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YARD CRANE DISPATCHING BASED ON REAL TIME DATA DRIVEN SIMULATION FOR CONTAINER TERMINALS

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ABSTRACT

This paper studies the problem of real time yard crane dispatching in container terminals. Many technologies, including transponders, RFID and GPS have been used in the container terminal setting for real-time tracking of terminal equipment. A judicious integration of real-time data into the yard crane management system will allow better utilization of terminal resources to improve overall terminal productivity. We propose a yard crane dispatching algorithm based on real time data driven simulation to solve the problem of yard crane job sequencing to minimize average vehicle waiting time. The algorithm will produce optimal operation sequence for each planning window. Several policies to select jobs to form the planning window are also proposed. Our simulation results show that dispatching yard crane based on real time data driven simulation is of great value in improving yard crane performance in 3 scenarios with different vehicle arriving patterns and our results are 10% worse off a loosely estimated overall optimal performance result.

1 INTRODUCTION

Many technologies, for examples, transponders, RFID, and GPS, have been used in the container terminal setting for real-time tracking of terminal assets. A judicious integration of real-time data into the terminal operation management system will allow better utilization of terminal resources to improve overall terminal productivity. This paper reports a study in using real time data driven simulation to solve the problem of yard crane job sequencing to minimize average vehicle waiting time in order to shorten vessel turnaround time at container terminals.

When a vessel berths at a container terminal, a number of quay cranes will be allocated to serve the vessel. Quay cranes first unload containers onto vehicles for transferring them to the storage yard. Yard cranes pick up containers from vehicles and store them in the yard blocks for transshipment or local import. Yard cranes are also needed at various times later to transfer import containers from yard blocks to local trucks to move them out of the terminal. The loading of containers onto the vessel is carried out in the reversed manner.

Figure 1 shows 2 berths and 2 yard blocks of a typical container terminal. A block may have more than 30 slots of containers stored in length depending on individual terminal layout design. Vehicles travel along lanes shown by the dotted lines in the counterclockwise direction. Both the yard crane and the vehicle must be at the same slot position for loading or unloading of containers to be carried out and vehicles may arrive at different slot positions to store or retrieve containers. As a result, the yard crane may need to gantry between different slot positions between 2 consecutive loading/unloading operations. The objective of a yard crane is to serve every vehicle as soon as possible so that the vehicles will continuously feed the quay cranes so as to minimize vessel turnaround time. This means to minimize the average job waiting time for yard crane service. A secondary objective is to minimize the total crane gantry distance. Dispatching cranes with a smaller total gantry distance would reduce total energy usage of cranes thus reducing operational cost. The third objective is to shorten the longest job waiting time by any vehicle. A service order which tries to minimize average job waiting time could possibly delay a single job for an unacceptable long time period. In real world terminal operations, this may lead to serious consequences like delaying all subsequent jobs of a certain quay crane. In summary, proper management of yard crane operations is of great importance to overall terminal performance, in terms of reducing vessel turnaround time for the customers, increasing productivity and saving energy consumption for the terminal operators.

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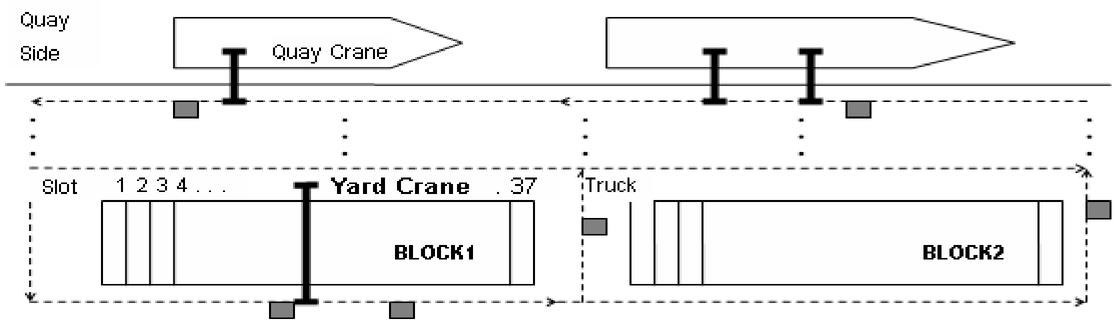

Figure 1: Container flows in a typical terminal.

