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ABSTRACT

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With the development of larger ships, modernized wharves, standardized production, meticulous management, and flexible service in container transportation, port production management is becoming increasingly intelligent. How to improve the efficiency when making stowage plans, the core issue in container terminals, has become a popular topic in research. Starting with the stowage issue, this paper provides rational solutions to stowage location and loading sequence of unloaded containers on the yard, giving overall consideration on ship owners' requirement and dock authority's practical operation. Considering turnover on yard, RTG cross-container operation and RTG shifting, based on loading principles and constraints, this paper establishes an optimized model for multiple targets and creates an MCTS method, where five procedures including extension and option, together with corresponding strategies, are designed according to the search tree. Practical numerical examples indicate that the suggested model and algorithm can produce effective solution in due time. This is the first time that MCTS is applied for loading issues in container terminals, so this paper does not only use and perfect theories on optimizing, system analysis and decision, but also contribute to the intelligentization of container terminals. Relevant methods and thinking are referential and applicable to the study of issues of the same kind.

ADDITIONAL INDEX WORDS: *Container terminal, intelligentization, ship stowage, Monte Carlo Tree Search (MCTS).*

INTRODUCTION

The operation and management in container terminals include mainly storage yard management, facility management, stevedoring operation, and sail schedule management. Stevedoring operation directly affects the productivity of the terminal, and ship stowage, one of the key sections, requires to match output containers with suitable slots and load them in right sequence. Thus, lean management on stowage operation is an important channel for container terminals to reduce cost and energy consumption and improve efficiency. In addition, an effective approach to it is to conduct intellectual loading with the help of current repository.

Aiming to improve stowage efficiency, this paper takes in to consideration the ship owners and dock authority's practical requirements. Based on previous study, it establishes an optimized model, covering such deciding factors as storage yard turnover, RTG cross-container operation and RTG shifting, cross-zone stacking, and slot weight gap. In addition, this paper borrows principles from artificial intelligence research to design an MCTS for stowage solution, realizing intelligent stowage in container terminals so as to optimize the configuration of dock resources and improve its productivity and the usage of cargo handling equipment (Zhang *et al.*, 2011; Zhao *et al.*, 2011).

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OVERVIEW OF CURRENT STUDIES ON CONTAINER SHIP STOWAGE GLOBALLY

Studies and analysis on container ship stowage are mainly conducted from two perspectives, pre-stowage and actual stowage. Aiming at minimizing invalid turnover, Avriel, Penn and Shpirer (2000) created Liner Programming (LP) model in 2000, taking ship stability and other practical constraints into account. Avriel and Penn (1993) proved stowage to be an NP-Hard problem by contrast of graph coloring problem. They also put forward Suspension Heuristic Algorithm to deal with large-scale stowage problems, dynamically allocating containers for slots despite the restriction of shipping lanes. Imai and other researchers built a multi-objective stowage model, calculating the number of turnover in the field through estimation and pointing out that too many bivariates and, constraints makes it difficult to reach an optimum solution Imai and Miki (1989). Imai *et al.* (2006) defined pre-stowage problems as multi-object integer programming and worked out the non-inferior solution through weighting method. To solve MBPP, Ambrosino, Sciomachen and Tanfani (2007) tried to overcome structured operation and container parameters. They established 0-1 integer programming model for the purpose of minimizing total loading time and came up with a heuristic algorithm for pre-processing where proper loose constraint is allowed and cross-port stowage is accepted to avoid discharging and reloading, but turnover as a result of stacking is not considered (Fu and Liu, 2017). For the same problem, Sciomachen and Tanfani (2007) based on 3D-BPP (Bin Packing Problem), proposed an optimized modeling approach.

As part of Ambrosino's research in 2004, this approach is proved to be more effective after being applied with the numerical example of Porta Genova. Tierney and Pacino (2014) evaluated the influence of stowage plans on quay cranes with the aim to maximize efficiency and average crane productivity, proposing a heuristic algorithm, which was checked by the example of Porta Genova. As for multi-port pre-stowage, Tierney and Pacino (2014) defined stowage problem with the existence of hatchway cover, which requires to minimize the number of containers loaded on hatch cover. This is an NP-complete problem, belonging to the category of set-covering problem, in which even an abstract statement of container ship stowage plan problem is hard to be made.

