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Work Scheduling in Container Yard with Various Kinds of Handling Equipments

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Abstract: The efficiency of a container yard is an important factor for the performances of container terminals it serves. In one container yard, there are commonly different types of equipments suitable for different kinds of container handling tasks, which should be paid great attention to while making schedules for the equipments. Otherwise, the efficiency of the container yard could be greatly reduced. In this study, it is presented a tree-like model for this problem, in consideration of the relationship between types of equipments and kinds of handling tasks. Afterwards, it is used an A* search method to solve the model. Numerical Experiments are later conducted in order to verify the effectiveness and efficiency of the solution method.

Key words: Container yard, task scheduling, multiple kinds of equipments, A* search

INTRODUCTION

Container yards are inland sites in which containers are stored. Dissimilar to container terminals, there is no quay or quayside cranes for a container yard and containers are carried in and taken away by trucks through the gates only. Besides simple storage and stacking, in one container yard, containers could be packed, unpacked, or handed over to some other agent. Generally, container yards are recognized as an important ring in the global container transportation.

In some large container ports in China, container yards act as buffer areas for container terminals nearby. The outbound containers for one ship is collected first to container yards, scattered and then carried to the container terminal in batches. The inbound containers from one ship are carried from some container terminal to container yards first and then picked up by the owner gradually in the following days. It is well recognized that, the transfer of inbound and outbound containers at the container yards are with great benefit to the handling efficiency of the container terminals these yards serve. The batch arrival of outbound containers leads to rational stacking positions in the terminal, which makes container loading an easier work for the terminal operator. Moreover, the departure of inbound containers in time increases substantially the utilization of the storage space. Consequently, container yards in these ports play an important part in the container inbound and outbound processes. It should be guaranteed that, these container yards are efficient enough and they will never be the bottleneck of the whole container transporting process.

The working efficiency of one container yard depends on not only the amount and technical efficiency of equipments, but also the origin and destination positions of each container handling work and the type of the equipment that assigned to it. Generally, in one container yard, there are multiple kinds of handling equipments, such as Rubber Tired Gantry Cranes (RTG), Reach-stackers (RS), forklifts for Empty Container (FE) and forklifts for loaded container (FL). A container handling work could be either a storing work in which one container is stacked from one truck to some container block, a retrieving work in which one container is taken from one container block to some truck, or a re-handling work in which one container is carried to another stacking position. The performances of different kinds of handling equipments may vary when assigned to the same handling work, due to the fact that some kinds of equipments spend extra time in picking up the container from the origin position, or delivering it to the destination. Hence, when scheduling multiple kinds of equipments in one container yard, it is required a proper method considering the differences among kinds of equipments when assigned to one handling work, so that the works in the container yard could be finished fast enough.

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LITERATURE REVIEW

Up to now, there have been much researches on the crane transportation problem (Steenken *et al.*, 2004; Stahlbock and Vobâ, 2008), which considers mainly the transports of gantry cranes operating in stacks. In such problems, each crane is to be assigned with part of the container handling works, the sequence of which has to be determined at the same time. However, these studys concentrates mainly on single kind of handling equipment, such as RTG and Rail Mounted Gantry Cranes (RMG), while little attention are paid on scheduling multiple kinds of equipments. Moreover, it is widely assumed that the time one equipment spends in executing a handling work is fixed, which is obviously improper for scheduling equipments of different kinds.

Kim and Kim (1997) studied the single RTG routing problem during outbound container loading operation. It is determined the number of containers the RTG picks up in each bay, so as the sequence of bays the RTG visits. The objective is to minimize the total container handling time. In an extended study (Kim and Kim, 1999), they added to the previous model an extra assumption that the containers stacked in the same bay belong to the same group and a relaxation is made to the formulation.

Lin (2000) studied the dynamic deploying problem of multiple RTGs in one storage yard. With time divided into periods, it is no longer restricted that RTGs have to finish their movement within one period and the objective is to minimize the number of unfinished handling works at the end of each time period. Zhang *et al.* (2002) studied the same problem, but more practical constraints are considered in his model. For instance, each block hold at most two RTGs and the times of inter-zone movements for each RTG are limited.

