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An intelligent storage determining method for unloaded containers in a cycling trailer deployment mode

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Abstract: This paper discusses the problem of determining a storage location for each unloaded container in the principle of cycling trailer deployment. A mixed-integer programming model, which considers various constraints related to the operation of yard cranes and trailers, was formulated according to lots of operators' experience in different container terminals.

1. Introduction

With the swift development of container transportation industry, the operation and management of container terminal in our country have been improved a lot, especially in the informationization of the operation. In recent research of the storage space allocation problem in a container terminal, many scholars published a great deal of papers to study this problem. According to Iris F.A. Vis. [1], by using the total travel time required to handle storage and retrieval requests from both the sea- and landside of the terminal, they conclude that automated stacking cranes outperform straddle carriers in a stack with a span width smaller than nine containers. Another scholar Mohammad Bazzazi[2], suggests to use an efficient genetic algorithm (GA) to solve an extended storage space allocation problem (SSAP) which considers existing the several equality constraints in a container terminal. Chuqian Zhang[3] and other three researchers use a rolling-horizon approach to solve this problem. They decomposed each planning horizon into two levels and each level is formulated as a mathematical programming model. By this method, they significantly reduce the workload imbalance in the yard, avoiding possible bottlenecks in terminal operations in short computation time. About the problem of the yard crane scheduling in port container terminals, W.C. Ng and K.L. Mak[4] study the problem of scheduling a yard crane to perform a given set of loading/unloading jobs with different ready times. They use branch and bound algorithm to solve most problems of realistic sizes so that they can achieve to minimize the sum of job waiting times. Kap Hwan Kim[5] performed a simulation study to compare the performances of a static sequencing problem and a dynamic one. According to the viewpoint of Der-Horng Lee, Zhi Cao, and Qiang Meng[6], they provide a mathematical model to formulate the problem, which is to schedule two transtainers which serve the loading operations of one quay crane at two different container blocks so as to minimize the total loading time at stack area, and develop a simulated annealing (SA) algorithm to solve the proposed model. In the study of determining a storage location for each unloaded container, Ebru K. Bish[7] develops a heuristic algorithm based on formulating the problem as a transshipment problem, and analyzes the effecectiveness of the heuristic from both worst-case and computational points of view.

However, the research in import business, especially in the storage location determination for unloaded containers and intelligent position-choosing algorithm is not common.

2. Problem description

The yard position plan and the storage location determination for discharged containers are the most important and difficult tasks in the import business. The intelligent determination of storage location in the yard for the discharged containers is the process of calculation according to a series of algorithms in the inner system of the terminal operations. In the whole information system in the terminal, the model of the intelligent determination of storage location for the discharged containers is an important connection section in the import business, it collects information involved in the former sections like the EDI of BAPLIE and manifest of cargo for the import ships, and imports it into the information system, and then make plans for the import containers and arrange working lines. All these tasks are the bases of the subsequent discharging operations. The dispatching of quay cranes and yard cranes will affect the actual loading and unloading operation, and the reasonable and balanced storage location determination will reduce the operation time to a great extent.

In order to make sure the containers are operated in a balance to the greatest extent, the balance of efficiency between the loading and unloading operations should be taken into account on one hand, and on the other hand the operation tasks for each yard crane should also be uniformly dispatched when dealing with automatic storage position determination problems, which will avoid the waiting and block in the yard.

3. Mathematical model formulation

3.1 Definition of notations used in model

c The unloaded container waiting for a yard location determined by the database server.
i The trucks on which the unloaded containers are loaded.
s The size (length) of container, mainly 20ft, 40ft and 45ft.
p Container types, such as GP, OT, RF, etc.
g G-force, indicating the special requirement of cargo including dangerous and over-limited containers.
z The status of containers, such as IF, IE and TF, indicating import full container, import empty container and transfer container respectively.
o Owners of the containers.
u POD, the port of discharge.
a ID number of blocks in the yard-plan. A indicates the assembly of a.
b The number of yard-bays. B indicates the assembly of b.
y Yard cranes. Y indicates the assembly of y.
k Group number of the trailers.
λ An infinite positive number.

Ctn_size_{cs} Binary, the relationship between container c and size s. 1, if the size of container c is s; 0, otherwise.
YP_size_{abs} 1, if containers of size s can be stored in the yard-bay b of block a according to the yard plan.
Ctn_type_{cp} 1, if the type of the container c is p.
YP_type_{abp} Indicate whether containers of type p can be stored in the yard-bay b of block a according to the yard plan.
Ctn_gforce_{cg} 1, if container c is with some special requirement g; 0, otherwise.
YP_gforce_{abg} Indicate whether the containers with G-force g can be stored in the yard-bay b of block a according to the yard-plan.
Ctn_status_{cz} 1, if the status of container c is s, 0, otherwise.
YP_status_{abz} Indicate whether the container with status z can be stored in the yard-bay ab.
Ctn_owner_{co} 1, if container c belongs to owner o, 0, otherwise.
YP_owner_{abo} Indicate whether the containers of owner o can be stored in yard-bay ab according to the yard-plan.
Ctn_ulport_{cu} 1, if the POD of container c is port u, 0, otherwise.
YP_ulport_{abu} Indicate whether containers of unload port u can be stored in yard-bay ab according to the yard-plan..
$YC\_deployment_{yab}$ 1, if the working area of yard crane y covers yard-bay ab, 0, otherwise.

