

Dynamic yard crane dispatching in container terminals with predicted vehicle arrival information

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ABSTRACT

The performance of a container terminal depends on many aspects of operations. This paper focuses on the optimal sequencing of a yard crane (or YC for short) for serving a fleet of vehicles for delivery and pickup jobs. The objective is to minimize the average vehicle waiting time. While heuristic algorithms could not guarantee an optimal solution, a conventional mathematical formulation such as mixed integer program would require too much computing time. We present two new algorithms to efficiently compute YC dispatching sequences that are provably optimal within the planning window. The first algorithm is based on the well-known A* search along with an *admissible* heuristics. We also incorporate this heuristics into a second backtracking algorithm which uses a prioritized search order to accelerate the computation. Experimental results show that both new algorithms perform very well for realistic YC jobs. Specifically, both are able to find within seconds optimal solutions for heavy workload scenarios with over 2.4×10^{18} possible dispatching sequences. Moreover, even when the vehicle arrival times are not accurately forecasted, the new algorithms are still robust enough to produce optimal or near-optimal sequences, and they consistently outperform all the other algorithms evaluated.

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1. Introduction

Containerization has revolutionized cargo shipping and resulted in increased global cargo flow. Container terminals serve as crucial hubs in the transportation chain of trade flows. In providing efficient services, minimizing vessel turnaround time is a common and key performance goal of terminal operations. The vessel turnaround time is calculated by vessel unberthing time minus vessel berthing time. When a vessel berths at a terminal, a number of quay cranes (QCs) are allocated to serve the vessel. QCs first unload containers from the vessel onto in-terminal vehicles for transferring them to the container storage yard. A vehicle would arrive at a specific job location at a yard block and be served by a yard crane (YC) to pick up the container and to temporarily store it in the yard block. The operation of loading containers onto a vessel is carried out in the reverse order. Previous studies on YC dispatching/scheduling have pointed out that YC operations are of great importance and likely to be a potential bottleneck to the overall terminal performance [1].

One common way to organize the yard operations is to partition a container storage yard into a number of zones for each planning

window. Each zone is handled by one or two YCs according to the predicted number of loading and unloading operations in the next planning window, e.g. 1 or 2 h. In most cases, the partition is done in units of yard blocks. Because YC gantry to a different row may take around half an hour or more, yard blocks in different rows usually will not be grouped into the same zone. Fig. 1 shows a possible partition of a storage yard in a typical container terminal where a zone may not be whole blocks.

In a yard block, containers are arranged in a number of rows and slots as shown in Fig. 2. A number of adjacent rows across a few slot locations form a cluster. Vehicles travel along lanes for container jobs. When a vessel is unloading, vehicles carry containers to different yard clusters. When multiple vessels are loading and unloading at the same time, vehicles will arrive at different slot locations. Local trucks carrying export containers may also arrive at any time to unload at certain designated slot locations. As a result, YCs need to move between different slot locations in their assigned zones to serve vehicle jobs. When an YC is busy serving other vehicle(s), a vehicle needs to wait for it. A vehicle may also need to wait for the YC to move to its job location.

The overall objective of terminal operations is to reduce vessel turnaround time [8]. While trying to minimize vessel turnaround time, the terminal also gets the benefits of improved berth utilization and higher productivity. This also means lower manpower costs. Therefore at the yard side, YCs need to service in coming

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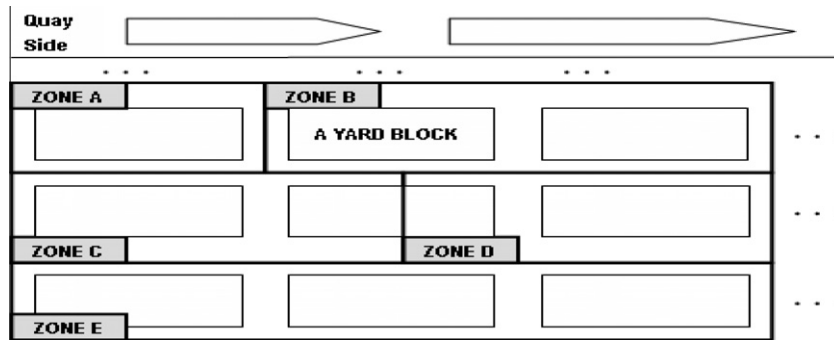


Fig. 1. Storage yard partitioned into zones.