The purpose of Yard Crane dispatching policy is to determine the order in which the vehicles (the loading or unloading jobs) are served. Yard crane dispatching problem has been proved to be NP-complete (Narasimhan and Palekar 2002). Obviously, no guarantee could be made to always find the optimal solution within a time limit as required in a real time dispatching system where a yard crane needs to handle many jobs. In addition, operations of quay cranes/yard cranes and transportation by vehicles are inter-related and stochastic, leading to actual vehicle job arrivals at a yard block hardly as exact as in the schedule. For example, the traveling time of a vehicle from one place to another is not deterministic due to possible congestions, breakdowns and human factors involved like individual driver behaviors. These make techniques like integer programming which require vehicle job arrival times to be completely known in advance not realistically feasible.

Two common policies are First Come First Serve (FCFS) and Nearest Job First (NJF). FCFS often incurs a lot of gantry movements and results in yard cranes spending significant amount of time on gantry. NJF may starve a job if it is at an isolated slot position. A common shortcoming of the existing policies is that a yard crane would only start gantry towards a vehicle after it has arrived at a yard block. However, with technologies like DGPS, RFID and wireless communication, real time advanced information has great potential in helping to make optimal or near optimal decisions.

The sources of real time information include vehicle/container arrival information from terminal gates, container lists from planned berthing vessels, location information of traveling vehicles and yard crane status. Based on these, vehicle job arrivals in the near future could be predicted with high accuracy. One possibility is the enabling of Pre-Gantry. Pre-Gantry is the ability of yard crane to start moving towards a next job location before the actual vehicle arrival. Once the next job location and arrival time is known, pre-gantry makes use of the crane idle time between jobs whenever possible so that the job waiting time for crane could be minimized. Greater potential in performance improvements would come from a new dispatching algorithm using not only the information of next job but that of next several future jobs. These next several future jobs will form a planning window. The new dispatching algorithm will be based on real time data driven simulation to compute the optimal job service order for the jobs in the time window.

Consider the various operations of the whole terminal, it is noted that the yard crane dispatching plan computed can benefit not just the yard crane operations. The plan is useful in estimating when vehicles will finish their current transportation jobs. These will be valuable information for the vehicle dispatching system to choose the most suitable vehicle for the future transportation jobs. Thus, the yard crane dispatching systems and the vehicle dispatching system may interact and coordinate to optimize the performance of terminal operations.

A yard crane dispatching algorithm based on real time data driven simulation is proposed in this paper. The dispatching algorithm makes full use of the real time predicted vehicle arrival information to carry out what-if experiments and find the optimal service order for the yard crane to serve the jobs in the planning window. An important issue to solve is how to group the near future jobs into a planning window so that the dispatching decisions for multiple planning windows will return near optimal performance in the yard crane's continuous operations. A delicate balance in selecting of decision points has to be found. The window size, that is, the number of jobs in one planning window, needs to be small for the dispatching algorithm to respond in critical time while at the same time to be sufficiently large for generating a high quality schedule. In this paper we propose and evaluate several approaches in choosing a planning window for the dispatching algorithm.

The rest of the paper is organized as follows: Section 2 briefly describes related work on yard crane dispatching. A formal definition of the yard crane dispatching problem is given and it is used to illustrate the benefit of pre-gantry in Section 3. In Section 4, a yard crane dispatching algorithm based on real time data driven simulation and several approaches to decide on the planning window are proposed. Section 5 provides performance evaluation of the dispatching algorithm and the windowing approaches in three scenarios with different vehicle arriving patterns. Conclusions and possible future work are summarized in Section 6.

