Stacking Position Allocation Model Based on Automatic Rail Crane

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Abstract. In order to reduce the energy consumption of the automated container terminal, based on the operation of the container in the yard, this paper used the travel distance of the automatic rail crane to represent the energy consumption problem to study the problem of container allocation. Under the premise that the operating time of inbound container was known, this paper took the number of pressurized containers as a limiting condition, and established the allocation model of the storage space to minimize the travel distance of the automatic rail crane. Considering that the model had a large calculation scale and was an NP-hard problem, a genetic algorithm was used to solve it. Example analysis results show that the model and algorithm can effectively reduce the travel distance of the automatic rail crane by 17.02% under the premise of controlling the number of pressure boxes.

Keywords: Automated track crane; Automated terminal; Container allocation; Genetic algorithm; Terminal energy consumption.

1. Introduction
Reducing the transfer time of containers and increasing the throughput of containers have always been the goal of container terminal development, and automated terminals have emerged in this context. In order to reduce the docking time of container ships at the docks and make full use of the resources of the docks, the operations of the containers at the docks need to be closely connected, and the optimization of container binning operations is at the forefront. On the basis of not increasing the work of all links in the container, energy consumption should be reduced as much as possible, and the utilization efficiency of resources should be improved. The container allocation problem of the container terminal is an NP-hard problem, and a heuristic algorithm is needed to solve it. In this paper, heuristic algorithms will be used to solve the container allocation problem, and the objective function considers both the number of pressure boxes and energy consumption to improve the operating efficiency of the terminal.

With the development of automated terminals and the development of container transportation, the problem of containers’ position optimization has become a hot spot in recent years. From the perspective of workload, Park [1] et al. established an optimization function that balanced the workload of different tank areas, and selected specific tanks based on the weighting function determined by space and yard utilization. Mohammad Bazzazi, Nima Safaei and Nikbakhsh Javadian [2] classified containers into different types according to the nature of the work. They solved the problem...
while balancing the workload between different container areas and minimizing the working time of the container. Tonguç Ünlüyurt and Cenk Aydınlı [3] minimized the working time of removing containers from the container area in a predetermined order while taking into account the travel distance of the crane. They designed a branch and bound algorithm to solve the problem. Gamal Abdelnasser [4] minimized the distance traveled by container trucks and balanced the workload of different bins. Jiabin Luo, Yue Wu and André Bergsten Mendes [5] focused on vehicle scheduling and container allocation in automated terminals. They used a mixed integer programming model to minimize the waiting time of ships, and solved the problem through genetic algorithms. Bo Lu, Jiazhi L and Qiancheng Zeng [6] comprehensively considered the terminal's transportation operations and storage operations, and set the objective function as minimizing working time. They established a model of automatic lifting vehicles and container allocation, and used a heuristic algorithm based on genetic algorithms to solve the model. Chenhao Zhou, Ek Peng Chew and Loo Hay Lee [7] studied an automatic terminal that using a hybrid GRID system, then established an empirical model based on mixed integer programming, and proposed a near-optimal container allocation strategy.

From the angle of the number of pressure boxes, Huang and Ren [8] classified the container into three levels based on weight and minimized the number of press boxes through the simulated annealing algorithm. Christopher Expósito-Izquierdo, Belén Melián-Batista and Marcos Moreno-Vega [9] determined the priority of the containers according to the operation time, then established the objective function with the least number of operations. Huirong Wu and Xiaoning Zhu [10] divided containers into six categories according to the operation content of the container. Considering the operation of the container, the objective function was set to minimize the number of press boxes generated after the container was stacked. In terms of energy consumption of automated terminals, Ding, Y., Wei, X. J., Yang, Y. and Gu, T. Y. [11] established a two-layer mathematical model which focused on automated container terminal cranes and used tandem elevators to determine the order of operations for containers during feasible calculation time. Mengjue Xia, Ning Zhao and Weijian Mi [12] designed a two-level structure for the container allocation problem of an automated terminal, and established a mixed integer programming model for the upper structure and solved it by particle swarm optimization.

Through the literature review, it can be found that the allocation of containers affected by the energy consumption is still rare. According to the operation line of the container in the dock yard, this paper transforms the energy consumption problem into the travel distance of the automatic track crane, and considers the influence of the number of pressure boxes to design the tank allocation plan.

The rest of the paper is organized as follows: Section II introduces the background of the automated terminal. Section III introduces the research methodology used in this paper. Section IV provides the calculation results. Section V is the conclusion and future outlook of this paper.

2. Background
The location of containers in the yard of an automated container terminal is often determined by the following factors.
- The container area: the interior of the yard is divided into large areas according to the type of container and the operating range of the automatic rail crane.
- The number of shells: the same container area is divided into several parts according to the length of the container.
- The number of rows: the same container area is divided into several parts according to the width of the container.
- The number of layers: the same container area is divided into several parts according to the height of the container.

