AN OPTIMAL STRATEGY FOR YARD TRUCKS MANAGEMENT IN HONG KONG CONTAINER TERMINALS

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ABSTRACT

Since the premium prices of yard trucks and significantly daily volatility of containers serving demand, it is an uneconomic method to keep a full team of fleet to cover the entire service. Some of the transportation services are outsourced to other external companies. The strategy of outsourcing yard trucks is a decision making problem that container terminals are currently facing. Yard truck scheduling and storage allocation are two major operations that related to yard trucks management problem. In this paper, the studied yard trucks management problem is focused on integration of the yard truck scheduling and the storage allocation problems. The objective is to minimize the total operation cost of in-house trucks, out-sourced trucks, and delay of requests. As the proposed problem is an NP-hard problem, a hybrid heuristic approach with genetic algorithm and linear programming is proposed to solve the problem. The effectiveness of the proposed method is analyzed from using practical data obtained from Hong Kong terminals.

Keywords: Logistics; Transportation; Assignment; Genetic Algorithm

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INTRODUCTION

Containers are standard-sized metal box, which are used for transporting cargos by kinds of transportation, such as vessels, trains and trucks. Since the first regular sea container served about six decades ago, cargos are increasingly containerized. Nowadays, the throughput of containers in the worldwide is more than 500 million twenty-foot-equivalent units (TEUs) a year. The considerable number of containers needs a large number of seaport container terminals to handle it. As a result, competition among container terminals will emerge and container terminals have to promote competitiveness to attract customers and earn more money. Companies managing container terminals put much effort on cutting down the cost in order to be competitive. A crucial competitive advantage is the rapid turnover of the containers, which corresponds to a reduction of the time in port of the containers ships, and of the costs of the transshipment process itself (Steenken et al. 2004).

Hong Kong Port is one of the busiest hub ports in the world. Fig. 1 shows that, the container throughput of Hong Kong Port is continuously increasing these years except the years of the financial crisis happened after 2008. With the development of container throughput, Hong Kong container terminal companies are dealing with more and more containers which are needed to be transported on time and at low cost. Since the daily throughput of containers in Hong Kong fluctuates significantly and yard truck is quite an expensive equipment, it is economical not viable to keep a full team of fleet to cover the entire service. Indeed it is a common practice for Hong Kong container terminals to outsource some of the transportation service to other external companies. Hence, the decision of how many trucks should be maintained in-house and how many should be out-sourced become a problem that will influence the operations expenses of the terminal. However, the strategy of determining the number of the two different kinds of trucks used in container terminal is related to the operations in container terminals. In general, operations in container terminals include berth allocation, quay crane scheduling, yard truck scheduling, yard crane scheduling and storage allocation (Lee et al. 2009). Yard truck scheduling and storage allocation (YTS-SAP) are two major factors that determine the trucks routing and the amount of trucks and also relate to the strategy of employing trucks. A container terminal usually can serve a customer more quickly as more yard trucks are used, but too many trucks will cause congestion and a waste of money of using the trucks. However, not sufficient trucks will result in a delay of transporting a container and low efficiency of quay cranes which is the bottleneck of a container terminal.
In this study, the strategy of employing yard trucks is integrated with the YTS-SAP with the objective to minimize the total delay of container and the cost of employing different types of trucks. To deal with the real-world problem of determining the strategy of managing yard trucks to minimize the cost, a two steps method is proposed. The first step is to calculate the amount of trucks that should be used in every single day. A genetic algorithm (GA) is proposed to solve it, and the second step is to calculate the number of bought trucks and rent trucks. This step is formulated as a Mixed Integer Programming (MIP) model and Ilog Cplex is used for solution. This paper is organized by this introductory section and following sections: Section gives the literature review. Section 3 provides a mathematical model and problem description. Section 4 presents the proposed methodology. Section 5 presents the computational experiments results and section 6 concludes the paper.

**LITERATURE REVIEW**

Some researchers have studied the problem of minimization vehicle fleet size under different circumstances. Dell'Amico et al. (1993) studied the problem in which vehicles must serve a set of different depots within a given set of time windows. The objective is to minimize the number of vehicles and the total operational cost. A new polynomial-time heuristic method is proposed to deal with the problem. Rajotia et al. (1998) considered the problem of determining the number of vehicles to perform a set of tasks in a flexible manufacturing system. Loading time of vehicles, empty travel time, waiting time and congestion time are considered in the model with the objective of minimizing empty travel of vehicles. Vis et al. (2001) considered the problem of determination of the number of trucks required in a container terminal. The problem
was solved by using a polynomial minimum flow algorithm. Vis et al. (2005) discussed the problem in a container terminal buffer area that a container was needed to be transported within a certain time window with the objective to minimize the vehicle fleet size. The problem was formulated as an integer linear programming.