$Taskcount\_YC_y$	The sum of yard crane y's task number.
YC_status_y	The status of yard crane y, 1 for operating, 2 for maintenance, 3 for breakdown.
$Sending\_task_{ak}$	1, if there are some sending tasks for loading process in block a and the loading QC's group number is k, 0, otherwise.
$Truck\_groupnum_{ik}$	1, if truck i belongs to the truck-group k, 0, otherwise.
$Discharged\_task_{ci}$	1, if the unloaded container c is carried by trailer i.
$Yardbay\_capacity_{ab}$	The number of containers that still can be stored in yard-bay b of block a.
$Yardbay\_seq_{ab}$	The entrance sequence of yard-bay b in block a.
Pos_assign_{cab}	Binary Decision variable.1, if container c should be stored into yard-bay ab. Objective1, Objective2, Objective3, three objectives.
$Total\_objective$	The total objective.

3.2 Constaints formulation

$$Ctn\_size_{cs} * Pos\_assign_{cab} <= Pos\_assign_{cab} * YP\_size_{abs} \forall c,a,b,s \quad (1)$$

$$Ctn\_type_{cp} * Pos\_assign_{cab} <= Pos\_assign_{cab} * YP\_type_{abp} \forall c,a,b,p \quad (2)$$

$$Ctn\_gforce_{cg} * Pos\_assign_{cab} <= Pos\_assign_{cab} * YP\_gforce_{abg} \forall c,a,b,g \quad (3)$$

$$Ctn\_status_{cz} * Pos\_assign_{cab} <= Pos\_assign_{cab} * YP\_status_{abz} \forall c,a,b,z \quad (4)$$

$$Ctn\_owner_{co} * Pos\_assign_{cab} <= Pos\_assign_{cab} * YP\_owner_{abo} \forall c,a,b,o \quad (5)$$

$$Ctn\_ulport_{cu} * Pos\_assign_{cab} <= Pos\_assign_{cab} * YP\_ulport_{abu} \forall c,a,b,u \quad (6)$$

$$\sum_{c \in C} Pos\_assign_{cab} <= \lambda * \sum_{y \in Y} YC\_deployment_{yab} \forall a,b \quad (7)$$

$$Pos\_assign_{cab} * YC\_deployment_{yab} * YC\_status_y <= 1 \forall c,a,b,y \quad (8)$$

$$\sum_{c \in C} Pos\_assign_{cab} <= Yardbay\_capacity_{ab} \forall a,b \quad (9)$$

$$\sum_{a \in A, b \in B} Pos\_assign_{cab} = 1 \forall c \quad (10)$$

The first one is the container size constraint. For example, if yard-bay ab is allocated to container c. And based on the yard plan, the yard-bay ab can be used to store a cluster of containers with size S. That means the size of container c must be included in set S. The constraint (7) makes the target position covered by at least one yard crane. Constraint (8) takes account of the yard cranes' work status, such as operating, maintenance and breakdown. If some yard crane is breakdown or under maintenance, no more tasks should be assigned to it. Constraint (9) reserves an amount of restow positions. Constraint (10) is for the sake of obtain a feasible solution, each container must be assigned to enter a yard-bay in this model.

3.3 Objectives of the model

In cycling trailer deployment mode, some of the trailers can take a loading container from the yard side successively after moving an unloaded container to a certain yard-bay. In this way, the horizontal moving efficiency of all trailers will get promoted. The number of full trailers' cycling moving can be formulated as follow:

$$O1 = \sum (Pos\_assign_{cab} * sending\_task_{ak} * Discharged\_task_{ci} * Truck\_groupnum_{ik}) \quad (11)$$

All kinds of tasks distributed in different blocks in the yard. And in the covering areas of each yard crane, the type and quantity of tasks is different, which means the YCs' busy extent are unbalanced. This objective can be formulated below:

$$O2 = \sum (Pos\_assign_{cab} * YC\_deployment_{yab} * Taskcount\_YC_y) \quad (12)$$

As shown in fig.1, location determination in sequence can minimize the moving times of yard cranes. To store the same kind of containers into the same block orderly, the parameter $Yardbay\_seq_{ab}$ is indispensable. So that under the constraint of yard-bay capacity, just minimizing the number of yard-bay storage sequence of the containers can reach the following objective:

$$O3 = \sum_{c\in C, a\in A, b\in B} (Pos\_assign_{cab} * Yardbay\_seq_{ab}) \tag{13}$$