First of all, most of the solutions from academics are pre-stowage plans from the standing of ship-owning companies, and practical considerations from the dock's point view are rare. Secondly, accompanying the development of discrete-time system study and deepening research on container stowage, researchers are prone to apply mathematical programming models, including linear programming, integer programming, or mixed programming when describing the problem in question. Most of them describe it as a single-object or multi-object combination optimization problem and utilize mixed integer programming for modelling (Ben Mariem and Chaieb, 2017; Jeon *et al.*, 2018).

More and more factors are taken into account in this issue, and many researchers tried to split this problem into smaller scales and tackle it by stages. In addition, for each sub-problem, they adopted suitable models and algorithms. Wilson and Roach (1999); Wilson and Roach (2000); Wilson, Roach and Ware (2001) divided stowage process into two stages. At the first stage, containers on cargo concentration are allocated into a block on ship and branch-bound algorithm is employed. The second phase is about how to match every specific container with a particular block and tabu search algorithm is applied herein. Ambrosino *et al.* (2009) proposed a three-stage algorithm to tackle the MBPP problem, aiming at minimizing total loading time. First, the whole ship is divided into several blocks and containers on the spot are allocated accordingly so as to reduce searching space. Then a 0-1 integer programming model is established to optimize the loading plan for each block. Finally, local search and exchange strategy are integrated. Adopted to the numerical example of Porta Genova, this approach proved to be fairly effective. Álvarez (2006) came up with a tabu search planning approach based on a couple of initial solutions, an algorithm able to solve cases of up to a hundred containers within a few seconds. Álvarez (2007) proposed Lagrangian Relaxation Approach and used Subgradient optimization to figure out relaxation factors. This approach performs more efficiently than improved MIP approach when solving small-scale problems and consumes less time in case of larger scale. Ambrosino *et al.* (2009) team employed 3D-BPP to optimize the stowage plan, evaluating both the total amount of time for loading and the usage of quay crane. Delgado *et al.* (2012) broke the problem into two phases, the first of which is to allocate containers to different bays and the second is to match bays with specific vessel slots. For the second phase, they thought of a constraint programming and integer programming. Due to the fact that it is an NP-hard problem, they turned to advanced constraint solver and modelling technique. In Delgado *et al.* (2012), two-stage method, containers are distributed to different bays at the master bay stage and then specifically located in the bay at the sub-bay stage. Monaco, Sammarra and Sorrentino (2014), however, after considering storage yard and horizontal transport, came up with 0-1 integer programming model and two-stage heuristic algorithm.

For container informations to support ship stowage planning, Mi *et al.* (2013); Mi *et al.* (2016) have done a bunch of researches about information acquisition of inbound and out bound containers.

Overall, given the complexity of stowage problem, most recent researches divided it into several stages where different sub-problems are solved. The decision variable is usually limited to location decision, namely how to match containers with slots. Most frequently used strategy is to divide it into Master Bay Plan (MBP) stage and Vessel Slot Plan (VSP) stage. The above studies did not distinguish the targets of ship-owning companies and those of the ports. Merely considering the matches between containers and container slots on ships, they gave little consideration to turnover, moving, and loading sequence in on-yard practice.

Because of NP-hard property of stowage problem, this paper chooses to design an intelligent heuristic algorithm. Probability-based MCTS, mainly applied in such gambling games as Go, multi-armed bandit, and so on, is to estimate the results based on statistics and create the search tree for stowage problem through corresponding heuristic search algorithm, strengthening the guidance to the target and reaching the ideal result. Therefore, by means of MCTS, this paper can produce valid solutions for stowage problem.

CONTAINER SHIP STOWAGE MODEL

Symbol Definition in Container Ship Stowage Model

(1) Dimension of the Model

I : aggregate of all containers to be loaded on the yard, $i, i' \in I$;

J : aggregate of container slots in bays, $j, j' \in J$;

R : aggregate of all bay numbers, $r, r' \in R$;

K : aggregate of stowage sequence numbers, namely the sequence for loading, $k, k' \in K$;

(2) Parameters of the Model

TP_i : Binary, stands for the model of container i , 1for 40-foot container, 0 for 20-footcontainer;

GP_i :Binary, stands for the height of container i , 1 for general purpose container (GP), 0 for high cube container (HC) ;

GP_r' : the number of GP on the column r of the ship's bay;

HC_r': the number of HC on the column r of the ship's bay;

CP_j : pre-planned weight of container slot j on the ship's bay;

W_i : actual weight of container i ;

$Wmin_j$: minimal weight of container slot j on the ship's bay;

$Wmax_j$: maximal weight of container slot j on the ship's bay;

$\bar{W}_r$: maximal weight for each column of the ship's bay;

