DISPATCHING TRANSPORT VEHICLES IN MARITIME CONTAINER TERMINALS

by

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ABSTRACT

This paper addresses transport vehicle dispatching problems in container terminals. The vehicle dispatching decision should be carefully made since it significantly affects the ship turnaround time, a key performance measure. We present vehicle dispatching heuristics which are based on a network flow optimization and look-ahead concept. Through the experiments, the performance of several dispatching heuristics is evaluated. Performance of work-initiated and vehicle-initiated dispatching is also discussed.

KEYWORDS
Dispatch, Transport, Maritime, Container

INTRODUCTION

Productivity at a container terminal is often measured by ship turnaround time, a time period for which a container ship stays at a dock for its loading or discharging operations. The ship turnaround time determines the amount of the containers to be handled at a container terminal during a given time period. The handling resources at the container terminal should work in a way to minimize the ship turnaround time. This paper addresses a dispatching problem for transport vehicles that travel between the ship and yard areas. The vehicle dispatching at the container terminals is a process of assigning containers and vehicles to each other. The commonly used method for dispatching vehicles is an event-driven dispatching where a vehicle dispatching decision is invoked whenever a move request is issued or whenever a vehicle completes its current job and becomes idle. When the dispatching decision is triggered by a move request, one of the idle vehicles is selected to handle the move request. If all the vehicles are busy, the move request is put in a queue of pending transportation orders. When a vehicle becomes idle, a transportation job is assigned to the vehicle. Egbelu and Tanchoco (1984) called work-initiated dispatching for the former case and vehicle-initiated dispatching for the latter case.

Vehicle dispatching problems have been studied mostly in manufacturing systems using automated guided vehicles (AGVs) as transporters. (Egbelu and Tanchoco, 1984; Bartholdi and Platzman, 1989; Koo et al., 2003). The dispatching methods for manufacturing systems may not be implemented efficiently in the container terminals because of their distinct characteristics including predetermined job sequence, no in-between buffer storage. The vehicle dispatching problems in seaport container terminals have gained attention only recently due to the importance of marine transportation systems caused by increased world trade volume. Kim and Bae (1999) present mixed integer linear programming models and a heuristic for dispatching containers to AGVs such that the delay of the ship and the total travel time of the AGVs is minimized. Bae and Kim (2000) extend their previous work by considering multiple vehicles shared by multiple quay cranes. Grunow *et al.* (2004) present a priority-rule based dispatching procedure for a container terminal where AGVs with multiple-load capability are used as container transporters. Chen *et al.* (1998) present a greedy dispatching algorithm in which the next unloaded container in the crane sequence is taken by any waiting vehicle or is taken by the first arriving vehicle if no vehicle is waiting. Bish *et al.* (2001) develop a heuristic to assign each container to a yard location and dispatch vehicles to the containers so as to minimize the ship turnaround time. A variety of decision problems at container terminals are extensively reviewed in Vis and de Koster (2003).

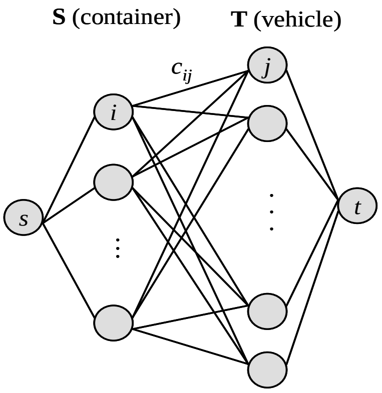
One of the important issues in vehicle dispatching is the selection of performance criteria. A performance criterion often adopted in existing methods is minimizing the deadhead travel time (or idle travel time) from the place where the vehicle is stationed idle to the place at which the part to be moved is located. This objective may be valid when we look at the problem from the viewpoint of vehicles, since minimizing the deadhead travel times will maximize the utilization of vehicles. However, in the seaport container terminals, there is a more important performance measure, ship turnaround time. In most container terminals, quay cranes are a bottleneck resource that limits the amount of containers handled in a given period of time. In order to minimize the ship turnaround time, the quay cranes should be operated efficiently. The idle time in the quay crane results in a longer ship turnaround time. Therefore, vehicle dispatching decision should be made in a way to reduce the quay crane idle time. This paper addresses vehicle dispatching problems in a highly loaded container terminal. We present a new vehicle dispatching heuristic with objective of minimizing quay crane idle times. Through the experiments, the performance of several dispatching heuristics is evaluated. Performance of work-initiated and vehicle-initiated dispatching in the container terminals is also discussed.