For example, a code 05030202 represents a location of containers in 5th-area, 3rd-shell, 2nd-row and 2nd-layer. The representation of the containers is shown in Figure 1.
During the automatic container terminal yard operation, containers need to be extracted or stacked. When the containers are stored in a mixed storage at the terminal, due to the different departure time of the containers, there may be cases in which containers with a later departure time need to be stacked above the departing containers. In this case, when the lower-level container needs to be extracted, the upper-level container needs to be placed in another container position first in which usually stacked in the same area, and this operation is called flipping. The interference from the upper container to the lower container is called pressing, and the number of pressing boxes is the number of upper containers which pick-up time is later than the lower containers. In Figure 2 below, the number of press boxes in the first row is 0, the number of press boxes in the second row is 1, and the number of press boxes in the fifth row is two.

There are multiple operations of the container at the automatic terminal. Taking the operation process of a container arriving at the automatic terminal on the ship as an example, the process will be briefly introduced. First, the main trolley of the automatic double trolley suspension bridge will grab the container on the ship through the keyhole, and after transporting to the bridge crane platform, the corresponding trolley will place the container on the automated guided vehicle (AGV) which waiting under the corresponding crane. AGV will deliver the container to the terminal yard. During the transportation, AGV will adjust the route according to the traffic conditions inside the terminal, optimize the instructions, and prevent friction and collision. Finally, AGV will arrive at the yard, and stay at the designated position by laser or other positioning system. The container will be grabbed by the automatic rail crane to the corresponding container location.

### Research Methods

According to the operation process of the container in the automated dock, this paper establishes a model of the automatic rail crane which is the equipment for grabbing the container, to give a plan of container allocation.

#### 3.1. Model hypothesis

- Each location is determined by three factors: shell number, row number and layer number. When considering the movement of the automatic rail crane, three directions are considered, and the automatic rail crane moves from the starting position to the containers that need to be stacked.
- The orders in which containers come in and come out are known, and the total number of containers are known.
• The container yard only stacks containers during the stacking process.
• All containers’ type is 40 feet.

3.2. Symbol and variable definition

\( n \) indicates the order of operations of containers within the planned period:

\[ n = \{ n \mid n = 1, 2, \ldots, N \} \]

\( b \) indicates the shell number in the box area:

\[ b = \{ b \mid b = 1, 2, \ldots, B \} \]

\( r \) indicates the number of rows in the box area:

\[ r = \{ r \mid r = 1, 2, \ldots, R \} \]

\( l \) indicates the number of layers in the box:

\[ l = \{ l \mid l = 1, 2, \ldots, L \} \]

\( d_{brl}^n \) indicates the distance that gantry crane moving the \( n \)th work container from starting point to the position of \( b \)-shell \( r \)-row \( l \)-layer.

\( Y_{brl} \) indicates the condition of the position of \( b \)-shell \( r \)-row \( l \)-layer:

\[ Y_{brl} = \{ Y_{brl} \mid Y_{brl} = 1 \text{ if the position is assigned to a container}, \quad Y_{brl} = 0 \text{ if the position is unassigned to a container} \} \]

3.3. Objective function

\[ f = \min \sum_{n=1}^{N} \sum_{l=1}^{L} \sum_{r=1}^{R} \sum_{b=1}^{B} d_{brl}^n \]

\[ \sum_{l=1}^{L} \sum_{r=1}^{R} \sum_{b=1}^{B} d_{brl}^n = l \]

\[ Y_{brl} - Y_{br(l-1)} \leq 0 \]

\[ b \in [1, B], r \in [1, R] \]

\[ l \in [1, L], e \in [1, l-1] \]

The objective function of this paper is to minimize the travel distance of the automatic rail crane. As shown in Equation 1, the distance that the automatic rail crane places all containers along the three directions is the shortest. Equation (2) means that each container can only occupy one position. Equations from (3) to (5) indicate that the container cannot be suspended, and it also specifies that when \( l = 1 \), \( Y_{br(1-e)} = 1 \).

3.4. Genetic algorithm

Since the container allocation problem is an NP-hard problem, heuristic algorithms are often used to solve them, and genetic algorithm one of the heuristic algorithms is commonly used. Taking into account the characteristics of container positions, this paper uses genetic algorithms to solve the model.

3.4.1. Chromosome coding and generation of initial solutions

In order to facilitate the storage information of the arrival container, an array \( A(x, y, z, n, t) \) is designed, where \( x \) is the shell number of the container, \( y \) is the row number of the container, and \( z \) is the layer number of the container, \( n \) is the serial number of the container’s arrival code, and \( t \) is the serial number of the container’s left code. The formation of the initial solution is generated by means of random numbers,
and then its feasibility is tested, and the infeasible individuals are corrected until all individuals in a population are feasible solutions.

3.4.2. Design of fitness function

The fitness function takes the shortest travel distance of the automatic rail crane into account. At the same time, it considers the time problem of the scheme, so a penalty function is added to the fitness function. For the two containers in the same row, if the upper container’s picking time is later than the lower container, the value of the fitness function will reduce.