ξ : maximal weight gap in double lifting operation ;

θ : maximal weight for upper container on a lower one on the ship's bay ;

$VC_{jj'}$: Binary, stands for the positions of any two container slots on the bay; the value is set to be 1when container j lies right above *container* j' , otherwise, it is 0;

$WC_{jj'}$:Binary, stands for the positions of two container slots' operation; 1 represents that they belong to the same major bay and 0 represents otherwise;

$YP_{ii'}$: Binary, stands for the positions of any two containers on the bay of the storage yard; the value is set to be 1when container j lies right above *container* j' , otherwise, it is 0;

$OB_{ii'}$: Binary, stands for the distances between any two containers and the traffic lane outside of the container area; when container i is closer to the traffic lane than container i' , it is set as 1, otherwise it is 0;

VB_{jr} : Binary, stands for the position of container slot and bay column; 1 represents that container j is located at column r and 0 represents otherwise;

S_k : the loading sequence number for container k , $S_k = 1, 2, 3, \cdots, I$;

YB_i : the bay slot number of container i on the storage yard;

BN_i : the container slot number of container i on the storage yard;

XZ_i : the container group number of container i ;

VD_j : represents that container slot j locates the lowest on the ship;

T : the greatest height of containers stored on yard.

(3) Decision Variables

independent variable:

X_{ijk} : 0-1 decision variable, indicates whether container i on storage yard could be loaded to container slot j on ship in sequence number k;

dependent variable:

$\alpha_{ii'}$: the difference between the loading sequence number of container i and container i' ;

$\beta_{ii'}$: Binary, stands for any two containers' loading sequence; if container i is loaded ahead of container i' , the value is 1, otherwise it is 0;

$\varphi_{jj'}$: the difference of container zone numbers of container slot j and j' ;

$\eta_{jj'}$: Binary, indicates whether two containers located at slot j and j' belong to the same container zone. If so, the value is 1; otherwise it is 0;

$\zeta_{jj'}$: the difference of container group numbers of containers located at slot j and j' ;

$\rho_{jj'}$: Binary, indicates whether container slot j and j' belong to the same group; if yes, the value is 1;if not, it is 0;

γ_k : the difference of zone numbers for containers of continuous loading sequence numbers;

τ_k : Binary, describes whether containers of continuous loading sequence numbers are located at the same zone. If yes, the value is 1; if not, it is 0;

ε_1 : actual weight difference of container slots on ship;

ε_2 : the difference between actual loading weight and the maximal container slot weight;

ε_3 : the difference between actual loading weight and the minimal container slot weight;

$E_{jj'}$: the weight difference between containers on slot j and j' .

Stowage Model and Constraints

subject to:

$$\min F_1 = \sum_{i,i \in I} YP_{ii'} \cdot \beta_{ii'} \tag{1}$$

$$\min F_2 = \sum_{j,j' \in J} VC_{jj'} \cdot \eta_{jj'} \cdot (1 - \rho_{jj'}) \tag{2}$$

$$\min F_3 = \sum_{i,i' \in I} OB_{ii'} \cdot \beta_{ii'} \tag{3}$$

$$\min F_4 = \sum_{k \in K} \tau_k \tag{4}$$

$$\min F_5 = \sum_{j \in J} \left| \sum_{k \in K} \sum_{i \in I} X_{ijk} \cdot W_i - CP_j \right| \tag{5}$$

$$\alpha_{ii'} = \sum_{k \in K} \sum_{j \in J} X_{ijk} \cdot S_k - \sum_{k' \in K} \sum_{j' \in J} X_{i'j'k'} \cdot S_{k'} \tag{6}$$

$$\beta_{ii'} = \begin{cases} 1 \ , \ \alpha_{ii'} > 0 \\ 0 \ , \alpha_{ii'} \le 0 \end{cases} \tag{7}$$

$$\varphi_{jj'} = \sum_{k \in K} \sum_{i \in I} X_{ijk} \cdot BN_i - \sum_{k' \in K} \sum_{i' \in I} X_{i'j'k'} \cdot BN_{i'} \tag{8}$$

$$\eta_{jj'} = \begin{cases} 1 \ , \varphi_{jj'} \ne 0 \\ 0 \ , \varphi_{jj'} = 0 \end{cases} \tag{9}$$

$$\zeta_{jj'} = \sum_{k \in K} \sum_{i \in I} X_{ijk} \cdot XZ_i - \sum_{k' \in K} \sum_{i' \in I} X_{i'j'k'} \cdot XZ_{i'} \tag{10}$$