2 RELATED WORK

The problems of scheduling and dispatching resources in logistics, such as material handling in manufacturing industry, have been widely studied by researchers from different fields (Bramel and Simchi-Levi 1997). However, the results reported in the research literature are not directly applicable to a container terminal due to its unique characteristics (Ng and Mak 2005). Scheduling problems in container terminal are more complex and dynamic because the less deterministic operational times and interdependencies among subsystems make the system states fast changing.

Several focused studies on yard crane dispatching or scheduling problem in container terminals have been carried out. Kim and Kim (1999) proposed a Mixed Integer Programming (MIP) method for the problem of routing single yard crane to support the loading operations of a vessel. Based on the MIP formulation, an optimal algorithm is presented. Kim and Kim (2003) presented heuristic algorithms for the same problem. The proposed algorithm outperforms a Genetic Algorithm (GA) as shown by numerical experiments. However, the assumption in these work of having dedicated yard cranes just to support vessel loading operations is not always practical for terminals with larger number of berths.

Ng (2005) studied the problem of scheduling multiple yard cranes and modeled it as an integer program. A heuristic was proposed to minimize total loading time. However, the approach does not consider loading sequence requirements. Zyngiridis (2005) presented linear integer programs to schedule routes for one and two equal sized Automated Stacking Cranes in a single block working with straddle carriers. The primary objective is to minimize the total travel distance of cranes while giving priority to export containers. The difference between this study and others in the field is the use of straddle carriers instead of normal vehicles. Straddle carriers could carry out self picking up and placing down of containers while normal vehicles need crane assistance in carrying out these operations on container. Lee et al. (2007) addressed the problem of vessel loading with two yard cranes serving one quay crane. A simulated annealing algorithm was presented which aimed at minimizing the total loading time at the stack area. Computational experiments show that completion time of the proposed algorithm is on average 10.03% above a loosely estimated lower bound.

Guo et al. (2007) used computer simulation to compare the effectiveness of predicting vehicle job finishing time and proposed a dispatching algorithm for better use of the inferred job finishing time. The results show that precise real time vehicle location information is valuable in better vehicle dispatching decisions and it contributes significantly to the overall terminal performance.

3 PROBLEM DEFINITION

In this work, we consider the yard crane dispatching problem where one yard crane is assigned to handle all the jobs of storage and retrieval of containers brought in by vehicles to one yard block. We make the following assumptions in the yard crane dispatching problem:

- Each vehicle job handles one container only
- Advanced information on each vehicle arrival time and the location of the storage/retrieval job will come in real time and is assumed to be accurate

There are N jobs in the current planning period with (predicted) vehicle arrival times A_i ($i = 1, 2, \ldots, N$), To formulate the problem of dispatching a yard crane to handle all the jobs with different vehicle arrival time and different job slot locations, the following notations are used to describe the problem:

- A_k Arrival time of vehicle for job k , where k = 1,2…N and $A_k \le A_{k+1}$,
- F_i Finish time of yard crane service for job i,
- S_i Service time of job i,
- G_{ij} Gantry time from the location of job i to the location of job j
- $[i]$ The job to be handled in the ith position of a job sequence

Let the time when the yard crane is available for the first job to be $F_{[0]}$. Given A = {$A_1, A_2, \ldots, A_N$} where each arrival time will come in real time and N is not known in advance, find a sequence J = $\{J_1, J_2, \ldots, J_N\}$ for the yard crane to handle in order to minimize the average job waiting time defined as

$$\text{Minimize} \quad \frac{1}{N}\sum_{i=1}^{N}(F_i - S_i - A_i)$$

When a yard crane does not have information about vehicle arrivals in advance, it can only start to move towards a next job location after the vehicle arrival. Job finishing time can be represented by Equation (1). On the other hand, when advanced information is available in real time, the yard crane could possibly start moving towards the next job location in advance of the actual vehicle arrival, which is referred to as pre-gantry ability. Job finishing time with pre-gantry ability is shown in Equation (2).