Other researchers have studied the yard truck scheduling and storage allocation operations in container terminals. Bish et al. (2001) are the first who considered the YTS-SAP as integration. Each import container can be stored in a series of potential storage locations in the yard side, and a fixed number of trucks were employed to transport the containers with the objective to minimize handling time of the containers. But the two problems were solved separately. The storage location for an import container was firstly determined by ignoring the scheduling of trucks. Then based on the storage location for each container, a truck would take a set of containers sequentially. The problem was solved using a heuristic algorithm. Bish (2003) further extended his previous study. The integration of allocating a storage location for each import container, scheduling yard trucks to handle containers, and determining the container sequence on each quay crane was studied. The objective was to minimize the maximum turnaround time of a set of vessels. Bish et al. (2005) continued his study and proposed an easily implementable heuristic algorithm for solving the problem studied in 2003. Han et al. (2008) studied the storage management problem in a container terminal. Sub-blocks reserved for each vessel was determined and the minimum of yard cranes to handle all containers was calculated. The problem was modeled as a mixed integer programming and an iterative improvement method was proposed to deal with the problem. Lee et al. (2008) first solved the yard truck scheduling and storage allocation problem as integration. A genetic algorithm and a greedy heuristic algorithm were proposed to solve the problem with the objective to minimize the makespan of unloading containers by reducing congestion and waiting time of yard trucks. Later on, Lee et al. (2009) further extended the previous study in 2008 and a new mixed integer programming model was proposed to describe YTS-SAP. The problem was solved by a proposed hybrid insertion algorithm.

**PROBLEM DESCRIPTION AND FORMULATION**

The optimal number of the two different kinds of trucks required in a container terminal to cover all the containers with no delay will be calculated in two steps. The first step is to calculate the number of trucks required in each day and the second step is to determine the optimal strategy of employing the two types of truck.

**Determination of Number of Trucks to Cover Jobs with No Delay**

A container terminal transports a number of containers every day. We define a container as a job, denoted by $i$ and $j$. There are two different types of jobs in a
container terminal: the loading job and the unloading job. A loading job is a job which needed to be loaded from the yard side to the vessel. An unloading job is to unload the job from the vessel to the yard side. The origin of a loading job, which is predetermined by the terminal operator, is the place where it is stored in the yard. The destination of a loading job is the vessel which is about to carry the container and leaves the port. Moreover, the origin of an unloading job is the vessel which transports the container to the port. The destination of an unloading job is a potential space where the container will be stored in the yard side. Usually, the number of jobs on each day is different. So, on day \( r \), let \( N_r \) be the set of jobs, \( N_r^+ \) be the set of loading jobs, \( N_r^- \) be the set of unloading jobs, with the cardinalities of \( n_r, n_r^+, n_r^- \), respectively and \( R \) be the set of day \( r \). Additionally, the set of storage locations which can potentially store an unloading container is defined as \( M_r \) with the cardinality of \( m_r \) and the total number of yard trucks employed on day \( r \) is \( T_r \).

The container terminal operator will generate a soft-time window \( [a_i, b_i] \) for each job based on the loading and unloading information before a vessel berthed on the yard. A soft-time window is a period of time which consists the earliest possible time \( a_i \) and the due time \( b_i \). A job can only be served after the earliest possible time \( a_i \), and job severed beyond \( b_i \) can be viewed as penalty. Let job \( i \) start to be serviced at starting time \( c_i \) and \( i \) is completed at completion time \( f_i \). The delay of job \( i \) is \( d_i = \max \{0, f_i - b_i\} \).

In the quay side, containers are delivered by quay cranes while containers are transported by yard cranes in the yard side. It is assumed that the processing time \( w \) of quay cranes and yard cranes to process a job is identical with a known constant. Each job should be transported by both quay cranes and yard cranes, thus a yard truck is needed to wait for two processing time \( 2w \) when the truck is doing a job. The time lapsed to process job \( i \) from origin to destination is defined as processing time \( p_i \) of job \( i \). We also define the travel time of empty trip between two successive jobs \( i \) and \( j \) as setup time \( q_{ij} \) of the two jobs.