$$\rho_{jj'} = \begin{cases} 1 \ , \zeta_{jj'} \ne 0 \\ 0 \ , \zeta_{jj'} = 0 \end{cases} \tag{11}$$

$$\gamma_k = \sum_{i \in I} \sum_{j \in J} X_{ijk} \cdot YB_i - \sum_{i' \in I} \sum_{j' \in J} X_{i'j'k-1} \cdot YB_{i'} \tag{12}$$

$$\tau_k = \begin{cases} 1 \ , \ \gamma_k \ne 0 \\ 0 \ , \ \gamma_k = 0 \end{cases} \tag{13}$$

$$\sum_{k \in K} \sum_{j \in J} X_{ijk} = 1 \tag{14}$$

$$\sum_{k \in K} \sum_{i \in I} X_{ijk} = 1 \tag{15}$$

$$\sum_{i \in I} \sum_{j \in J} X_{ijk} = 1 \tag{16}$$

$$\sum_{k \in K} \sum_{i \in I} \sum_{j \in J} X_{ijk} \cdot VB_{jr} \cdot (1 - \mathrm{GP}_i) = HC'_r \tag{17}$$

$$\sum_{k \in K} \sum_{i \in I} \sum_{j \in J} X_{ijk} \cdot VB_{jr} \cdot GP_i = GP'_r \tag{18}$$

$$Wmin_j \le \sum_{k \in K} \sum_{i \in I} X_{ijk} \cdot W_i \le Wmax_j \tag{19}$$

$$E_{jj'}=\sum_{k\in K}\sum_{i\in I}X_{ijk}\cdot W_i-\sum_{k'\in K}\sum_{i'\in I}X_{i'j'k'}\cdot W_{i'} \tag{20}$$

$$E_{jj'}\cdot VC_{jj'}\cdot\left(1-\rho_{jj'}\right)\le\theta \tag{21}$$

$$\sum_{k\in K}\sum_{i\in I}X_{ijk}\cdot S_k\le\sum_{j'\in J}\left[\sum_{k\in K}\sum_{i\in I}\left(X_{ijk}\cdot S_k\right)\right]\cdot VC_{jj'} \tag{22}$$

$$0.5\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}X_{ijk}\cdot TP_i\cdot VB_{jr}\cdot W_i+\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}X_{ijk}\cdot(1-TP_i)\cdot VB_{jr}\cdot W_i\le\overline{W}_r \tag{23}$$

$$\sum_{k\in K}\sum_{j\in J}X_{ijk}\cdot(1-TP_i)\cdot VD_j\cdot S_k\le\sum_{j\in J}VD_j \tag{24}$$

$$\sum_{k\in K}\sum_{j\in J}X_{ijk}\cdot(1-TP_i)\cdot(1-VD_j)\cdot S_k<\sum_{k\in K}\sum_{j\in J}X_{ijk}\cdot TP_i\cdot S_k \tag{25}$$

$$\sum_{j\in J}VD_j<\sum_{k\in K}\sum_{j\in J}X_{ijk}\cdot(1-TP_i)\cdot(1-VD_j)\cdot S_k \tag{26}$$

$$\left|\sum_{k\in K}\sum_{i\in I}X_{ijk}\cdot(1-TP_i)\cdot S_k-\sum_{k'\in K}\sum_{i'\in I}X_{i'j'k'}\cdot(1-TP_{i'})\cdot S_{k'}\right|\cdot WC_{jj'}\le 1 \tag{27}$$

$$\left|\sum_{k\in K}\sum_{i\in I}X_{ijk}\cdot(1-TP_i)\cdot W_i-\sum_{k'\in K}\sum_{i'\in I}X_{i'j'k'}\cdot(1-TP_{i'})\cdot W_{i'}\right|\cdot WC_{jj'}\le\xi \tag{28}$$

In objective functions, Equation (1) stands for minimal number for turnover, Equation (2) for minimal cross-zone stacking on the bay, Equation (3) for minimal times of RTG cross-container operation, Equation (4) for minimal time of RTG shifting, and Equation (5) for weight gap among container slots.

