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Study on Container Yard Pick-up Operations based on Distributed Decision-making

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Abstract: In this study, a state-of-the-art strategy of distributed decision-making is proposed for pick-up operations in a container yard which secures an important position during the container handling process. According to the pick-up principles in the storage yard and corresponding practical experience, a distributed decision-making algorithm is formulated which is intended to assist yard operators to figure out the best solution, thus maximally raising operational efficiency in container yard and avoiding unnecessary traffic congestions of container trucks. Moreover, the workflow of yard cranes is efficiently optimized to reduce their movement frequency. In the entire decision-making process, numerous workloads are distributed to all yard cranes. The optimal scheme will be generated after individual computation for each yard crane. Numerical tests are carried out and their results show the effectiveness and feasibility of the algorithm. The application of the proposed theory provides a practical significance to improve operational efficiency when picking up containers.

Key words: Distributed decision-making, container yard, pick-up operation, operational efficiency

INTRODUCTION

With the rapid growth of container throughput in worldwide ports, the container yard which is a core node of container supply chain, has gained more and more attention. Currently in China, the extensive management of the storage yard leads to lower operating efficiency and other issues which has become the barrier of today's container yard development. With regard to the decision-making problem during the container pick-up operations, a new distributed algorithm is proposed in order to speed up the decision-making and its quality. Furthermore, container retrieval efficiency can be upgraded and unproductive waiting time will be cut down.

The decision-making problem for picking up containers in the storage yard has been widely recognized in the previous literature. Different algorithms were applied to enhance the operational efficiency of a container yard. Hao *et al*. (2000) employed image search technology and pattern recognition theory to establish an optimization model for yard bays to produce the decision-making sequence under stochastic conditions. Gao *et al*. (2008) proposed a nested heuristic algorithm to formulate a mathematical model which was focused on an optimization problem of container reshuffles and yard crane movements. Yu and Wang (2007) studied a Multi-Agent fuzzy decision algorithm for truck scheduling based on contract net. They graded each yard crane according to the importance degree and the optimal solution was then selected. Liu (2008) made a research on the yard position allocation for export containers where some of these containers were planned to be reshuffled in the storage yard. Qing (2007) proposed an optimization model of the anterior yard and designed a genetic algorithm to solve the position assignment problem for export containers. Wang and Zhao (2007) adopted a Six Sigma theory to improve the container receiving and retrieval operations. Kim (1997) studied different layouts of container yard and their impact on the average number of container re handles. The stacking conditions are accordingly analyzed. Kozan and Preston (1999) used the genetic algorithm to reduce the number of container reshuffles and the transportation time to optimize pick-up operations. Kim *et al.* (2000) proposed a dynamic allocation method for outbound containers to improve vessel loading efficiency and storage yard utilization. Preston and Kozan (2001) proposed a multi-objective function for a variety of container handling plans so as to improve retrieval efficiency with reasonable classification.

More recently, Wang and Fu (2010) studied yard position allocation strategies, in which the genetic algorithm was utilized to solve the proposed problem and

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prove the superiority and practicality of genetic algorithm optimization strategies. They also found out that different container storage positions have various impacts on container pick-up plans. Ngoc and Moon (2011) conducted a research on the capacity expansion problem for container terminals. In order to solve the related decision-making problems, a mixed integer linear optimization model was established and a heuristic algorithm was developed on the basis of Lagrangian relaxation. Computational experiments showed the effectiveness of the proposed algorithm. Douma *et al.* (2011) presented a practical approach for the alignment of barge and terminal operations. The performance of the proposed Multi-Agent system was evaluated by means of a comprehensive simulation study. The result demonstrated that the system enabled barge and terminal operators to align their operations efficiently. Lee and Yu (2012) addressed the price competition problem between a container terminal and a remote container yard for temporary storage of inbound containers. Pricing game models were then put forward between them. The mathematical model provided operational insights into the effectiveness of the storage pricing behavior and competition outcomes of the container terminal and the remote container yard. Van Asperen *et al.* (2013) studied the impact of truck announcements on the container stacking efficiency. A discrete-event simulation model was used to evaluate the impact of truck announcement system on the performance of online container stacking rules.