VEHICLE DISPATCHING HEURISTICS IN CONTAINER TERMINALS

As stated earlier, the vehicle dispatching decision can be made in two situations: vehicle-initiated and work-initiated. Two vehicle-initiated dispatching heuristics that are commonly used in industries are quay crane dedicated dispatching (QDED) and vehicle initiated greedy dispatching (VIGD). In QDED, every vehicle is assigned to one of the quay cranes. Whenever a vehicle completes a delivery operation, it returns to the previously assigned quay crane. In VIGD, the vehicles are shared by the quay cranes. A greedy algorithm discussed in Chen et al. (1998) is used in this environment: i.e., when a vehicle completes a delivery operation, it is assigned to the job available first. For the work-initiated dispatching, we utilize the fact that the container terminals have predetermined QC job sequence. We introduce a work-initiated dispatching method called container initiated look-ahead dispatching (CILD). In CILD, when a container is ready to be moved, it selects a vehicle that can arrive at the pick-up place first. CILD considers all the vehicles whether they are idle or working at the decision time. A container initiated idle-vehicle dispatching (CIID) is a variation of CILD where only idle vehicles are considered when a container is ready.

With some look-ahead information about vehicles and containers to be moved, the dispatching decision may be made through n:m assignment process where there are n candidate containers and m candidate vehicles. The container-vehicle matching problem can be represented as a minimum cost flow problem as seen in Figure 1. The nodes in S represent the candidate containers, and the nodes in T indicate the candidate vehicles. The network has a source node s and a sink node t, with an arc connecting s to each node in S and an arc connecting each node in T to t. The net flow at the source node s is n while the net flow at the sink node t is the negative value of n. For the other nodes, the incoming flow is equal to the outgoing flow, i.e., the net flow is equal to zero. Each arc has a capacity of one. The problem is to send n items from the source s to the sink t with the objective of minimizing total cost. Here, the cost of an arc between S and T represents the time for a quay crane to wait for a vehicle. The cost values of the arcs connecting s and S, and T and t are all zero.

FIGURE 1
ASSIGNMENT PROBLEM BETWEEN CONTAINERS AND VEHICLES



The overall decision procedure of NET is as follows:

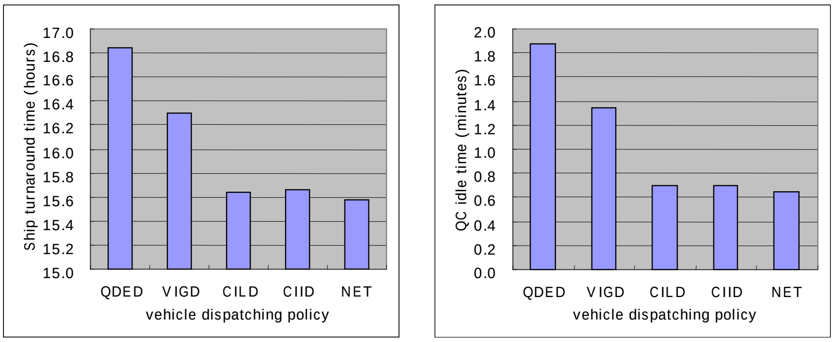
Step 1: The first n containers are selected among the containers that have not been assigned.
Step 2: A minimum cost flow network is constructed with n containers and m vehicles.
Step 3: The network optimization algorithm is applied to produce an optimal matching.
Step 4: Update information related to vehicles, quay cranes and containers.

The decision process described above is repeated from step 1 to step 4. For each iteration, *n* assignments are determined in an optimal way. The time period between the decisions and the actual loading start time is determined in consideration of the vehicle travel time.

EXPERIMENTAL RESULTS

Simulation experiments have been performed to evaluate the proposed dispatching heuristics. In the system under consideration, four quay cranes (QCs) serve a container ship. Each QC should discharge 400 containers off the ship in a predefined order. There are 12 vehicles to transport containers between containership and yard blocks. When QDED is applied, three vehicles are assigned to each quay crane. The container yard consists of 16 yard blocks. The average vehicle utilization is 86 %. Since the discharging plan can affect the performance of the vehicle dispatching heuristics, 10 discharging plans are generated randomly with which the experiments are performed. Figure 2 shows the experimental results with ship turnaround time and QC idle time for each vehicle dispatching strategy. The values have been averaged from the 10 random experimental results. It is seen that QDED provides the highest ship turnaround time and QC idle time while NET provides the lowest.