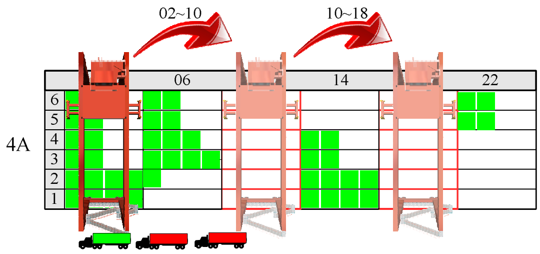

Fig.1 Yard Crane Moving

The total objective can be formulated as follow:

$$Total\_objective = \alpha * O1 \ + \ \beta * O2 \ + \ \gamma * O3 \tag{14}$$

α , β , γ are the weights of the sub objectives. To minimize the total objective, α should be negative. In this model, we can set $\alpha = -3 * \beta$, which means the objective1 will be firstly satisfied when the quantity of task of the second freest yard crane minus that of the freest one is less than 3, on the other hand, when the quantity of task of the second freest yard crane minus that of the freest one is more than 3, the objective2 will be satisfied in priority. Only when would objective1 and objective2 be satisfied, the objective3 can be minimized, so $\beta = 10 * \gamma$.

3.4 Solution procedure

The total objective can be simplified as follow:

$$Total\_objective = \sum_{c\in C, a\in A, b\in B} (Pos\_assign_{cab} * Parameter_{cab}) \tag{15}$$

Of course, in the above formulation, $Parameter_{cab}$ should be formulated as follow:

$$\begin{aligned} Parameter_{cab} &= \alpha * \sum_{i\in I, k\in K} (sending\_task_{ak} * Discharged\_task_{ci} * Truck\_groupnum_{ik}) \\ &+ \beta * \sum_{i\in I, k\in K} (YC\_deployment_{yab} * Taskcount\_YC_y) + \gamma * Yardbay\_seq_{ab} \end{aligned} \tag{16}$$

Since the decision variable is a binary matrix, we can set $Pos\_assign_{cab} = \begin{cases} 0, Parameter_{cab} \geq 0 \\ 1, Parameter_{cab} < 0 \end{cases}$ to get the initial solution $Pos\_assign'_{cab}$. And the corresponded value of objective is $Object\_initial$. Search the optimal solution by the following steps:

Step1: Check whether $Pos\_assign'_{cab}$ can meet all the constrains, Y→ Step End，N→step2；

Step2: Set $|Parameter_{cab}|$ in ascending order to get a vector Parameter. V1 = Parameter(i)，viz., the smallest absolute value of element. The initial value of i is 1;

Step3: For the first element of Parameter (i), set the corresponding element of Pos_assign_{cab} inversely, viz.,0→1 or 1→0. And then check whether Pos_assign_{cab} can meet the constraints or not again, Y→ Step End，N→step4；

Step4: Set V1 = Parameter(i++), Parameter2(t)= Parameter(i) + Parameter(j). Parameter2 is the combination of two arbitrary elements of Parameter(i), and after sorted, we always make V2 equals to the smallest Parameter2(t). Compare V1 with V2, if V1 ≤ V2, back to Step3. Otherwise if V1 ＞ V2, go to Step5;

Step5: Based on Parameter2(t), find its Parameter(i) and Parameter(j). Set their corresponding element of Pos_assign_{cab} inversely, viz.,0→1 or 1→0. And then check whether Pos_assign_{cab} can meet the constraints or not again, Y→ Step End，N→step6；

Step6: Set V1 = Parameter(i++), V2 = Parameter2(t++) and similarly figure out the sorted vector Parameter3 of 3 elements' combination. Set Min = min(V1, V2, V3). If V1 = Min, then back to Step3, else if V2 = Min then back to Step5,and if V3 = Min then go to Step(7);

Step… ~ Step(2*c*a*b+1);

Step End: The optimal solution is the transformed Pos_assign_{cab}, and $Total\_objective = Object\_initial + V_{\min}$.

4. Conclusion

On the basis on analysis and summarization of operators' experience, the determination of storage location for each unloaded container in the principle of cycling trailer deployment was studied theoretically and practically. An intelligent programming model was built, which considers various constraints related to enter-yard plan, principles of yard area regulation and yard cranes dispatching, and the algorithm for the solution was also put forward. In the end, the intelligent storage position determination system, which can be embedded in to the current operation system, was developed on the basis of investigation of the data structures of the operation management system of container terminal. Through a large number of case studies and system tests, it was confirmed that the intelligent programming model was valid and effective in storage position determination, the involved database was reasonable in data structure and extensive. Furthermore, the application of this determination system could effectively improve the operation efficiency of the container terminal. The position determination model and algorithm developed in the system could also be referrible in the study of operation scheduling problem of the same kind.

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