One of the major problems that a container terminal operator is confronted with is how to quickly make a decision for the arriving drivers. In this study, a series of rules are developed to select the alternative containers which is based on the comprehensive analysis of container pick-up operations. Then a distributed decision-making algorithm is designed to help operators to quickly determine an accurate and reasonable pick-up sequence.

In summary, few research works have been carried out in the field of distributed decision-making container pick-up. And this is the research area of this study. The related assignment principles will be carefully taken into account.

The rest of study is structured as follows. Section 2 briefly explains the problem addressed in this study. In section 3, the implementation of a novel algorithm is discussed which is related to the container pick-up operations. Then the detailed computational results are given in section 4. Conclusions are discussed in section 5.

PROBLEM DESCRIPTION

With the fast development of computer technology and ever-growing demand for container transportation and handling efficiency, modern management information systems for handling operations have been widely applied in container terminals all around the world.

Generally, the entire process of pick-up operations in a container yard is specified as follows: A container truck arrives→the operator inputs the reservation number of pick-up operation→Terminal Operation System (TOS) checks the container clearance→TOS obtains the container distribution inside the container yard→TOS generates the corresponding stacking location and working conditions of yard cranes→Select a target block→Calculate the number of container re handles→Select the target container→Create the pick-up task for the selected container→Print a checklist for the task→A yard crane performs the pick-up task→The vehicle returns to the exit→The gate operator checks and releases the container truck. Figure 1 is a typical illustration of the distributed decision-making process.

During the pick-up process, there are a large number of computational workloads for TOS, especially within peak hours. The traffic flow may be affected.

The distributed decision-making in pick-up operation is relatively scientific and effective. When TOS acquires the pick-up information at the entrance gate, it will be posted to the server. Then the related information will be transformed into bidding format by the server and delivered to yard cranes. The yard crane obtains the tendering information and the target container is selected according to the pre-established set of rules, including minimum number of container reshuffles, the specified owners, the specified container size, the assigned container application, the principle of proximity and so forth. After selection of the target container, three scores are computed by the yard crane which are yard crane movements, utilization of yard cranes and fitness degree

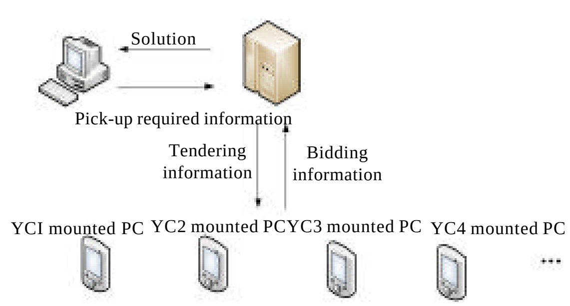

Fig. 1: A schematic diagram of distributed decision-making

of workloads, respectively. The final result will be sent back to the gate server and the server will make the integrated decision.

SOLUTION METHOD

Notations: The relative symbol definitions contain the workloads of yard cranes, aggregation degree of various tasks and other information which are listed as follows:

R = Workloads of the target yard crane, namely the total number of tasks under all working types of the yard crane
D = Aggregation degree of tasks which refers to the unified tasks of a specific yard crane. The value of D stands for the quality of the pick-up plan
Q = Location of the yard crane
d = Score of yard crane movements
X = Score of yard crane workloads
Y = Score of fitness degree
Z = Synthesis score

Tendering and bidding information: When the gate operator inputs the pick-up information into TOS, the TOS will generate the tendering information which includes the size, owner and purpose of the container and such information will be sent to the yard cranes. The yard cranes receive the tendering information and the bidding information is produced based on rules and all these two information will be sent back to TOS. The bidding information must include the following information: Workloads (R) and fitness degree (D); then the scores, respectively measured by X (the score of yard crane movements), Y (the score of yard crane workloads) and Z (the score of fitness degree). A string type of information can be formed in the following format: "R; D; X; Y; Z". When the TOPS receives all the bidding information, the synthesis score M will be calculated. The best pick-up plan will be eventually accepted.