Ng and Mak (2005) studied the single RTG scheduling problem in which the RTG performs a given set of handling works with different ready times. The objective is to minimize the sum of job waiting times. Li *et al.* (2009) focused on the minimization of the prime movers' waiting time. Based on Ng and Mak (2005), a mixed integer programming model is developed, taking into account some actual operation constraints such as inter-crane interference, fixed RTG separation distances and simultaneous storage/retrieval works handling.

Javanshir and Ganji (2010) presented a mixed integer programming model for the RMG scheduling problem, with non-interference constraint on a same trail.

Huang and Guo (2011) proposed two improved Least Cost Heuristic algorithms for the RTG deploying problem in one container terminal. The algorithms considered practical operation constraints and it was verified that the performance of the two algorithms are better than the original one. They also proposed a mixed integer programming models focusing on the optimal sequencing of a RTG in serving a fleet of vehicles (Guo *et al.*, 2011). The objective is to minimize the average vehicle waiting time.

Liang *et al.* (2011) studied the multiple RTG deploying problem while performing more than one container flows. The objectives are to minimize the maximum completion time of each container flow and to minimize the make-span of all tasks in the container flows. In a later study (Liang *et al.*, 2013) they discussed the yard crane scheduling problem with multiple work lines, which focused on the container loading and unloading processes only.

Li *et al.* (2012) developed a continuous time mixed integer linear programming model for RTG scheduling, which was efficient for reason that far fewer integer variables are required.

Boysen *et al.* (2012) considered the transshipment yard scheduling problem in a rail to rail transshipment yard, in which huge gantry cranes tranship containers between different freight trains. In this problem, trains have to be assigned to bundles, which jointly enter and leave the yard. The objective is to minimize split moves and revisits.

The rest of this study is constructed as follows. In the next section, it is given a detailed description of the execution times of different kinds of equipments when assigned to some container handling work and a mixed integer programming model is proposed for the scheduling problem with multiple handling equipments. In section 3, the model is reduced to a tree search problem an A* search method is applied to solve the model. Numerical Experiments are conducted in section 4, as evaluation of the performance of the proposed algorithm. Conclusion is drawn in Section 5.

PROBLEM DESCRIPTION

The key factor of the multiple handling equipment scheduling problem is that, the execution time of one container handling work may vary when assigned to different kinds of equipments. This variation is relative to the container's origin and destination positions in the container yard, the process of the handling works and the characteristics of each kind of handling equipment.

Yard layout and the handling equipments: In one container yard, one block is a stacking unit in which containers pile up. One block could be differentiated into bays, rows and tiers, dividing the storage spaces into

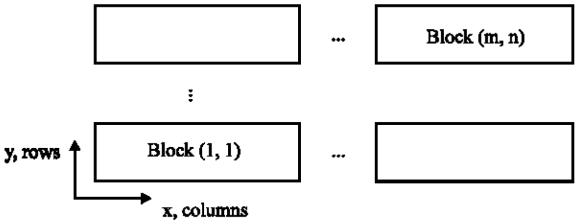

Fig. 1: A regular layout of blocks in one container yard

grids which holds one 20 feet container each. Several blocks array in a disjoint manner to form the whole storage space of the container yard, while the areas between two blocks are left for truck traffic and equipment movement. Figure 1 shows a typical layout of one container yard, in which the blocks is arrayed regularly in m rows and n columns. Hence, the position of each block could be presented using a pair of x-y coordinates. In difference with the container rows in one block, the row and column of one block in the block array is presented as block-row and block-column in the rest of the study.

RTG is the most common gantry crane used in container yards and container terminals in China. These cranes are much flexible in operation, for reason that they could move along both the block-row and block-column direction and handle containers in every block in the container yard. As a gantry crane, one RTG could pick up directly any container as long as no other container is stacked above and put it down to the top of the container pile without reshuffle. However, much time is needed to change the tire direction of one RTG, hence the movement of one RTG between two blocks in different block-rows is very time-consuming.