The following decision variables are used to describe the problem studied in this paper:

Decision variables

\[
\begin{align*}
x_{imr} & = 1, \text{ if container } i \text{ is allocated to storage location } m_r, \\
& = 0, \text{ otherwise.} \\
y_{ij} & = 1, \text{ if request } i \text{ is connected to request } j \text{ in the same route.} \\
& = 0, \text{ otherwise.}
\end{align*}
\]

In this step the problem is to determine how many trucks should be employed in each day to cover all the jobs with no delay. The problem formulation is shown as follows:
Objective function:

Minimize: \[ \Delta = \sum_{i \in N_r} d_i \] (1)

Subject to:

\[ \sum_{m \in M_r} x_{im} \leq 1 \quad \forall \ m_r \in M_r \] (2)

\[ \sum_{m \in M_r} x_{im} = 1 \quad \forall \ i \in N_r \] (3)

\[ \sum_{j \in N_r} y_{ij} = 1 \quad \forall \ i \in N_r \] (4)

\[ \sum_{j \in N_r} y_{ij} = 1 \quad \forall \ j \in N_r \] (5)

\[ \sum_{j \in N_r} y_{ij} = T_r \quad \forall \ i = I_s \] (6)

\[ \sum_{j \in N_r} y_{ij} = T_r \quad \forall \ j = I_f \] (7)

\[ c_i \geq a_i \quad \forall \ i \in N_r \] (8)

\[ d_i \geq c_i + w + p_i + w - b_i \quad \forall \ i \in N_r \] (9)

\[ c_j + K(1 - y_{ij}) \geq c_i + w + p_i + w + q_{ij} \quad \forall \ i \in N_r \] (10)

\[ r \in R \] (11)

Constraint (2) make sure that one storage location can store one container at most. Constraint (3) mean that each container can only be assigned to one storage location. Constraints (4) and (5) form a feasible sequence of two jobs in one route. Constraints (6) and (7) calculate the number of trucks in each day. Constraint (8) ensure that a job can only be served after the earliest possible time. Constraint (9) calculate the delay of each job. Constraint (10) give the relationship between the completion time of a job and the starting time of its successor. Constraint (11) are domain constraints for \( r \).

**Determination of Number of Two Different Types of Trucks**

To transport containers, in-house maintained and out-sourced yard trucks are used in a container terminal every day in Hong Kong. The number of in-house maintained yard trucks \( H \) is a decision variable. The \( H \) yard trucks are always available to transport containers once they are served in the terminal. The number of in-house maintained yard trucks used on day \( r \), \( H_r \), is also a decision variable. In addition, the number of out-sourced yard trucks employed on day \( r \) is defined as \( S_r \). Then, the total number of yard trucks employed on day \( r \) should be \( T_r = H_r + S_r \).

The following notations are used in this paper:

**Problem data**

\( \alpha_1 \) The cost of buying a yard truck
\[ \alpha_2 \] The cost of using an in-house maintained yard truck per day

\[ \alpha_3 \] The cost of using an out-sourced yard truck per day

Based on the calculation of the first step, we can obtain the number of trucks in each day. Therefore, we focus on the problem of determination the strategy of employing the number of different types of trucks in this step. The problem formulation is shown as follows:

Objective function:

\[ \text{Minimize: } \prod = \alpha_1 H + \alpha_2 \sum_{r \in R} H_r + \alpha_3 \sum_{r \in R} S_r \]  

(12)

Subject to:

\[ T_r = H_r + S_r \quad \forall \ r \in R \]  

(13)

\[ H_r \leq T_r \quad \forall \ r \in R \]  

(14)

\[ S_r \leq T_r \quad \forall \ r \in R \]  

(15)

Constraint (13) make sure that the total number of two types of trucks equal to the result obtained in step one. Constraints (14) and (15) are domain constraints of decision variables.

**METHODOLOGY**

Since the problem considered in this paper is so complex. The problem is solved in two steps. The genetic algorithm (GA) is used for calculation of the minimum number of trucks to cover all the jobs. Holland (1975) developed the genetic algorithm in 1975. GA is one of the nature-inspired meta-heuristic optimization methods. It has been widely used in kinds of fields. A chromosome of GA represents a solution. A fixed number of chromosomes called population. Crossover and mutation operations are adopted on each chromosome in the population to generate offspring. By mimicking Darwinian evolution theory, the chromosome with bad fitness will be abandoned. Then, the population evolves through iterations.