$$F_{[i+1]} = \max\{A_{[i+1]}, F_{[i]}\} + G_{[i][i+1]} + S_{[i+1]} \quad (1)$$

$$F_{[i+1]} = \max\{A_{[i+1]}, F_{[i]} + G_{[i][i+1]}\} + S_{[i+1]} \quad (2)$$

The advantage of pre-gantry ability is the possibility of utilizing yard crane idle time between jobs to transfer between different job locations. This is illustrated in Figure 2. Without pre-gantry ability, when the next job arrival time is later than current job finish time, the crane would be idle at current job location and only start gantry after the arrival of next job $A_{[i+1]}$. When prediction information of the next job is available, yard crane could start gantry towards next job location immediately after completion of the current job. Partial pre-gantry could be made if the next job arrival is earlier than crane arrival at the job location. Full pre-gantry could be made if the next job arrival is later than crane arrival at the job location.

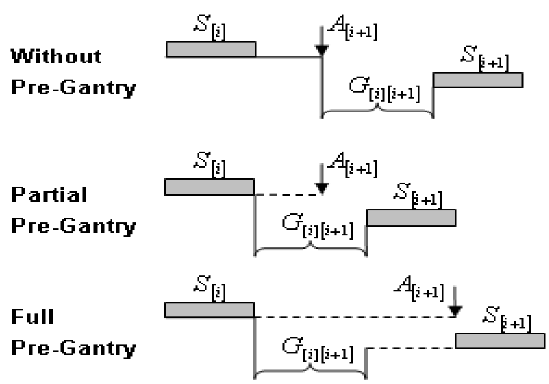

Figure 2: Prediction based yard crane pre-gantry ability.

The real benefit of a dispatching algorithm based on real time data driven simulation is to use real time information to compute a serving sequence of a number of jobs that minimize the average job (vehicle) waiting time.

4 THE ALGORITHMS

In this section, we present the dispatching algorithm based on real time data driven simulation to compute the optimal serving sequence for the jobs in a planning window. Then we propose the various approaches to choose the jobs to be included into a planning window.

The typical job list for a yard crane for a full terminal shift of eight hours could be of length greater than 100. However, computing for an optimal sequence for such a list is unacceptably time consuming as it is a NP-Complete problem. Even heuristic and branch and bound algorithms may not be able to provide good practical solutions. In addition, real world terminal operations are very dynamic and fast changing and quay crane, yard crane and vehicle operations are inter-dependent. It is not possible to predict the job arrival times for the entire shift in advance. Therefore planning yard crane operations too far ahead will not guarantee good practical solutions.

We propose a dispatching algorithm that will return an optimal sequence for the jobs in a planning window in Figure 3. The algorithm relies on simulation which is driven by the real time advanced job arrival information. For each job, the advanced information contains the time the vehicle is going to arrive at the yard block and the exact location of the storage/retrieval job. The predicted vehicle arrival time comes from real time terminal monitoring system and the job location information comes from other real time terminal subsystems like storage planning, vessel berthing and vehicle dispatching.

```
// Unfinished job list ranked according to vehicle arrival time
J = { J_1, J_2, ..., J_n }

DISPATCHING_YardCrane(J) {
// The function is triggered when the yard crane starts to serve
the last job in the current planning window
   Update J using real time predicted arrival information;
   Generate P, the job list for the next planning window,
from J based on specific job selection criterion;
   newP = φ, optimalP = φ;
   DISPATCHING_ORDER(P, newP);
}
DISPATCHING_ORDER (P, newP) {
 FOR each job J_i ∈ P, ( i = 1 to size of P )
   Select J_i as the next job to handle after jobs in newP;
   Simulate Gantry = G {speed_G, loc_pre, loc_cur};
   Simulate Service = S {loc_containerID, type_opt};
   Record waiting time for J_i and update TotalJobWaitingT;
   Remove this job J_i from P;
   IF P is not empty
        DISPATCHING_ORDER (P, newP);
   ELSE IF TotalJobWaitingT is smaller than currentSmallest
        Update currentSmallest as TotalJobWaitingT;
        Update optimalP as newP;
END FOR }
```

Figure 3. Pseudocode of dispatching algorithm.