RS is a special stacker used mainly in container yards. These stackers are able to transport a container short distances quickly and pile it in various rows of one bay if possible. As for empty containers, it could be stacked very high using a RS, much higher than a RTG could. However, the space required to handle one container using a RS is rather large.

FE and FL are common container forklifts in one container yard. One forklift could carry directly only the container it confronts, in case that no other container is stacked above it. Thus, in case that one forklift is to carry a distant container it can't reach, those separating containers located between them should be carried away first. As a result, forklifts are only suitable for handling containers at the edge of one block. Besides, FLs are designed for loaded containers and FEs are for empty containers only. One FE is not able to carry a loaded container, while it can stack empty containers rather high, which is beyond the capability of a FL.

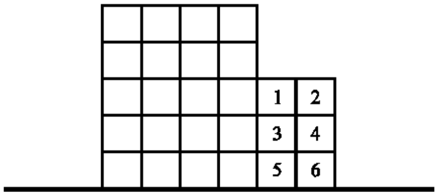

Fig. 2: An illustration of unavoidable reshuffles with different kinds of equipments

Handling times of different kinds of equipments: A container handling work is a process of pickup and delivery, no matter it is a storing work, retrieving work or a re-handling work, regardless of the kind of equipment assigned to it. Once some equipment is assigned to one handling work, the working process could be divided into four stages, namely arriving, pickup, delivery and putdown in sequence.

The arriving stage starts from the time that some equipment decided to take one handling work and ends when it arrives at the handling point. In a storing work, the handling point is at the destination bay where the container to be stored. In a retrieving work or a re-handling work, the handling point is at the bay where the container is stacked currently. The travel time of the handling equipment could be estimated with the distance and the speed, while RTG could spend extra time in case that turning is unavoidable. Moreover, due to interference of the equipments, the arriving stage could be further lengthened if there is some other handling equipment working in a nearby bay in the same block.

In a pickup stage, the equipment catches up the container of the handling work. The time spent in this stage depends mainly on the number of reshuffles in need, before which the container is not reachable, that is, this container could not be caught directly. As shown in Fig. 2, six numbered container are stacked in the same bay of some block in the yard and container 1 is to be picked up. One RTG could catch this container without any reshuffle. One RS needs a reshuffle to take away container 2, hence container 1 is reachable. AS for a forklift, it should take away container 2, 4 and 6 first, hence 3 reshuffles is unavoidable. Therefore, it is obvious that the time needed for a pickup stage may vary among different kinds of equipments.

In a delivery stage, one container is carried to the position. The delivery stage for a storing work or a retrieving work is often quite short, owing to little container transport. However, the delivery stage for a re-handling work may be much longer, since the destination position may be some distance away.

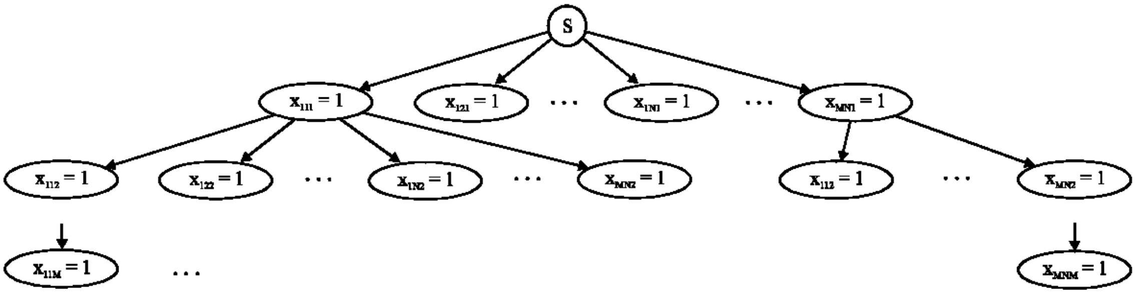

Fig. 3: Searching space of the probelm

The putdown stage is not time-consuming at all. In a retrieving work, the container is settled directly to some truck immediately. In a storing work or a re-handling work, the container could always be settled to the destination position without reshuffle.