Distributed decision-making algorithm: The bidding information is sent to the TOS from all the qualified yard cranes. Then a set of the alternative plans (indexed by C) will be created in the TOS. And the synthesis score M is produced which helps to choose an optimal solution.

When TOS receives the bidding information from yard cranes, it will count the synthesis score for all the alternative solution. Specific steps are described as follows:

Step 1: Calculate the score of the Yard Crane (YC) movement X. In order to evaluate the difficulty of YC movement, the score of the yard crane movement X is divided into five levels base on the distance and the difficulty of the movements

Step 2: Compute the score of the workloads of yard crane Y. In order to evaluate the workload of the yard crane, all the yard cranes should be taken into account. Firstly, the number of tasks for each yard crane is summed up. Secondly, the number of tasks for the target yard crane will be figured out. Lastly, the workloads of the target yard crane are evaluated among all the bidding yard cranes. The workloads of the target yard crane are subtracted from the sum of the total tasks of all the bidding yard cranes and the obtained value is compared with the summation of workloads

Step 3: Count the score of the fitness degree of the yard crane Z. The score Z is the suitability measurement of the solution and the resulting value reflects the yard crane's feasibility for the tasks

Step 4: Calculate the synthesis score *M*. According to a certain proportion of the weight of the composite scores, a comprehensive review of the above three calculated scores is taken. The synthesis score is calculated for the target yard crane

All the alternative containers selected by the set of rules need to be evaluated by the following equations:

- **Score of the yard crane movement X:** The score was described by the distance traveled for the yard crane to execute its task. Q is the objective block of the container, d is current location block of the objective yard crane, formulas to calculate the score X is expressed as follows:

$$X=\begin{cases}100 & \text{if } Q=d\\ 80 & \text{if } |Q-d|\le 10\\ 60 & \text{if } 10\le |Q-d|\le 20\\ 40 & \text{if } 20\le |Q-d|\le 30\\ 20 & \text{if } 30\le |Q-d|\le 40\\ 0 & \text{if } 40\le |Q-d|\le 50\end{cases} \tag{1}$$

- **Score of the workload of yard crane Y:** The score describes how busy the yard crane is. R_L is the number of tasks for the bidding yard cranes, R_0 is the number of tasks for the target yard crane. The score Y can be expressed as follow:

$$Y=\frac{\sum_L R_L - R_0}{\sum_L R_L}\times 100 \tag{2}$$

- **Score of the fitness of the yard crane Z:** The score describes the fitness of the target yard crane for the pick-up operations. The higher proportion of the yard crane tasks in the pick-up solution means that the yard crane is more suitable for that task. This can be shown in Eq. 3:

$$Z=\frac{D}{R}\times 100 \quad (3)$$

In the above formula, D is the task number of the yard crane in this solution and R is the total task number of the yard crane

- **Synthesis score M:** In the above equation, D is the task number of the yard crane in this solution and R is the total task number of the yard crane

Since, X, Y, Z are all percentile dimensionless and the importance rank is as follow: Imp_x, Imp_y, Imp_z. So, we define their weights α, β, γ and set their value as fellow: $\alpha+\beta+\gamma=1, \alpha=0.45, \beta=0.2, \gamma=0.35$ The final synthesis score M is described as follow:

$$M=\alpha\times X+\beta\times Y+\gamma\times Z \quad (4)$$

NUMERICAL EXPERIMENTS

Here, the numerical experiments are performed by a personal computer with duo CPU@ 1.8 GHz and 1 GB RAM. The container retrieval planning is studied by using the actual data. The proposed problem is solved through the application of CPLEX 10.0. And moreover, the experimental tests are carried out to evaluate the effectiveness and reliability of the algorithm.

Input data:

- Tendering information from the gate operator which contains size, container owners and container types
- Yard crane information which contains yard crane ID, yard crane number, coverage area for each yard crane and the task number of each yard crane
- All the information about alternative containers, including their locations, sizes, purposes and so on
- Number of the alternative containers in each block

The input data are shown as the Table 1-2.

Selection alternative containers: To select the alternative containers from all the possible containers in the block under the fellow rules.

