k for $i = 1, 2, \ldots\ m_k$, $k \in K$.

TEU	Twenty-foot Equivalent Unit
tlv_{ki}^{lj}	The pure travel time of ALV from $l(a_i^k)$ to (a_j^l) .
TQ	The travel time of quay cranes between the ship and the quay area.
tr_{ki}^{lj}	The time required for an AYC to be ready for jth container of QC_l after it experienced the ith container of QC_k .
tyc_{ki}^{lj}	The pure travel time of AYC from $l(o_i^k)$ to (o_j^l) .
U^k	The set of Unloading tasks for QC_k , $k \in K$.
UNCTAD	United Nations Conference in Trade And Development
V	The set of ALVs.
x_{ki}^{lj}	A decision variable that becomes 1 if a_j^l be executed directly after a_i^k by the same ALV, $k \in K'$ and $l \in K"$, the assignment of a_i^k to a_j^l shows that the ALV, which have just delivered the ith container of QC_k, is planned to deliver the jth container of QC_l.
y_i^k	The completion time of q_i^k. When the ith operation of QC_k is a loading operation, y_i^k corresponds to the completion time for pickup of the ith container by QC_k from the buffer at QC_k. When the ith operation of QC_k is an unloading operation, it corresponds to the release of the ith container by QC_k into the buffer at QC_k.
Y_i^k	The completion time of o_i^k. Y_i^k is the moment that AYC picks up a container from buffer space when unloading is the ith operation of the QC_k, and while the AYC releasing the container onto the buffer space when loading is the ith task of QC_k .
YC	Yard crane
z_i^k	The completion time of a_i^k.

CHAPTER 1

INTRODUCTION

1.1 Container Transportation

Maritime transport remains the strong backbone supporting globalization as 80 percent of international trade by volume is transported via sea (UNCTAD, 2013). The usage of container as a common carrier for various goods has increased rapidly over the last century. It has turned into a standard in worldwide transportation because of the rapid increase in containerization operations within the recent years (Cheng et al., 2005). As a result of increasing world trade, new container terminals are now being built and existing ones are expanded. With world trade booming, competition between major seaports has become intense (Ng, 2005). Hence, it's very important for port operators to develop different decision tools and optimization algorithms in order to improve its performance and increase its competitiveness.

To boost productivity of the terminal, it's essential to coordinate different terminal equipment to ensure a smooth flow of containers within the terminal. A schematic diagram of the conventional processes in a container terminal is shown in Figure 1.1. Container activities could be categorized into three types: import, export, and transshipment activities (Kim et al, 2000). In automatic container terminals, for export activities, the containers are brought in by shippers and will soon be stored in their designated locations in the storage yard. When it's time to load the containers, they're retrieved from the stored locations by automated yard cranes (AYCs) and transported by automatic vehicles such as, for example, automated guided vehicle (AGV) or automated lifting vehicle (ALV) to the quay side. The automatic quay cranes (AQC) then take the containers from the vehicles and load them onto the vessels. The processes for import activities are performed similarly, except they are done in the reverse order. For transshipment activities, the processes are slightly different. The containers will be stored in the storage yard after they're unloaded from the vessel, and will be finally loaded onto other vessels.

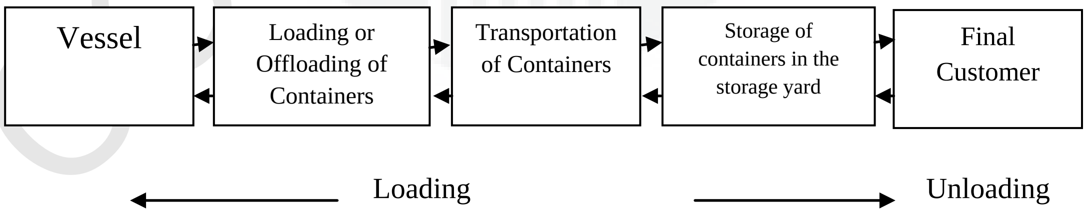

Fig.1.1. Flow diagram of the interaction between terminal processes (Vis et al, 2004)

Figure1.2 shows areas of a container terminal. Each time a ship arrives at a port, a berth is assigned for unloading. After the ship is positioned underneath the automatic quay crane(s) (AQCs), the containers are unloaded by the AQC and are loaded to automated vehicles and transported to yard area for storage. At the storage space containers are stacked into blocks. Automatic yard cranes (AYCs) serve the blocks. On the berth, a required number of automated quay cranes (AQCs) are allocated to unload the containers. Automated vehicles transport the containers. When an automated vehicle arrives at the yard, it puts the container down or the automated yard crane takes the load off the automated vehicle and stores it in the stack. A similar process is found for loading the export and transshipment containers from the yard side to the ship.