Tree-like searching model for the scheduling problem: It is not suitable to solve the scheduling problem in this study using integer programming approaches, for reason that one equipment may be assigned with multiple handling works in sequence and the works executed earlier may influence those to be executed. Therefore, the scheduling problem is described using a tree-like model, as shown in Fig. 3.

A scheduling starts from a start node S where no handling work is assigned. In every node, one unassigned work is added to the end of the work plan of one equipment. Given M works and N equipments, there are $N \bullet M!$ possible solutions for the problem. The model is built on the following assumptions:

- The handling works could be arranged in order of importance: The time one handing equipment spend in any stage of every handling works is predictable, regardless of the kind of the equipment
- No two equipments could work in the same bay simultaneously. No other interference is considered

The notations used in this model are listed below:

- M Total number of handling works
- I Ordinal number of handling works, $i = (1, 2, \ldots, M)$
- N Total number of handling equipments
- j Ordinal number of handling equipments, $j = (1, 2, \ldots, N)$
- T Total number of the kinds of handling equipments. In this model, $T = 4$
- t Ordinal number of the kinds of handling equipments. Especially for this model, $t = 1$ for RTG, $t = 2$ for RS, $t = 3$ for FL and $t = 4$ for FE
- k Ordinal number of layers, $k = (1, 2, \ldots, M)$
- P_{it} The time length one equipment of kind t spends in the picking up, delivering and putting down process of work i. In case that the equipments of such kind is unable to execute the work, P_{it} is set very large
- B_{jt} A 0-1 constant for the kind of equipment j. In case that equipment j belongs to kind t, then $B_{jt} = 1$; else $B_{jt} = 0$
- $F_{ii'}$ A 0-1 constant for the conflict between work i and i'. If work i and i' are located in the same bay, then $F_{ii'} = 1$, else $F_{ii'} = 0$
- R_{ij} The time equipment j is ready when to assign work i
- AW_i The arrival time of handling work i
- Ae_{ij} The time length equipment j spends in arriving at the work i
- S_{ij} The time equipment j starts to pick up work i
- H_{ij} The time length equipment j spends in picking up, delivering and putting down the container of work i
- E_{ij} The time work i is finished by equipment j

The decision variable is explained as follows:

- x_{ijk} An 0-1 variable indicating the decision made at some node in layer k. If handling equipment i is assigned to work j in layer k then x_{ijk}=1, else x_{ijk}= 0

The objective is to minimize the total waiting and execution times of the handling works:

$$\text{Min } f = \text{Min}\sum_{i=1}^{M}\left(\sum_{j=1}^{N}\sum_{k=1}^{M}\left(x_{ijk}.\, E_{ij}\right) - A_i\right) \tag{1}$$

The constraints are listed below:

$$Sij = \text{Max}\ (AWi, Rij+AEij) \tag{2}$$

Equation 2 indicates the actual start time of the pickup stage of handling work i when assigned to equipment j. The pickup stage won't start until the equipment and truck have arrived at the handling point both:

$$H_{ij} = \sum_{j=1}^{N}\sum_{k=1}^{M}\left(x_{ijk} . \sum_{t=1}^{T}\left(T_{jt} . P_{jt}\right)\right) \tag{3}$$

Equation 3 is for the time length of pickup, delivery and putdown stages, given that work i is assigned to equipment j in layer k. The time length is related to the equipment kind:

$$Eij = Sij+Hij \tag{4}$$

Equation 4 is the definition of E_{ij}:

$$R_{(i+1)j} = x_{ij} . E_{ij} + (1 - x_{ij}) . R_{ij} \tag{5}$$

Equation 5 means that one equipment should not take another work until the current one is finished:

$$AW_{i'} = O_{ii'} . \text{Max}\,(AW_{i'}, E_{ij})+(1\text{-}O_{ii'}) . AW_{i'} \tag{6}$$

Where:

$$\sum_{j=1}^{N}\sum_{k=1}^{M} x_{i'jk} = 0$$

Equation 6 is derived from the equipment interference. In case that handling work i is assigned to some handling equipment, the arrival time of the unassigned works in the same bay are justified:

$$\forall j, \sum_{t=1}^{T} T_{jt} = 1 \tag{7}$$

Equation 7 means that the kind of each handling equipment is unique:

$$\forall j, \sum_{t=1}^{N}\sum_{k=1}^{N} x_{ijk} = 1 \tag{8}$$

Equation 8 means that each handling work is assigned only once.