DISPATCHING_ORDER() employs an approach of modified exhaustive search in its what-if scenarios to consider in the simulation. The simulation uses real time predicted vehicle arrival information. The yard crane service time for each job used in the simulation takes into consideration the container location. Recursive search saves re-computation of common prefix part of job sequences. As each planning window is relatively small in size, we could afford the computation time to find an optimal dispatching sequence to serve jobs within this local window. Each time planning for the next dispatching window is triggered when the yard crane starts to serve the last job in the current planning window. Decision of how many jobs to plan in one window depends on specific window selection criterion explained as follows.

One key concern of our dispatching method is how to form the planning windows. The size (number of jobs) of the planning window needs to be considerably small for the dispatching algorithm to respond in real time while at the same time sufficiently large for generating a high quality schedule. We propose several candidate windowing solutions as follows with jobs sorted into ascending order according to their predicted vehicle arrival time:

a. Job Oriented Fixed Size Windowing
The idea is to group a fixed number of consecutive jobs N_{fix} into the next window as the search space for dispatching:
$P = \{J_1, J_2 ...., J_k\}$, where $k = N_{fix}$

b. Time Oriented Fixed Length Windowing
The idea is to group consecutive jobs whose arrival time falls in a fixed time interval (e.g. every 15 minutes) into the next planning window for dispatching:
$P = \{J_1, J_2 ...., J_k\}$, where $A_k \le t_{cur} + T_{fixed}$
t_{cur} is the end time of the current time window.

c. Dynamic Windowing
The idea is to find a large gap between two job arrivals. Let $T_{threshold}$ be the threshold for this gap:
$P = \{J_1, J_2 ...., J_k\}$, where k is the smallest integer such that $A_{k+1} - A_k \ge T_{threshold}$
Both the number of jobs and the time length of each local planning window are not fixed.

d. Combo of Dynamic and Fixed Size
The idea is to combine (a) and (c) above.
$P = \{J_1, J_2 ...., J_k\}$, where k is the smallest integer such that
$(A_{k+1} - A_k \ge T_{threshold}) \| (k = N_{\max})$

Each of these window selection criteria has its own characteristics. Deciding local planning window with fixed job numbers or fixed time interval as criterion (**a**) and (**b**) is relative easy and convenient for real world terminal to implement. Intuition behind criterion (**c**) is the fact that when two consecutive job arrivals have a large gap in arrival time, it is less justified to keep the earlier arrivals waiting and give priority to serve the later job.

Windowing approach reduces the computation cost substantially, but it may lead to overall performance loss. When partitioning a list of jobs into planning windows, it enforces all jobs in an earlier window to be served prior to any jobs in a latter window. However, it might be better to serve a job in the latter window earlier than certain jobs in the earlier window if these jobs were considered as one continuous planning sequence for overall performance. Dynamic windowing criterion (**c**) tries to reduce this possible disturbance between local windows by choosing a relatively large gap in arrivals between the last job of the current window and the first job of the next window. However, this dynamic selection criterion has the risk of including in a planning window a large number of jobs which would drastically increase the computation time. A combined method of dynamic windowing while limiting the max number of jobs in each planning window to ensure reasonable computation time is the logic behind criterion (**d**). The performance of these windowing criteria also varies with different parameter settings of the respective criterion. More of these are discussed and examined in the next section.

5 PERFORMANCE EVALUATION

5.1 Experimental Design

To evaluate the performance of our online yard crane dispatching method, simulation studies driven by data obtained from real world terminal models are carried out. The objective of the experiments is to assess the performance improvement obtained from online dispatching using real time data.

Each experiment run lasts for one shift of eight hours as it does in typical real world terminal operations. The warm up period is one hour. The yard crane in the experiment employs a gantry speed of 7.8km per hour within yard blocks and a simplification of yard crane service simulation is made so that a service time of 180 seconds is used for all container storage and retrieval operations. These parameter settings for yard crane are also obtained from the real world.