**Representation**

Two different genes are adopted to compose a chromosome. A job gene which is a positive integer number represents a job which contains the information of container ID, time window, origin and destination of the job. A truck gene which is a negative integer number represents a yard truck which contains the information of truck ID. The jobs between two truck genes are served by the same truck. A truck will serve the jobs according to the sequence of job genes. Fig. 2 shows an example of a representation of a chromosome. The decoding of the chromosome is illustrated in Fig. 3.
To get the genetic algorithm started, we generate the first generation for the genetic algorithm. The first generation of the genetic algorithm is generated by two steps. The truck gene is firstly assigned to a chromosome randomly. Then all the job genes are generated randomly.

**Mating Pool and Selection**

The roulette wheel selection method is a common selection mechanism and it is adopted in this paper. Each slice represents a chromosome in roulette and the proportion of the slice is assigned based on the fitness value of the chromosome. Mating pool is generated by using the roulette wheel selection method.

**Fitness Value**

Since the objective of scheduling yard trucks in each day is to minimize the total delay of all jobs. Then the reciprocal of objective function can be the fitness value of a chromosome. Fitness value can be calculated by using the following function:

\[
\text{Fitness} = \frac{1}{\Delta}
\]  

(16)

**Crossover and Mutation**

The crossover operation is based on the instance-specified information so as to make the genetic algorithm searching process more effective. In this study, the crossover operation is ranking the job genes according to the earliest possible time and due time.

Mutation operation helps the genetic to prevent premature convergence and obtain the global optimal solution. In the proposed genetic algorithm, the mutation
operation is a combination of three methods which are randomly change the storage location, randomly swap two jobs and randomly take a job from one truck and insert the job into another truck.

**Algorithm for the Number of Trucks Determination**

An iteration method is applied for calculation of the number of trucks to cover all the jobs with minimum delay. Assuming the number of trucks is fixed at first, and use the genetic algorithm to calculate the delay of jobs. Then, add one more truck and calculate the delay again. If the delay becomes shorter, continue to add one more truck and do the re-calculation until no changes on the delay, otherwise, minus one truck, and calculate the delay until the delay become longer.

**COMPUTATIONAL EXPERIMENTS**

In this section, computational experiments are proposed to analyze the performance of the proposed algorithm. In the computational experiments, the container throughput of Hong Kong is obtained from the website of Hong Kong government and we use the data in the year of 2012. The number of storage locations is always larger than the number of unloading jobs. The storage locations are generated through a two-dimensional square from (0, 0) to (1500, 1500) (unit: meter). Both loading process and unloading process cost 2 minutes and the truck speed is 3 m/s (11km/h). Moreover, we assume a truck work 20 hours a day and the rest of time for maintenance or fuel filling. Then, the beginning of a time window is generated from (0, 72000) (unit: second) uniformly and the due time is generated from (1000, 1500).

The computer programs of GA are coded by using Java Language and executed on a PC with Intel Core i7 3.4 GHz and 8 GB RAM. The commercial software Ilog Cplex is used for calculation of the liner programming with the same computer. We first calculate the minimum number of trucks needed in every day as shown in Fig 4.

After the number of trucks in each day is obtained, the optimal strategy of employing yard trucks can be calculated. The cost of buying and renting trucks is defined as: $\alpha_1$ equal to 150000 USD, $\alpha_2$ equal to 50 USD and $\alpha_3$ is 500 USD. In addition, another three strategies of employing trucks are proposed for comparison. In the second strategy, the number of indoor maintained trucks equal to the annual average number of trucks. For the third strategy, all the trucks are out-scored. Enough trucks are brought to cover all the jobs in the fourth strategy. Fig. 5 shows that the cost of the four strategies of employing trucks.
CONCLUSIONS

This paper studied the integration problem of strategy of employing yard trucks, yard truck scheduling and storage allocation in container terminals. The problem is modeled as a mixed integer programming. Since the complexity of the problem, we solve the problem in two steps. The first step is to calculate the number of trucks needed in each day with no delay. The second step is the determination of the strategy of employing yard trucks, for example in-door maintained of out-sourced. A proposed
genetic algorithm is used for the calculation in the first step. The second step is modeled as a linear programming and Ilog Cplex is used for solution. The computational experiments show that the proposed method minimizes the delay of jobs and cost of employing different types of yard trucks.

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