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Swarm intelligence algorithms for Yard Truck Scheduling and Storage Allocation Problems

Ben Niu [a,b,*], Ting Xie [a], Lijing Tan [c,**], Ying Bi [a], Zhengxu Wang [b]

[a] College of Management, Shenzhen University, Shenzhen 518060, China
[b] Faculty of Engineering, The Hong Kong Polytechnic University, Hong Kong
[c] Department of Business Management, Shenzhen Institute of Information Technology, Shenzhen 518172, China

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ABSTRACT

In this paper we focus on two scheduling problems in container terminal: (i) the Yard Truck Scheduling Problem (YTSP) which assigns a fleet of trucks to transport containers between the QCs and the storage yard to minimize the makespan, (ii) the integrated Yard Truck Scheduling Problem and Storage Allocation Problem (YTS–SAP) which extends the first problem to consider storage allocation strategy for discharging containers. Its object is to minimize the total delay for all jobs. The second model is improved to consider the truck ready time. Due to the computational intractability, two recently developed solution methods, based on swarm intelligence technique, are developed for problem solution, namely, particle swarm optimization (PSO) and bacterial colony optimization (BCO). As these two algorithms are originally designed for continuous optimization problems, we proposed a particular mapping method to implement them for YTSP and YTS–SAP, both of which are discrete optimization problems. Through comparing the PSO algorithms and BCO algorithm with GA by an experiment conducted on different scale instances, we can draw a conclusion that LPSO perform best in YTSP while BCO perform best in YTS–SAP.

1. Introduction

The trend towards globalization of trade, together with the subsequent breakdown of trade barriers, has dramatically stimulated the growth of marine transportation. In the 1960s, the container, a relatively uniform boxes, as a universal carrier for various goods, was introduced, and has achieved undoubted importance in international sea freight transportation [28]. Since the container has many advantages, such as easy and fast handling in discharging and loading process, the overwhelming majority of general cargo has been containerized [15], resulting in dramatically change in the seaport terminals.

As an intermodal interfaces in the global transportation network, container terminals have been increasingly important and this trend is expected to continue. In addition to providing the container vessels with loading and unloading service, container terminals are responsible for serving as a temporary storage space for containers [32]. In order to meet the demand of continuously increasing container trade and compete with other terminals, many terminals are now working at or close to capacity. Therefore, to meet the challenges in the future, container terminals are forced to study the optimal operation in marine transportation [7].

Operations in the field of container terminal involving Berth Allocation, Quay Crane (QC) Scheduling, Yard Crane (YC) Scheduling, Yard Truck (YT) Scheduling, Container Storage Allocation, etc. [5]. The YT connects the two ends, i.e., the QC and YC, therefore the YT scheduling is an important component of container terminal operations that needs to be addressed. Hence, we firstly study the Yard Truck Scheduling Problem (YTSP) of assigning a fleet of trucks to transport containers between the QCs and the storage yard under the situation where the locations of loading and discharging containers are predetermined. In addition, for discharging operation, the efficiency depends greatly on the strategies of allocating storage space to discharging containers. Hence, we further extend the study to the area of the integrated Yard Truck Scheduling and Storage Allocation Problem (YTS–SAP) for the more general situation.

Since many operations and supply chain management problems such as scheduling, organization of production and vehicle routing problems cannot be solved in optimality within reasonable time, many researchers turned to use nature inspired intelligent technique driven by concepts from biology or nature to find near optimal solutions for them. Among these diverse natural inspired

* Corresponding author at: College of Management, Shenzhen University, Shenzhen 518060, China.
** Corresponding author.
E-mail addresses: drniuben@gmail.com (B. Niu), mstlj@163.com (L. Tan).

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intelligent technique, particle swarm optimization (PSO), which motivated by the behavior of fish and bird [13], and bacterial colony optimization (BCO), which simulates some typical behaviors of E. coli bacteria [23], are very promising members. Like many management problems mentioned above, the YTSP and YTS–SAP we try to address in this paper are also proved to be NP-hard [16,21]. Therefore, two swarm intelligence-based approaches with effective and simple problem mapping mechanism are developed to tackle these NP-hard problems.

The remainder of this paper is organized as follows. The literature review is given in Section 2, Section 3 formulates two mathematical models: YTSP and YTS–SAP. PSO (global and local version) and BCO with two mainly mapping mechanisms are proposed in Section 4 to solve the scheduling problems. Computational experiments compared with genetic algorithm (GA) are reported in Section 5. Finally, conclusions and future work are summarized in Section 6.