In model constraints, Equations (14), (15), and (16) stand for the relations of containers, yard container slots, and ship container slots; Equation (18) means that each column of the bay is subject to its number limit of HC and GP containers; Equation (19) indicates that containers are subject to the weight limit of the storey where they are located; Equation (21) means that for sake of navigability, heavier containers on lighter ones shouldn't overweight the established limit; Equation (22) represents that containers' loading sequence should conform to upper or lower relationships between ship container slots; Equation (23) shows that total weight of containers in a column should accord with the ceiling of the column, for which 40-foot containers are calculated by half of their actual weight and 20-foot ones are added according to their actual weight. In Equations (24), (25), and (26), it is shown that containers at the lowest slot should be first loaded, double 20-foot containers second and 40-foot ones the last. Equation (27) suggests that two 20-foot containers must be loaded continuously and Equation (28) demonstrates that in double-lifting operation for 20-foot containers, the weight gap between the two containers should be within a given limit.

Normalization of General Objective Function

The container ship stowage plan is a multi-object combination optimization problem. Sub-objects are normalized first and then their weight determined. Finally, the general objective function is generalized.

Sub-objective functions are normalized through maximum normalization, which lead to the general objective function as follows (λ_1, λ_2, λ_3, λ_4, λ_5 represent the weight of each objective.):

$$\min F=\lambda_1F_1'+\lambda_2F_2'+\lambda_3F_3'+\lambda_4F_4'+\lambda_5F_5' \tag{29}$$

ALGORITHM DESIGN FOR CONTAINER SHIP STOWAGE

MCTS Algorithm Design

To deal with the concern that stowage problem is often subject to several rules and objects, the MCTS algorithm flow is designed as shown in Figure 1.

The five steps to generate Monte Carlo stowage search tree with the help of MCTS involve five major policies, i.e. Tree Policy, Expansion Policy, Pruning Policy, Stowage Simulation Policy, Back propagation Policy. As is shown in Figure 2, all the policies are designed in accordance with Monte Carlo basic approach. By inserting stowage objects and given constraints into the search approach, we get the container ship stowage search tree based on Monte Carlo principle, so as to generate solutions for the matches between containers and slots on ship one by one.

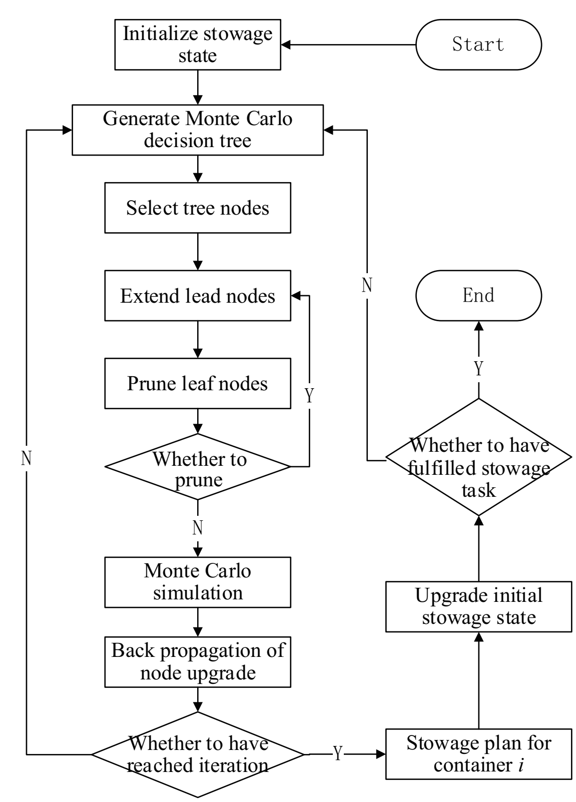

Figure 1. Flow chart of stowage plan based on MCTS algorithm.

Search Tree Node Selection Policy

After upgrading tree nodes information, the algorithm conducts the selection from root nodes to leaf nodes according to assessed value. Different selection policies lead to different approaches for tree node evaluation, among which, common methods include UCT, AMAF (All Moves As First) and RAVE (Rapid Action Value Estimation). While UCT returns a relatively ideal result, it has a slow convergence rate. Moreover, AMAF converges quickly but its result is a biased estimate. This paper adapts RAVE, which combines the two mentioned above.

UCT formula is shown in Equation (30), where Q_i stands for the returning value of node i, subject to its average expected value $\overline{E}_Q \in (0,1)$. In this formula, $\sum Q_i$ is the cumulative sum of node i's returning value after the back propagation of node message, n_i for the time node i visited and n for that of its father node.

$$UCT_i = \frac{\sum Q_i}{n_i} + 2C_p\sqrt{\frac{2\ln n}{n_i}} \tag{30}$$

AMAF formula is shown in Equation (31).

$$AMAF_i = \frac{\sum (Q_i + Q_i')}{n_i + n_i'} + 2C_p\sqrt{\frac{2\ln(n+n')}{n_i + n_i'}} \tag{31}$$

RAVE, combining the strengths of AMAF and UCT, calculates as follows:

$$RAVE_i = \alpha AMAF_i + (1-\alpha)UCT_i \tag{32}$$

Leaf Node Expansion and Pruning Policy

The expansion policy of leaf nodes is to, subsequent to the selection; enumerate all possible decisions in the next step based on current stowage state, which must be subject to all constraints in stowage model.