Table 1: List of yc coveravge area and task number in a block

YC ID.	Coverage	Task num	YC ID.	Coverage	Task num
L01	B120	4	L02	B210	3
L03	B312	5	L04	B411	6

“Coverage” stands for the location of the yard crane

Table 2: List of container information in a block

CTN. No.	Location	CTN. owner	Size (#)	Special flag
CCLU2026752	B12121	COSCO.	40	GP
CCLU2203502	B14011	COSCO.	20	GP
CCLU2236466	B15232	CSC.	40	GP
CCLU2393866	B12451	COSCO.	20	GP
CCLU2651430	B23032	COSCO.	20	RF
CCLU2737447	B24351	COSCO.	40	GP
CCLU3030037	B23224	COSCO.	20	GP
FSCU9003479	B33321	COSCO.	40	GP
TGHU3089323	B34121	COSCO.	20	RF
CCLU0000001	B32032	CSC.	40	GP
CCLU0000002	B43011	COSCO.	40	GP
CCLU0000003	B44131	COSCO.	20	RF
CCLU0000043	B42541	COSCO.	40	GP

HC: High cube container, GP: General purpose container and RF: Reefer container

Rule 1: The lower rehandling work (The first lowest 40% containers will be pass)

For example, in block B1, to pick up the container (No.: CCLU2026752) do not need any rehandling work, it will go on to the next.

Rule 2: Right container owner: All the alternative containers owner need to be the requited one.

Rule 3: Right container size: All the alternative containers must to be the requited size.

Rule 4: Right purpose: All the alternative containers must to be the requited purpose.

The above rules will help to select the alternative containers.

Bidding information: When the alternative containers are selected, the TOS will calculate the bidding information according to the algorithm formulas in section 3.3.2. The examples are given as follows.

Score of the yard crane movement X: To calculate the scores of the yard crane movement with the Eq. 1, the results are illustrated as follows.

In block B1, X_{B12121} = 80, X_{B14011} = 60, X_{B15232} = 20.

Because X_{B14011} and X_{B15232} are in the same task with a same bill number. They can be combined to obtain an erected alternative solution X_A = 40:

- In block B2, X_{B24351} = 20
- In block B3, X_{B33321} = 40
- In block B4, X_{B43011} = 60 and X_{B42541} = 60.

Score of the workload of yard crane Y: To calculate the scores of the workload of the yard crane with the Eq. 2, the results are stated as follows:

$$Y_{L01} = \frac{18-4}{18} \times 100 = 78$$
$$Y_{L02} = \frac{18-3}{18} \times 100 = 83$$
$$Y_{L03} = \frac{18-5}{18} \times 100 = 72$$
$$Y_{L04} = \frac{18-6}{18} \times 100 = 67$$

Score of the fitness of the yard crane Z: To calculate the scores of the fitness of the yard crane with the Eq. 3, the results are illustrated as follows:

$$Z_{L01} = \frac{2}{4} \times 100 = 50$$
$$Z_{L02} = \frac{1}{3} \times 100 = 33$$
$$Z_{L03} = \frac{1}{5} \times 100 = 20$$
$$Z_{L04} = \frac{2}{6} \times 100 = 33$$

When each yard crane calculated the three scores, they will create the bidding information to the TOS. The example of the bidding information is shown in Table 3.

Synthesis score M: When the TOS receives the bidding information, the synthesis scores can be calculated as the Eq. 4 in the previous sub-section 3.3.2. The results are shown in the following equations:

$$M_{B12121} = 80 \times 0.45 + 78 \times 0.2 + 50 \times 0.35 = 69.1$$
$$M_{A} = 40 \times 0.45 + 78 \times 0.2 + 50 \times 0.35 = 51.1$$
$$M_{B24351} = 20 \times 0.45 + 83 \times 0.2 + 33 \times 0.35 = 37.15$$
$$M_{B33321} = 40 \times 0.45 + 72 \times 0.2 + 20 \times 0.35 = 39.4$$
$$M_{B43011} = 60 \times 0.45 + 67 \times 0.2 + 33 \times 0.35 = 51.95$$
$$M_{B42541} = 60 \times 0.45 + 67 \times 0.2 + 33 \times 0.35 = 51.95$$

At last all the alternative solution and the synthesis scores will be sent to the TOS for the door operator. The TOS will sort the synthesis scores and print the pick-up solution tickets by the order. In the example, the container CCLU2026752 has the highest synthesis score so it will be printed first. And the driver of the pick-up vehicle will take this ticket to pick up the container first. Then the container CCLU0000002 and CCLU0000043 have the second high score, so they will be pick up by the second.