As vessel arrival rate may vary during the shift, three different scenarios of variable incoming workload are generated:

1. The first scenario describes a relatively constant workload. For the entire shift, the vehicle inter-arrival times at the yard block follow an exponential distribution with a fixed mean of 300 seconds. This mean is derived from the real world situation where 6 vehicles and 2 yard cranes supports the operations of 1 quay crane and a round trip transporting containers between quayside and the yard takes about 15 minutes.

2. The second scenario describes a shift of varying workload which has an exponentially distributed job inter-arrival time with a mean that varies hourly following a uniform distribution between 180 seconds and 420 seconds. This adds the peaks and lulls to Scenario 1.
3. The third scenario also describes a varying workload shift with exponentially distributed inter-arrival time. Every hour the mean varies following an exponential distribution with mean = 300 seconds and within the range of (180, 420) seconds. This is another way of adding peaks and lulls to Scenario 1.

Job slot locations are randomly selected across the entire yard block.

For the dispatching algorithm to select jobs for a planning window, different values for the parameters as listed in Table 1 are explored. To assess the usefulness of real time job information, two commonly used yard crane dispatching rules that dispatches yard crane after vehicle arrival are used in the experiments for comparison. These two rules are first-come-first-serve and nearest-job-first. Yard crane drivers in real world terminal usually use either of or sometimes switch between these two rules depending on individual crane operators.

Table 1: Algorithms tested in the experiment.

Info Availability	Algorithms	Policy to select jobs for planning window
No advanced information on vehicle arrivals	First Come First Serve	
	Nearest Job First	
With advanced information on vehicle arrivals	Fixed Window Size = 1 jobs (same as FCFS with advanced information on one job)	criterion **(a)**
	Fixed Window Size = 3 jobs	
	Fixed Window Size = 6 jobs	
	Fixed Window Size = 9 jobs	
	Fixed Window Length = 15 mins	criterion **(b)**
	Dynamic Windowing Inter-Arrival Time (IAT) > 5 mins	criterion **(c)**
	Combo Method IAT> 5 mins OR Size = 6 jobs	criterion **(d)**

Nine sets of experiments as listed in Table 1 were conducted and each set tested three different workload scenarios discussed earlier and each experiment has seven runs. A loose estimate of the global optimal performance is obtained by computing the optimal vehicle waiting time from the first hour of a 8 hour shift for comparison purpose. The simulation model is programmed using C++ language under Visual C++ 6.0 complier on Pentium Core2 with 2.66GHz and 2GB of RAM

5.2 Performance Results and Discussions

The quality of real time yard crane dispatching algorithms highly depends on two key indicators: high quality in meeting terminal performance objectives and fast computation to satisfy the real time requirement of small decision time. Important performance factors of yard crane dispatching include average job waiting time, average job gantry distance and worst case job waiting time.

One most common objective is to minimize average job waiting time and therefore to reduce unnecessary blocking of vehicle resources at the yard side. Then the feeding of vehicles at the quay side would be relatively continuous so as to minimize vessel turn-around time. Figure 4 shows the average job waiting time of the 9 sets of experiments in three workload scenarios.

Results in Figure 4 show that FCFS performs worst when no advanced arrival information is available. Overall performance without advanced arrival information (FCFS and NJF) is outperformed by algorithms with advanced arrival information and pre-gantry. However, NJF performs relatively better than FCFS with advanced arrival information (FCFS_P). This means purely pre-gantry to the next arriving vehicle is not better than serving the nearest job first. In cases where more than one job have arrived upon crane finish of a previous job, pre-gantry is not possible but NJF would select a job nearer to its current location and save crane gantry time.