The pruning policy is to, following child nodes' expansion; examine all unloaded container slots with model constraints to find out the possibility of feasible solutions. If no feasible solution exists for an extension node, it will be pruned and replaced by a node randomly chosen from alternative one. The new node is examined again and the process moves onto simulation if it passes the examination.

Monte Carlo Simulation Policy

The simulation policy is to grade each pair of decisions in the simulation process in accordance with objective function, calculating the probability for each pair to be chosen, generating the sampling distribution, based on which, the process simulates to the end condition. As is shown in Figure 3, the policy finished the extension of a before simulating the stowage of container slot b to n, subject to constraints. When deciding for container slot b, 6 containers weighing 15 to 20 tons on yard A0102 are available, with the possibility to cause different results in terms of turnover, cross-zone stacking, cross-container operation, RTG shifting, and container slot weight gap. Therefore, the policy uses random

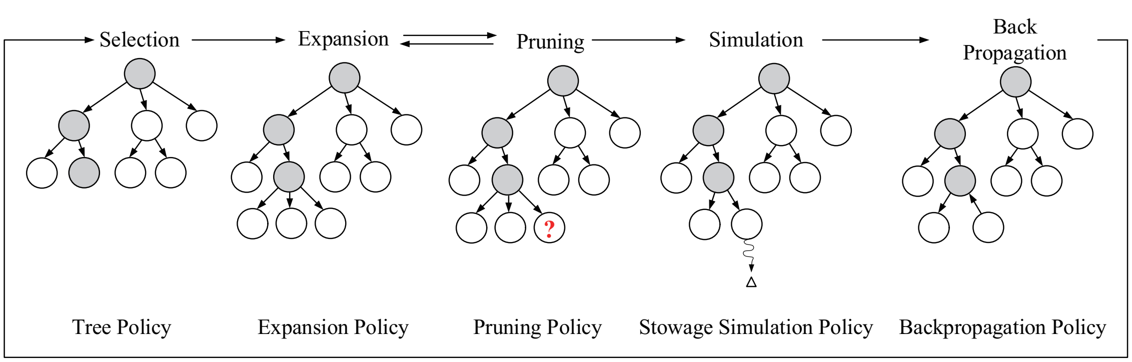

Figure 2. Framework of MCTS stowage plan algorithm.

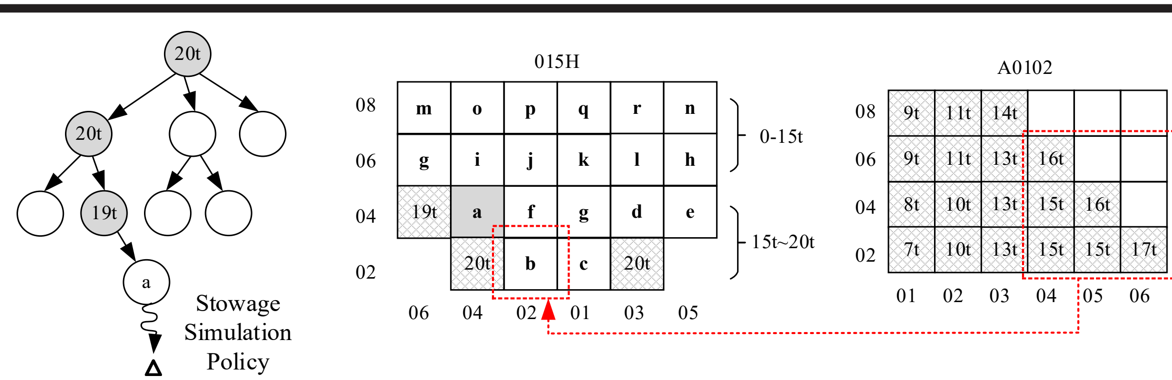

Figure 3. diagram of simulation decision.