Table 3: List of bidding information

CTN. No.	Bidding information
CCLU2026752	4; 2; 80; 78; 50
CCLU2203502 CCLU2393866	4; 2; 40; 78; 50

And the containers with the identification number CCLU2203502, CCLU2393866, FSCU9003479 and CCLU2737447 will be picked up by turns.

In this study, 15 numerical experiments are performed. The results are shown in Table 4.

From the experiments' results, we find that all the computational time are less than 5 seconds. It means that the distributed decision-making algorithm is effective and reliable.

The relation between the computational time and yard crane numbers is shown in Fig. 2. And Fig. 3 is the relation between the computational time and pick-un container numbers.

From Fig. 1 and 2 we can find that the numbers of the yard cranes has a direct bearing on the computational time. It proves that large number of computational workloads for TOS can be effectively distributed to the

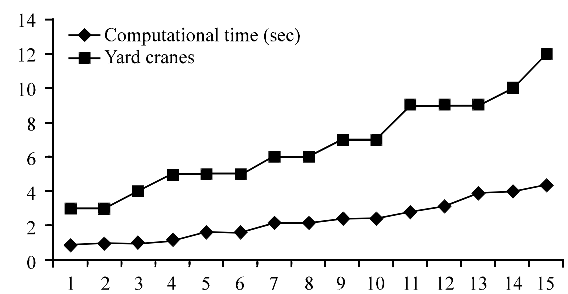

Fig. 2: Relation between the computational time and yard crane numbers

Table 4: List of numerical experiments' results

ID	Yard cranes	Block No.	Pick-up container No.	Alternative containers	Computational time (sec)
1	3	3	6	41	0.87
2	3	4	6	43	0.96
3	4	4	7	52	0.98
4	5	5	9	65	1.12
5	5	5	11	78	1.65
6	5	6	11	76	1.61
7	6	6	12	85	2.16
8	6	6	14	83	2.15
9	7	7	14	91	2.43
10	7	7	16	94	2.47
11	9	9	21	106	2.83
12	9	10	25	113	3.14
13	9	10	27	121	3.89
14	10	10	27	137	4.02
15	12	12	34	154	4.41

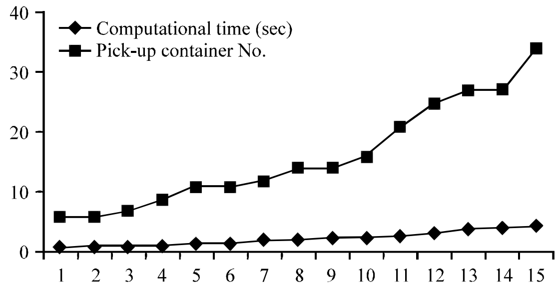

Fig. 3: Relation between the computational time and pick-un container numbers

YC mounted computes by the distributed decision-making method. The numerical experiments demonstrates that the distributed decision-making method in the pick-up operation can work effectively and has good applicability.

CONCLUSION

A distributed decision-making algorithm is proposed in this study to resolve the pick-up operations in the container yard. Under the study of the pick-up operation business process, some rules are used to select the alternative containers. And then a distributed decision-making algorithm was proposed. At last a numerical example was given. In the example the tendering and bidding information was created and the pick-up operation order list was given.

During the decision-making process, the tendering information was given to all the yard cranes. And the yard cranes calculate the bidding information for all the alternative containers in its work scope. And at last the bidding information was sent to the TOS to make the result. The distributed decision-making algorithm distributed the huge calculation woks to the multipoint decision-making nodes and received the final bidding information to get the best solution. It makes the decision-making process easy and fast. So, this method can be used in the busy pick-up operation system in the container yard.

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