2. Literature review

Over the past few decades, there emerges an increasing trend to investigate the scheduling of different types of operations at a container terminal. For the YTSP, a straddle carrier routing problem was studied by Kim and Kim [15]. They proposed an integer programming model aiming at minimizing the total travel distance of the straddle carrier, and a beam search algorithm was proposed to solve the established model. Nishimura et al. [24] used a heuristic approach to tackle the dynamic routing problem at a maritime container terminal. Ng et al. [21] solved the problem of scheduling trucks in container terminal with different ready times and sequence-dependent processing times by formulating a mixed integer program and subsequently solving it via a genetic algorithm. Nguyen and Kim [22] formulated a mixed-integer programming model for dispatching automated lifting vehicles with both precedence and buffer constraints and solved with a heuristic algorithm. In the work by Loo Hay et al [19], the capacity of the quay side and yard side was considered when studying the vehicle dispatching problem, with the aim to minimize the makespan at the quay side by applying the neighborhood search and GA. In a similar study, Skinner et al. [27] developed a genetic algorithm-based optimization approach to study the scheduling for container transfers. He et al. [8] investigated a strategy of sharing internal trucks among multiple container terminals (SIMT) for the container terminals with adjacent locations, in which a simulation optimization method integrated with GA is introduced to obtain the near optimal solutions. Tang et al. [18] develop a mixed integer programming model for the joint quay crane and truck scheduling problem with only inbound containers. The model was then extended to consider outbound containers. A PSO algorithm with new velocity strategy and disturbance method is used to solve the model.

The YTSP has been studied extensively, but few works address the YTS–SAP. Bish et al. [2] firstly considered the two problems as a whole by formulating an assignment model and subsequently solving it via a heuristic algorithm. Bish [3] extended the problem to a more complex situation, which not only consider the yard location assignment and the vehicle dispatching, but also include the scheduling of loading and discharging operations at QC. Bish et al. [4] further solved the problem via new heuristic algorithms which the asymptotic and absolute worst-case performance ratios were identified. To address the traffic congestion in a transshipment hub with heavy loading and unloading activities, Han et al. [7] proposed a mixed integer programming model aimed at balancing the workload of each yard block. This model was then solved by dedicated heuristic algorithms. Lee et al. [16] developed a mixed integer programming model considered the Yard Truck Scheduling and the Storage Allocation at the same time to minimize the weighted average of total requests delay and total trucks travel time. A hybrid insertion algorithm was proposed to solve the model. Xue et al. [31] studied the integration of YT scheduling, the QC scheduling and the yard location assignment for the discharging containers. A two-stage heuristic algorithm was developed for solving it. Similarly determining the storage location to containers is developed by Sharif and Huynh [26] in a recent study. The route for each container is determined in the model. An ant-based control method is used to solve the model.

Throughout above literatures, the linear programming approach and heuristic algorithm such as GA are always used as the solver. Regarding such NP-hard problem, although exact methods can obtain optimal solutions, most of them are only suitable for small sized problems. Heuristics are the major trend in solving NP-hard problems, in which swarm intelligence is one of the promising one. This paper shows how to solve efficiently YTSP and YTS–SAP using two swarm intelligence algorithms. Regarding the discrete characteristic of YTSP and YTS–SAP, an effective PSO and BCO algorithm are presented. PSO has been successfully applied to many fields of continuous and combinational optimization problems [30]. BCO performances very well on almost all the benchmarks problems [23]. Therefore, it is worthwhile to evaluate the PSO and BCO for this task. The innovation of the work of this paper can be listed as follows: We modify the YTS–SAP model to consider the truck ready time. The second is to firstly apply PSO and BCO to both YTSP and YTS–SAP. The third, a novel scheduling solution representation is designed.

3. Problem description

3.1. YTSP

The YTSP model used in this paper is the same as that used in literature [21] and the notations and mathematical model are given as follows.

There are N containers to be processed by M $(N>M)$ identical yard trucks which has one-container carrying capacity in the current planning period. To simplify notation, we define job to be the movement of a container between its pick-up location and drop-off location. For each route, we add a dummy job L_m to denote the initial location of truck m, and let time r_m be the available time for processing its first job at location L_m. We denote by P_i and D_i the pick-up location and drop-off location of job $i\,(i=1,2,\ldots,N)$, respectively. The pick-up/drop-off location of each job is unique and identified by its (x,y) coordinates. Information about the pick-up/drop-off location of all containers is known in advance. We also denotes the travel time of truck along the shortest route between location l' and location l'' by $t_{l'l}$,$l'=L_1, L_2,\ldots,L_M,P_1,P_2,\ldots,P_N,D_1,D_2,\ldots,D_N$, $l''=P_1,P_2,\ldots,P_N,D_1,D_2,\ldots,D_N$. Let duration time T_i represents the time from a truck dispatched for job i arrives at P_i to the time that it begins to leave D_i. Let us assume that T_i is known in advance. Similarly, let processing time of job $i$denotes the time that from a truck starts moving from its current location to P_i to the time that the truck starts leaving D_i. The processing time of job $i$consists of two parts: the travel time of an empty truck from the destination of last job to the origin of the succeeding job, and the duration of job i. Thus the processing time of all jobs is sequentially dependent. Finally, let a_i be the starting time of job i, that is, job i should be processed at or after a_i.

The following are additional notations used in model desc ription:

X_{ijm} $=1$, if truck m $(m=1,2,\ldots,M)$ handles job i $(i=1,2,\ldots,N)$ before job j $(j=1,2,\ldots,N+1)$, where job $N+1$ is a dummy job.
$=0$, otherwise.