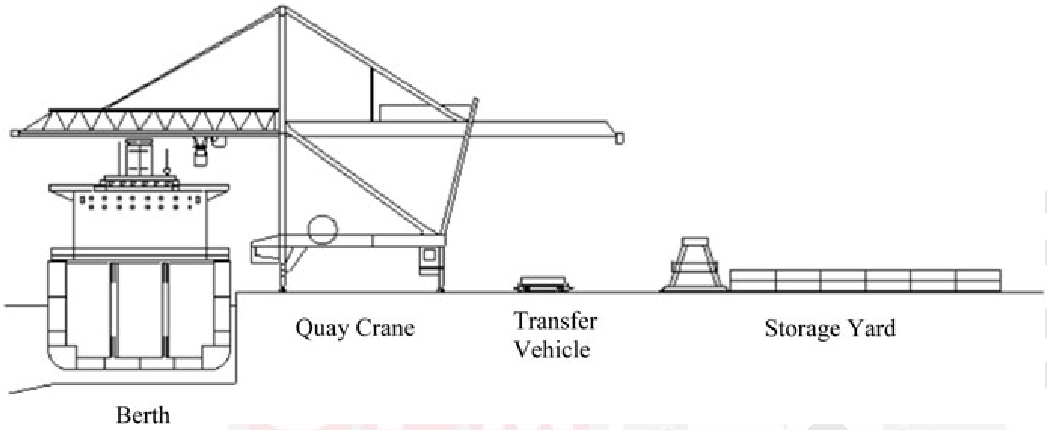

Fig.1.2. Illustration of Container terminal areas (Carlo et al., 2013)

1.2 Integrated Dispatching in Container Terminals

Generally, operational problems of container terminal have already been divided into several problems such as berth assignment, scheduling of QCs, scheduling of YC, scheduling of vehicles and storage container problem.

Many researches being done on mentioned field. But usually previous dispatching studies only focused on optimizing the job sequence on each vehicle while assuming that yard area for unloading the container is known. However, it may be sub-optimal when we focus merely on planning vehicle dispatching without taking into consideration the yard and berth activities.

By increasing usage of containers to enhance productivity of the container terminals, it's necessary to coordinate different terminal equipment to make sure a seamless flow of containers within the terminal.

The transportation between the quay side and the yard side plays a crucial role in determining the productivity of the terminal, because it would delay the AQC or AYC operations if automated vehicles don't arrive in time or could cause traffic congestion when they arrive too early. In practice, as the coordination between the different types of equipment at the operational level is complex, so optimizing this dispatching problem becomes very challenging.

Based on the previous researches, integrated scheduling of handling equipment improves the performance of handling equipment and automated container terminals (Meersmans and Wagelmans, 2001a, b; Chen et al., 2006; Chen et al., 2007; Lau and Zhao, 2008a, b; Liang et al., 2009b).
In other words, integration has been introduced by researchers to decrease the labor costs and to make sure that port terminals utilize the whole capacity of the equipment.

Since each of the equipment within the integrated scheduling method plays a different role in the terminal, it is needed to consider various objectives for this process (Meersmans and Wagelmans, 2001a, b; Lau and Zhao, 2008a, b). As an example, for the quay cranes, it is essential to decrease delays within their tasks. However, for the vehicles, it is important to decrease their total travel time. Therefore, integration of AQCs, automated vehicle and AYC can help us to reach a proper objective for optimization.

1.3 Problem Statement

The main function of the terminals is delivering the containers to consignees and receiving containers from shippers, loading containers onto and unloading containers from vessels, vehicles and storing containers temporarily. The productivity of container terminals is usually measured in terms of the time required to load and unload containers by cranes, which are the most crucial and expensive equipment utilized in ports. The efficiency of a container terminal can also be measured by the degree of utilization of equipment, yard space, and cost of the operations.