PROPOSED SCHEME

As for the tree-like structure of the searching space, here we applied an A* search method for solution. A* search is a common method for graph search to find the optimal path from an initial node to one goal node. It keeps an open list of nodes to be expanded and always tries to select the most promising node based on an evaluation function as below:

$$f(x) = g\,(x) + h(x) \tag{9}$$

In Equation 9, g(x) is the cumulated cost from the start node to node x and h(x) is the estimated lowest cost from node x to the goal node. In case that h(x) is kept no more than the true cost h*(x), the method is to find the optimal goal node for sure. With a goal node found, a solution to the scheduling problem could be determined by tracking the nodes from the goal node back to the start one.

The maximal layer of the searching tree is fixed in this problem. Once a node is selected in a layer, one handling work is assigned to some equipment. Hence, the maximal number of layers in the tree equals to the total number of handling works to be assigned. Once a node in the highest layer is reached and no other node could be better than this one, this node is treated as the goal node and the search terminates.

The estimation function h(x) plays an important part in the searching process of A* algorithm. When at a non-leaf node x during a search process, there are still some handling works that have not been assigned yet and the finish time of these works if assigned to some handling equipment could be predicted. Hence, we define h(x) as the sum of minimal waiting and execution times of the unassigned works, in which it is allowed that two or more works are executed by the same handling equipment. This estimation may be less than the true cost at the early searching steps, while in the later steps, the value is precise in case no two handling equipments are to handle the same work when making the estimation.

The notations used in the algorithm are listed as follows:

- x,y,z Nodes in the search tree, where node x is the father node of node y and node y is the father node of node z
- g(x) Cumulated waiting and execution times of assigned works from start to node x
- h(x) Estimated cost from node x to the goal node
- w_{xy} Weight of the edge from node x to node y
- W Set of all works, |W| = M
- P(x) Set of works already assigned in the route from the start node to node x.
- U(x) = W-P(x)

```
A* search
Create a node with no work assigned as n_start
Calculate the total cost of n_start as Equ. (9) and (11)
Put n_start into s_open
WHILE s_open is not empty
 set the node with the least cost as n_curr
     IF n_curr is in the highest layer of the tree
     return n_curr as the goal node
     remove n_curr from s_open
     FOR each node in the neighbor nodes of n_curr
     Calculate the cost of this node
     Add this node to s_open
```

Fig. 4: Pseudo code of A* search

- a(x) The work assigned in node x
- b(x) The equipment assigned with some work in node x

The weight of the edge form node x to node y could be given by the equation below:

$$Wxy = Ea(y)\ b(y)\text{-}Aa(y) \tag{10}$$

The estimation function h(y) could be defined as follows:

$$h(y) = \sum_{z\in U(y)} \left(E_{a(z)b(z)} - A_{a(z)}\right) \tag{11}$$

The pseudo code of A* search method is presented in Fig. 4, in which n_curr is for the current node, n_start is for the start node, n_best is for the solution node and s_open for the open set.

NUMERICAL EXPERIMENT

We evaluate the performance of the A* searching method in two ways. In the first way, we tested our searching method with sets of random generated works in which the amount of works is fixed. In the second way, we tested the method with data collected from daily operation of some container yard.

Experimental design: Three sets of experiments were conducted to test the searching method while scheduling handling works in container yards with 4, 6 and 9 blocks respectively. Each block has a size of 30 bays, 6 rows and 4 tiers. The number of each equipment kind in these container yards is shown in Table 1.