FIGURE 2
PERFORMANCE OF THE VEHICLE DISPATCHING POLICIES



In order to compare the performance, statistical tests have been done for interesting pairs of dispatching policies. The results of the tests are shown in Table 1. For the test, null hypothesis, H_0, and alternative hypothesis, H_1, are as follows: $H_0 : \mu_1 - \mu_2 = 0$, $H_1 : \mu_1 - \mu_2 > 0$ where μ_1 and μ_2 are the mean of ship turnaround time (or quay crane idle time) of the pair of vehicle dispatching policies under consideration. The hypothesis is then determined based on z-valu:

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\sigma_1^2 / n_1 + \sigma_2^2 / n_2}}$$

where $\bar{x}_1$ and $\bar{x}_2$ are the mean values, σ_1^2 and σ_2^2 are the variances, and n_1 and n_2 are the numbers of experiments. We assume the level of significance, α , as 0.05. Then the null hypothesis is rejected if z > 1.645.

TABLE 1
RESULTS FROM THE STATISTICAL TEST FOR SOME VEHICLE DISPATCHING POLICIES

Dispatching policies	Ship turnaround time	QC idle time
QDED - VIGD	12.39	28.80
QDED - CILD	28.78	61.06
VIGD - CILD	15.08	41.21
CIID - CILD	0.58	-0.02
CILD - NET	1.45	3.24

In Figure 1, it is evident that QDED provides larger ship turnaround time and quay crane idle time than the other dispatching policies. Table 1 shows that z-value for QDED-VIGD and QDED-CILD is very large which means that the non-dedicated dispatching is much more superior to the dedicated dispatching in terms of ship turnaround time and QC waiting time. We also compare vehicle-initiated dispatching policy and work-initiated dispatching policy by using VIGD and CILD. Figure 1 and Table 1 indicates that the work-initiated dispatching is much more superior to the vehicle-initiated dispatching in terms of ship turnaround time and QC waiting time. This result says that the vehicle dispatching decision should be made from the perspective of the containers at the QCs, not the vehicles. The figure also shows that NET provides less ship turnaround time and QC waiting time than the other plolcies. The figure obviously shows that the performance of NET is better than that of VIGD. However, it looks that the performance of the work-initiated dispatching method is almost the same as that of NET. Since the performance of CILD is better than that of VIGD, statistical test is made between CILD and NET. Table 1 shows that the z-value of CILD-NET is 1.45 for ship turnaround time and 3.24 for QC waiting time. For this situation, we can say that the performance of NET is superior to that of CILD in terms of QC waiting time, but not in terms of ship turnaround time.

In order to identify the effect of vehicle utilization on the performance of the dispatching policies, some experiments were performed with different vehicle utilizations with different fleet size, 12 and 16. In QDED, 3 vehicles are assigned to each QC in 12 vehicle case while 4 vehicles are assigned to each QC in 16 vehicle case. Table 2 shows the results of experiments with the different fleet size. It is seen that the effect of vehicle dispatching policies is especially outstanding when vehicles are highly loaded with 12 vehicles.

TABLE 2
PERFORMANCE OF THE DISPATCHING POLICIES UNDER DIFFERENT FLEET SIZES

Fleet size / Dispatching	Ship turnaround time (hour)		QC idle time	
	12	16	12	16
QDED	16.84	15.12	1.88	0.19
VIGD	16.30	14.97	1.34	0.02
CILD	15.63	14.95	0.70	0.00
CIID	15.66	14.95	0.70	0.00
NET	15.57	14.95	0.64	0.00

CONCLUSION

This paper discusses vehicle dispatching problems in container terminals and presents vehicle dispatching heuristics with the objective of minimizing the QC idle times. Through the experiments, the performance of the proposed heuristics and various dispatching methods is discussed. It is observed that the quay crane dedicated dispatching which is widely used in container terminals provide worse performance than the non-dedicated vehicle dispatching policies. Among the non-dedicated dispatching policies, the work-initiated dispatching policy with some look-ahead ability provides higher performance than the vehicle-initiated dispatching. This result says that the vehicle dispatching decision should be made from the perspective of the containers at the QCs, not the vehicles. The optimization-based heuristic, NET, is a good option especially when the vehicle utilization is high. It is seen that the effect of dispatching policies is outstanding when the vehicles are highly loaded.

The vehicle dispatching problem is one aspect of material handling problems in the container terminals. This paper simplifies some material handling activities including storage activities in the container yards, the absence of buffer at QCs, deterministic material handling times. The current work may be extended by including some other critical material handling activities and by making assumptions reflecting real-world container terminal environment.

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