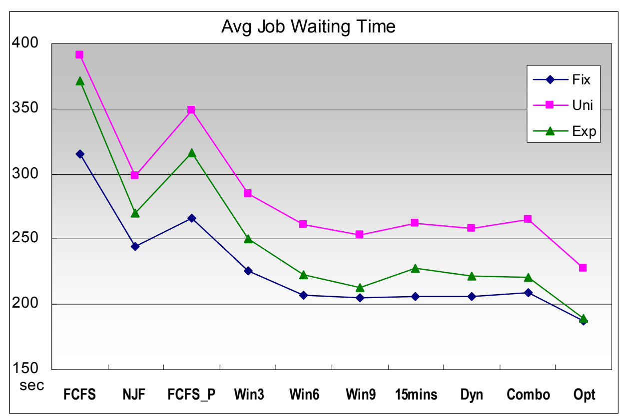

Figure 4: Average job waiting time in three scenarios.

Computing optimal job sequence for each planning window greatly reduce average job waiting time when compared to FCFS_P. Larger window size in the policy of choosing a fixed number of jobs for a planning window gives better performance and the best case here is the fixed window size of 9 jobs (Win9). The other 3 policies perform a little bit worse than Win9. Dynamic windowing with arrival time gap greater than 5 minutes (Dyn) outperforms fixed time interval of 15 minutes slightly as the first one tries to divide local windows in a way with greater possibility for crane to finish jobs in the current window earlier than the first job arrival of the next window. Combo method of Dyn and Win6 has similar but no conclusive performance compared with Dyn as its primary concern is to reduce computation time of Dyn. Greater variance in hourly workload results in larger average job waiting time of all 9 sets of experiments. Despite that, the characteristics of dispatching rules do not vary much across different workload scenarios.

The best performance obtained in yard crane dispatching based on real time data driven simulation is around 10% worse than the loosely estimated global optimal. We would like to emphasize here that this estimate of the global optimal by a local optimal in the first hour may deviate somewhat from the real global optimal for the entire shift. However, finding global optimal for the entire shift of 8 hours over around 100 jobs is very time consuming for such NP-complete problem. Furthermore, it is practically not meaningful to find such global optimal as only near future advanced vehicle arrival information are of high accuracy.

Another performance indicator is the average crane gantry distance for each job. It emphasizes the consideration of cost saving in energy consumption and equipment maintenance. Figure 5 shows the average job gantry distance in different experiment setting in three workload scenarios in number of yard slots travelled. NJF gives a relatively good performance of an average of 1.7 slots saving per job compared to FCFS. Methods that compute optimal sequence by real time data driven simulation for each planning window generally work well with an average traveling distance of 0.28 of full yard block length. The best performance (Win9) is around 1% worse than the loosely estimated global optimal.

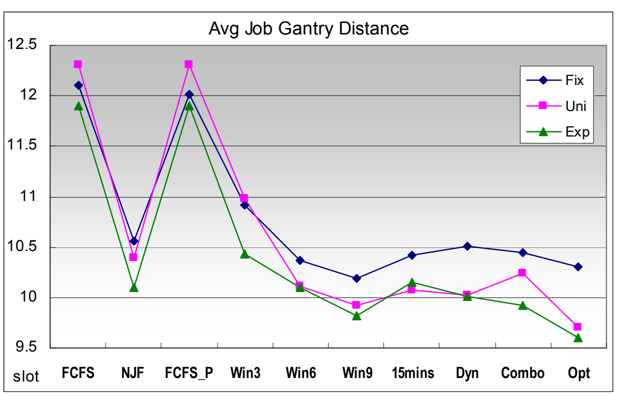

Figure 5: Average job gantry distance in three scenarios.

The worst case job waiting time is one factor that should be considered in the selection of dispatching algorithms. In the real world terminal operation, sometimes delaying a certain loading job for vessels might results in serious delay in the entire loading process. The worst case job waiting time is shown in Figure 6. It is easily seen that NJF could result in high worst case job waiting time of around 30 minutes. Generally speaking, a large fixed window size will lead to high worst case job waiting time. Win9 performs worst among windowing methods. This is the cost paid when the dispatching algorithm optimizes on low average job waiting time for the relatively larger planning window. Combo method performs worse than Dyn in the process to achieve shorter computation time. Local optimal of the first hour period does not mean much here, as worst case job waiting time among the entire shift has the same probability to occur in any hour.