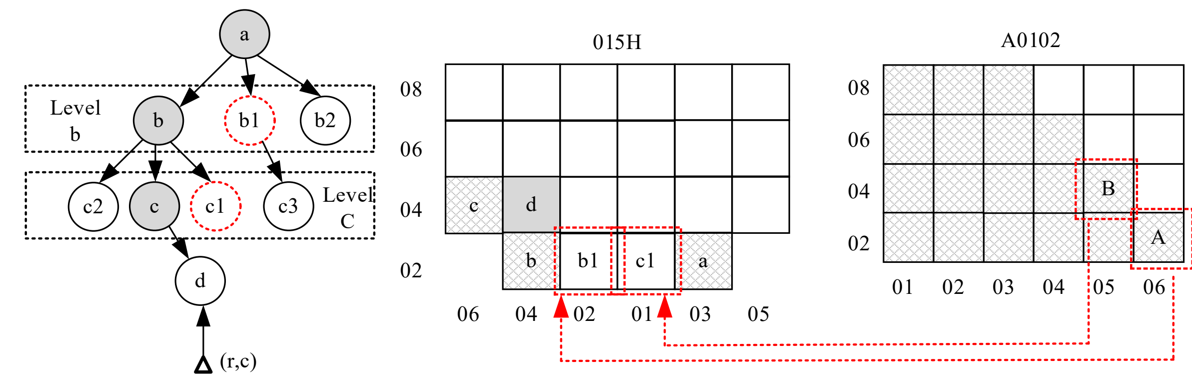

Figure 4. AMAF information back propagation strategy.

Table 1. *Calculating objective functions.*

Sub-objective function	Time of turnover	Number of cross-zone stacking	Time of cross-container operation	Time for RTG shifting	Weight gap of container slots
Weighting coefficient	0.2	0.1	0.1	0.3	0.3
Result	1	16	17	16	323.66

sampling to decide which container could lead the sampling in positive direction, thereby accelerating convergence.

In stowage simulation policy, every time a container's stowage is simulated, all containers on ship will be evaluated as a whole. This research introduces roulette wheel in simulation and calculates the probability to choose each solution by the overall evaluation.

There are two constrictions for termination status E_0 in the simulation. The simulation ends when the stowage is finished and the general objective function value is determined or when there is no container for loading during the process, marking the failure of this solution, and the general objective function value records 0.

Back Propagation of Tree Nodes

In this paper, we adopt AMAF strategy to conduct basic back propagation, as is shown in Figure 4. In this process, container A is allocated to b1 and container B to c1. Because of the existence of identical decision nodes c1 and b1 in the search tree, when (r , c) is updated in node c, the value of its sibling c1 at level c is updated at the same time; the same is true of node b and its sibling b1. In this simulation, r stands for return value, c for the times the node is visited. In addition, in UCT strategy, the selected nodes, d, c, b, a, are successively upgraded in back propagation.

CONTAINER SHIP STOWAGE CASE STUDY

The data used for case study is collected from a ship in a dwarf of Shanghai Port, involving 54 containers, including twenty-six 40-foot containers and twenty-eight 20-foot containers.

Sub-objective function values from the algorithm are shown in Table 1.

For stowage on bay, cross-zone stacking containers record 16 and weight gap of container slots on ship totals 323.66 tons.

In terms of stowage on yard, cross-zone stacking containers record 17 and the RTG moves for 16 times. In this case, containers to be loaded are distributed on 15 bays of 6 zones, thus the RTG will be moved at least for 14 times, plus 2 times of unnecessary moving.

Iterate RAVE-MCTS for 100 to 2000 times and we get convergence graphs of the five normalized sub-objective functions, as is shown in Figure 5. All the graphs converges, which means that the more it is iterated, the larger the samples, the more precise the estimation is. So, better solutions can be found. Nevertheless, the optimum solution doesn't show an opposite trend when iteration times accumulate, instead, it decreases before stabilizing, indicating that the algorithm shows good convergence characteristics.

Figure 6 shows the trend of general function value. When iteration time exceeds 1600, the curve tends to converge.

Monte Carlo algorithm is applied in the stowage of 20 container ships bearing different amount of containers in reality. Main parameters of the results are listed as below:

Table 2. *Results of large-scale examples.*

Main objective	Average turnover rate (%)	Average cross-zone stacking rate (%)	Average unnecessary RTG shifting rate (%)
value	7	32	17

In large-scale examples, the algorithm determines the values of the following objectives: Average turnover rate at 7%, average cross-zone stacking rate at 32%, average unnecessary RTG shifting rate at 17%. The results indicate that the algorithm meets the performance requirements of real-case production on the wharf.