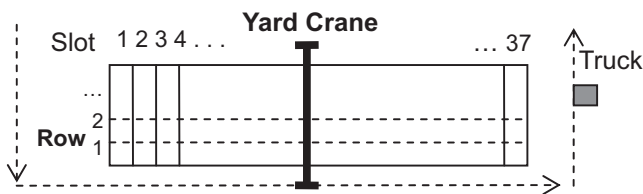


Fig. 2. A yard block with slots and rows.

vehicle jobs as fast as possible to minimize vehicle delays. This helps in supporting unblocked vehicle flows to the quay side to achieve overall objective of the terminal.

YC management involves two types of problems: YC deployment and YC dispatching. YC deployment is the problem of deploying YCs to various parts of the yard to serve in a zone for a planning period. YC dispatching is the problem of dispatching YCs to serve various vehicle jobs in its assigned zone within a planning period. The main focus of this paper is the YC dispatching problem. The YC dispatching algorithm proposed is part of the hierarchical YC management scheme for container terminals that we are working on. To help understand the context, the hierarchical YC management scheme is described in Section 3.

The YC dispatching problem is sometimes referred to as the YC routing problem in literature because YCs are routed among the various job locations. It is a complicated problem because: (1) both the job arrival times and the job locations affect the dispatching sequence. For example, a job arriving later but nearer to the current YC location could possibly be a better choice as the next job than a job arriving earlier but at a location further away. It also implies that the choice of the next job is affected by the YC's location and finishing time of the current job. Therefore the problem is sequence-dependent and could not be easily broken into simpler subproblems. This makes techniques like dynamic programming not quite applicable. (2) An idle YC can move to the chosen next job location before the actual job arrival to shorten vehicle waiting time. This is possible if the next several job arrivals can be predicted. So the time spent on YC gantry may or may not contribute to vehicle waiting times.

The main difficulty of the YC dispatching problem is possibly its computation complexity. The problem of single YC dispatching is NP-hard [3], which means the time it takes to find the optimal dispatching solution is likely to increase exponentially with the problem size. An YC with 10 job requests would have over 3.6 million possible dispatching solutions. Even when the planning window is small, it could still be too time consuming to find the optimal solution. The difficulty is aggravated as multiple YCs need to be dispatched in the yard. And in real world applications, operations are carried out continuously over time so computation for a solution has to meet the real time constraint. Conventional approaches include Mixed Integer Programming (MIP) and heuristic methods.

MIPs (e.g. [4]) are computationally intensive and only suitable for small-size problems while heuristic methods reduce computation time but sacrifice solution optimality (e.g. [5,12]).

In handling the YC dispatching problem, we propose two optimal algorithms for an YC to handle the jobs in its assigned zone within a planning window efficiently. The algorithms take the predicted job arrival times as input. The two algorithms find the best dispatching sequence with reasonable computational time in solving problems of practical sizes. This is achieved by using domain-specific knowledge beyond the definition of the searching problem itself. The first algorithm is a modified A* search algorithm. Experiments show that this algorithm could find the optimum out of 2.4×10^{18} possible dispatching sequences in about 2–4 s. We further hybrid the domain-specific knowledge with a Recursive Backtracking algorithm (RBA*) to improve the memory usage limitation. The RBA* algorithm is an anytime algorithm.

One concern of YC dispatching based on the predicted vehicle arrivals is the dynamics of these arrivals which make accurate predictions difficult. The advanced traffic information systems (ATIS) that can provide road-users and traffic managers with accurate and reliable real-time traffic information have been widely studied in recent years. A surge of research into reliable and accurate traffic and travel time prediction models have been developed in the past decades [2]. With real-time tracking of terminal assets, vehicle job arrivals in near future could be predicted. Predicting vehicles' arrival times in container terminals is relatively simpler than other problems because vehicle tracks in terminals are simpler than road networks in cities and vehicle speeds in terminals are more uniform than those in public roads. However it is possible that sometimes actual vehicle job arrival times deviate from the predictions. We evaluate the performance of the proposed algorithms under noisy conditions and show that our algorithms are robust enough to outperform the other heuristics.

The rest of the paper is structured as follows. In Section 2 we review the related works. Problems in YC management are discussed and a hierarchical YC management scheme is described in Section 3. A formal description of the YC dispatching problem is given and the problem is reduced to a tree search problem in Section 4. Our proposed algorithms are presented in Section 5. Section 6 is dedicated to the experimental evaluation of the performance of the proposed algorithms. Conclusion is drawn in Section 7.

2. Related work

The problems of scheduling and dispatching resources in container terminals have been widely studied in recent years. Surveys on researches of various container terminal operations have been done by Vis and de Koster [7], Steenken et al. [8] and Stahlbock and Voß [9].

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