Most terminals are now taking measures to boost their throughput and capacity by introducing new technologies, reducing equipment dwell times through increasing demurrage fees and/or limiting the advance delivery of export cargo, and increasing storage density by stacking containers 4 or 5 levels. The performance of the ACTs could be improved by integrating in scheduling of handling equipments, but previous research considered some assumptions, which significantly affect the applicability of these proposed methods in practical deployment; as an example, scheduling just one type of tasks, either loading or unloading operation (e.g. Meersmans and Wagelmans, 2001b; Chen et al., 2006; Liang et al., 2009b). On the other hand, there are some newly introduced vehicles that's not been included in the scheduling methods proposed in past literature, such as automated lifting vehicles (ALVs). To the best knowledge of the author, there's no integrated scheduling method for the automated lifting vehicle, in automated container terminals with unlimited buffer capacity, covering all three handling equipment such as QCs, ALVs and AYCs.

Since each of the equipment contained in the integrated scheduling method plays a different role in the automated terminal, one needs to consider various objectives for this method (Meersmans and Wagelmans, 2001a, b; Lau and Zhao, 2008a, b). Therefore, the initial problem of this research is how integrated scheduling of handling equipment (i.e. AQCs, ALVs, and AYCs) would enhance the performance of ACTs (in terms of minimizing “delays in AQCs completion time”, in addition to “travel time of ALVs, and AYCs operations”).

The integrated scheduling of handling equipment is a “non-deterministic polynomial-time hard” (NP-hard) problem (based on Meersmans and Wagelmans, 2001b; Steenken et al., 2004; Lau and Zhao, 2008a), i.e., and there's no systematic method to obtain the optimal solution of this problem, specifically for relatively large instances. The computation time and ease of application are very important for real practices of the scheduling methods. Therefore, the next problem is how to optimize the NP-hard integrated scheduling of handling equipment in a reasonable low computation time.

1.4 Objectives of the Research

The main objective of this research is to develop an integrated scheduling model, considering the constraints of handling equipment (i.e. automated quay cranes, automated lifting vehicles, and automated yard cranes) in automated container terminals with unlimited buffer capacity. The following specific objectives are pursued throughout the research:

(1) To develop a multi-objective mixed integer-programming model to optimize the integrated scheduling of handling equipment (i.e. QCs, ALVs, and AYCs) in automated container terminals with unlimited buffer capacity.

(2) To develop an improved meta-heuristic algorithm, based on genetic algorithm, for finding the near optimal solutions for the integrated scheduling of handling equipment in ACTs.

(3) To validate the developed multi-objective mixed integer-programming model.

(4) To evaluate the impacts of the various scheduling parameters on the performance of the proposed multi-objective optimization model for the integrated scheduling of handling equipment in ACTs.

1.5 Scope and Limitations of the Research

As described in section 1.2, various decision levels are involved in the operations of the container terminals. However, this research focuses on operations of material handling equipment in quay side and storage yard of the seaport container terminals. Therefore, vessel routing problems, liner operator's problem of distributing or reusing empty containers are excluded from the research. This research focuses on the integrated scheduling of handling equipment only (namely QCs, ALVs, and AYCs) in automated container terminals with unlimited buffer capacity. Thus, the upper and lower layers of the scheduling, such as overall sequence of tasks for the QCs in planning horizon, or the planning for receiving or dispatching of containers to the final clients are assumed to be predetermined or beyond the objectives of the research.

All of the analysis and discussions performed in this research are on the basis of the computational results of the proposed test cases. The raw data for designing the proposed test cases were collected from the literature from real container terminals.

1.5 Organization of the Thesis

This thesis consists of five chapters. Chapter one provides a brief introduction to the container terminals, their operations, and problems. Moreover, the integrated scheduling as the principal concern of this research been described in this chapter. Also objectives, scope, and limitations of this research are mentioned in the first chapter. The rest of the thesis is organized as follows:

Chapter 2 reviews related literature on the container terminals, handling equipment, and integrated terminal study.

In Chapter 3, the methodology of the research to optimize the integrated scheduling of handling equipment in the automated container terminals is presented.

Chapter 4 reports the results and analysis of test cases for the proposed methodology.

Finally, Chapter 5 contains the notes and concluding remarks and comments for future studies.

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