The technical datum of the equipments is shown in Table 2. One move is the process that one equipment processes one container handling work, besides the gantry moving. We assume that, the time one handling equipment spends on each move are the same and each reshuffle is treated as a move. We assume at the same time that, the move speeds of the handling equipments in the container yard are fixed.

Table 1: No. of equipments in container yards

	Equipment no.		
Equipment kind	4 blocks	6 blocks	9blocks
RTG	2	2	3
RS	1	2	3
FE	1	1	2
FL	2	3	4

Table 2: Technical datum of equipments

Equipment kind	RTG	RS	FE	FL
Time per move (sec)	180	240	300	300
Move speed loaded (m $\min^{-1}$)	30	200	240	220
Move speed empty (m $\min^{-1}$)	90	240	360	300
Tire turn time (sec)	50	-	-	-

Table 3: Work inter-arrival times in the yards

	Scenarios (s)		
Container yards	Dense arrival	Normal arrival	Sparse arrival
4 blocks	80	120	160
6 blocks	110	160	210
9 blocks	140	200	260

Table 4: Computational times of 20 works in different scenarios

	4 blocks	6 blocks	8 blocks
Dense arrival			
Mean	2.56	2.89	3.27
Upper	3.07	3.65	5.67
Lower	1.23	1.45	1.98
Normal arrival			
Mean	1.68	1.96	2.42
Upper	2.04	2.27	2.64
Lower	1.20	1.34	2.06
Sparse arrival			
Mean	0.95	1.32	1.73
Upper	1.28	1.71	2.01
Lower	0.67	0.84	1.53

For each set of experiments, three scenarios of different truck arriving rates were tested. The means of the inter-arrival times are listed in Table 3 in unit of seconds. For the same category of workload, a larger container yard is given a larger mean inter-arrival time for longer travel distances of the equipments. For each experiment, 20 arrivals are generated and solved using the algorithm. The positions of the works are generated randomly within the blocks, so as the other containers that is present in the blocks.

Tests with random generated works: Computational time is the only factor of interest since the A* search method returns always the optimal solution. To evaluate the mean computational time, for each arrival pattern in each scenario, 20 random arrivals are generated and solved, with the solution times recorded and stated. Table 4 shows the solution times when solving 20 handling

Table 5: Computational times of 40 works in different scenarios

	4 blocks	6 blocks	8 blocks
Dense arrival			
Mean	3.48	3.75	4.39
Upper	4.26	4.53	4.72
Lower	2.75	3.10	3.91
Normal arrival			
Mean	2.47	2.78	3.06
Upper	2.61	2.94	3.67
Lower	2.28	2.53	2.72
Sparse arrival			
Mean	1.64	1.95	2.14
Upper	1.87	2.18	2.43
Lower	1.43	1.74	1.80

Table 6: Computational times of real work arrivals

ID	No. of works	Computational time (sec)
1	61	12.7
2	83	16.8
3	94	22.3
4	57	9.6
5	63	12.4
6	82	16.5
7	64	11.6
8	90	17.4
9	46	8.4
10	75	15.8

works, while Table 5 shows the solution times of 40 container works. These tables indicate that the algorithm is usually effective in scheduling with multiple kinds of equipments in different sizes of container yards.

Tests with real work arrivals: We tests the algorithm further with datum collected form a real container yard. There are 18 blocks in this container yard, each with 6 rows and 4 tiers, while the bays range from 24 to 40. There are 20 handling equipments in the yard, consisting of 6 RTGs, 7 RSs, 3 FLs and 4 FLs. We selected 10 time periods each with the length of half an hour and got the work arrival recorded. These recorded arrivals are solved with the algorithm, with the solution times recorded in Table 6. It is verified that, the proposed algorithm is able to solve real scheduling problems with multiple kinds of handling equipments.

CONCLUSION

We proposed a scheduling scheme with multiple kinds of handling equipments in a container yard, both with an algorithm solving the scheduling problem. The scheduling problem is described in a tree-like model and an A* search method is applied to find the best solution. The algorithm is evaluated with both random generated truck arrivals and real datum collected from some real container yard. Results show that the performance of the proposed algorithm is always satisfactory no matter which test case it is placed in.

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