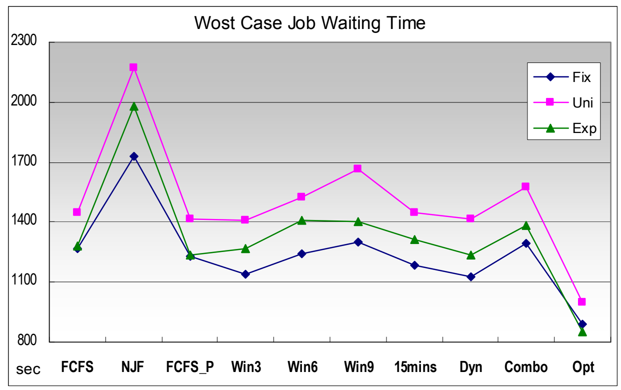

Figure 6: Worst case job waiting time in three scenarios.

Table 2: Computation time in three scenarios (seconds).

Algorithms	Fixed Mean	Uniformly Dist. Mean	Exponentially Dist. Mean
FCFS	<=0.01	<=0.01	<=0.01
NJF	<=0.01	<=0.01	<=0.01
FCFS Pred.	<=0.01	<=0.01	<=0.01
Win= 3 jobs	0.022	0.023	0.024
Win = 6 jobs	0.717	0.726	0.724
Win= 9 jobs	231.6	232.1	231.9
Win = 15 mins	3.297	3.043	4.765
Dyn > 5 mins	412.6	11278	10859
Combo (5 mins, 6 jobs)	0.547	0.604	0.584

Computation time is a critical factor in real time yard crane dispatching. Meeting the constraint of certain decision time could sometimes be the primary criterion in the selection of dispatching algorithms. The computation time in three workload scenarios with different dispatching algorithms is shown in Table 2. Generally speaking, the computation time does not depend on varying workload.

The results of Dyn varies a lot as the size of each local planning window could vary drastically. If a group of consecutive jobs happen to have relatively short inter-arrival time, they will be grouped into one local planning window. If the total number of jobs in a window is large, the computation time may increase exponentially and this would result in unacceptable computation time for decision making. Combo method intends to solve this computation time issue and simulation results show that it succeeds in achieving this objective.

In summary, four factors are discussed and examined in three different workload scenarios using 9 ways of setting parameters in the evaluation of real time yard crane dispatching algorithms. We find that real time data driven simulation employed by the new dispatching algorithm and pre-gantry results in great performance improvement in terms of various objectives. Selection of windowing criterion and parameters should be carefully made in combined consideration of affordable computation time, average job waiting time, average crane gantry distance and worst case job waiting time. Proper selection of windowing criteria and parameters results in performance around 1% worse in average crane gantry distance and around 10% worse in average job waiting time than a loosely estimated global optimal.

6 CONCLUSIONS

In this paper, the problem of real time yard crane dispatching in container terminal is studied. A formal definition of the problem is given and it is used to illustrate the benefit of pre-gantry ability using predicted vehicle arrival information of the next job. Furthermore, a new yard crane dispatching algorithm is proposed. The algorithm uses real time data driven simulation to generate optimal dispatching sequences for each planning window within acceptable decision time. Four possible window selection criteria are proposed to balance operational performance and computational costs. In evaluation of the usefulness of real time data driven simulation and the proposed dispatching algorithm, three key performance indicator and the computational costs are examined in three scenarios with different vehicle arrival patterns. The simulation results show that prediction information of near future jobs are of great importance to performance improvement of yard crane dispatching and the proposed new algorithm works well with the prediction information. Future work would includes studies on methodologies for prediction with better certainty for future terminal status including vehicles' and extending this real time dispatching approach to multi cranes in multi yard blocks.

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