CONCLUSIONS

This paper, based on comprehensive analysis of dock stowage operations and principles, divides practical stowage into two stages, i.e. container starting point calculation and container

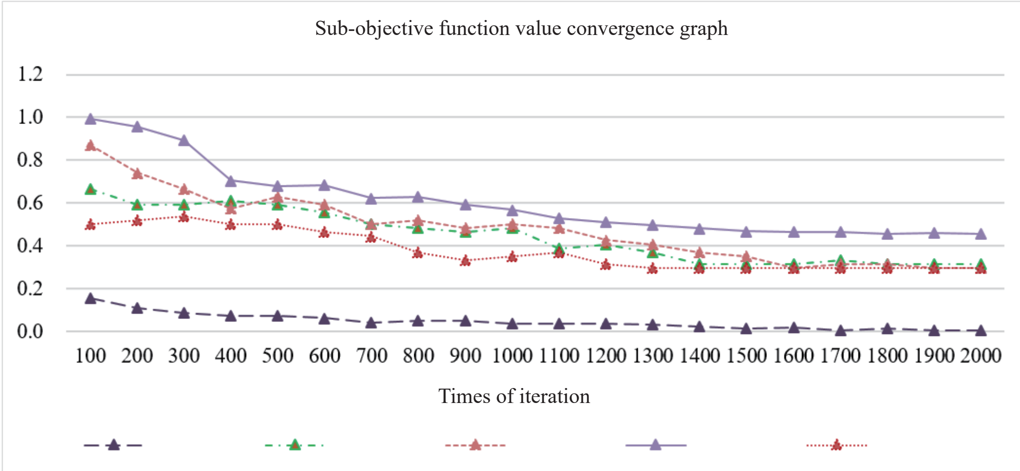

Figure 5. Sub-objective function value convergence graph.

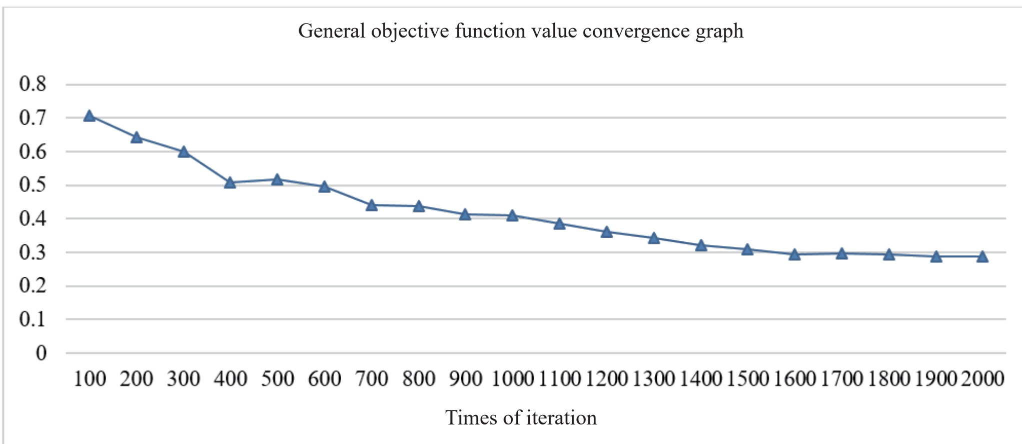

Figure 6. General objective function value convergence graph.

distribution decision, to deal with practical problems in stowage. Based on the results for starting point, it focuses on stowage decision. After extracting key objectives and constraints, this paper proposes a multi-object combination optimization model, in an effort to reduce turnovers on yard, RTG shifting and trolley moving, cross-zone stacking operation on the bay and to minimize the gap between calculated stowage results and the ideal result.

For the first time, this paper applies MCTS to container ship stowage solution and establishes a generating algorithm accordingly. In the simulation policy, it utilizes roulette wheel to design the simulation for stowage, for the purpose of stowage objectives. In this way, it keeps the algorithm in correct direction, increases its sufficiency and ensures that the process moves randomly, which conforms to its probability-based nature. RAVE-MCTS enables us to reach the ideal solution with greater possibility and less time, enhancing the effect of the algorithm in stowage problem.

For practical cases of some ships on a dock of Shanghai Port, the established model and algorithm result in relatively desired results, proving the model to be correct and the algorithm to be effective, applicable, and stable.

In conclusion, the stowage model and MCTS algorithm in this paper can provide feasible solutions for the complex problem of container ship stowage, which are applicable in practice. Relevant thinking and methods are referential and applicable to the study of planning and dispatching issues on container terminals.

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