3.4.3. Determination of genetic operators

a) Select operator

In this paper, the strategy of roulette is used to select individuals in the population. The probability that each individual be selected is proportional to its fitness value.

b) Crossover operator

In this paper, a random intersection is used. For the selected two individuals, the values of the three elements \((x, y, z)\) can be exchanged randomly. The specific situation is shown in Figure 3 below.

\[
\begin{array}{|c|c|c|}
\hline
\text{First generation} & \text{Container 1} & \text{Container 2} & \text{Container 3} \\
\hline
A & 12133 & 32124 & 21215 \\
B & 22133 & 32224 & 32115 \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{Second generation} & \text{Container 1} & \text{Container 2} & \text{Container 3} \\
\hline
A & 22133 & 32124 & 32115 \\
B & 12133 & 32224 & 21215 \\
\hline
\end{array}
\]

Figure 3. Stacking diagram of a container yard.

c) Mutation operator

By randomly generating a random number, determining which gene in the individual to mutate (only for the position variable), then generating appropriate a variant gene to replace the original gene.

3.5. Case analysis

In this example, the yard has a total of 400 containers’ positions in 5 shells, 20 rows and 4 lays, and it needs to allocate positions for 50 arriving containers at the port. Assuming that the order of the arrival containers is shown in table 1 and table 2, and the yard is empty. It is required to arrange the position of each container according to the pick-up time of the container and the total movement of the automatic rail crane.

Because the automatic rail crane grabs the container from the same position each time which means the travel distance of the automatic rail crane during the process of unloading and lifting the box is the same, so in this example the calculation is performed only once. The fitness function is calculated by adding and accumulating the length, width, and height of the container, that is, the distance between adjacent shells is the length of the container, the space between the rows is the width of the container, and the height between the floors is the height of the container. For the constraints of the objective function, a judgment function is used for the generated bin allocation scheme to ensure that the container is not suspended and its position is unique.
Table 1. Container arrival information from 1 to 30.

| number | left time | number | left time | number | left time |
|--------|-----------|--------|-----------|--------|-----------|
| 1      | 1         | 11     | 2         | 21     | 2         |
| 2      | 2         | 12     | 1         | 22     | 1         |
| 3      | 2         | 13     | 1         | 23     | 2         |
| 4      | 1         | 14     | 1         | 24     | 2         |
| 5      | 1         | 15     | 1         | 25     | 1         |
| 6      | 2         | 16     | 2         | 26     | 1         |
| 7      | 1         | 17     | 1         | 27     | 1         |
| 8      | 2         | 18     | 2         | 28     | 1         |
| 9      | 1         | 19     | 1         | 29     | 2         |
| 10     | 2         | 20     | 2         | 30     | 2         |

Table 2. Container arrival information from 31 to 50.

| number | left time | number | left time |
|--------|-----------|--------|-----------|
| 31     | 1         | 41     | 2         |
| 32     | 2         | 42     | 2         |
| 33     | 2         | 43     | 2         |
| 34     | 1         | 44     | 1         |
| 35     | 2         | 45     | 2         |
| 36     | 1         | 46     | 1         |
| 37     | 2         | 47     | 2         |
| 38     | 1         | 48     | 1         |
| 39     | 1         | 49     | 2         |
| 40     | 1         | 50     | 1         |

4. Experimental Result

In this experiment, the specified population is 80, and the number of iterations is 400, and the experimental hardware is i5 CPU 1.7GHz, 3.9GB RAM, Windows 8.1. After 400 iterations, the algorithm results converge. The distribution of the resulting container locations is shown in table 3 and table 4. The graphic representation of container allocation is shown in Figure 4. In the figure the green color indicates that the pick-up time is the first period, and the blue color indicates the second period. In this scheme, the distance directly traveled by the automatic rail crane is 2895.575m and the number of pressure boxes is 2. In the actual production, the general terminal often adopts the principle of bin allocation with priority and shell position without considering other factors. Under this principle, the distance of the automatic rail crane is 2475.873m, and the number of pressure boxes is 9. It is assumed that the automatic rail crane will generate the same travel distance as the current operation for the secondary operation of generating the pressure box container.

Table 3. Container allocation from 1 to 30.

| number | location  | number | location  | number | location  |
|--------|-----------|--------|-----------|--------|-----------|
| 1      | (4,19,1)  | 11     | (1,6,1)   | 21     | (3,16,1)  |
| 2      | (4,13,1)  | 12     | (5,10,1)  | 22     | (1,13,1)  |
| 3      | (2,3,1)   | 13     | (3,11,1)  | 23     | (1,1,1)   |
| 4      | (4,2,1)   | 14     | (4,4,1)   | 24     | (1,1,1)   |
| 5      | (4,7,1)   | 10     | (4,12,1)  | 25     | (4,1,1)   |
| 6      | (3,18,1)  | 16     | (2,9,1)   | 26     | (4,11,1)  |
| 7      | (5,1,1)   | 17     | (1,9,1)   | 27     | (3,16,1)  |
| 8      | (2,11,1)  | 18     | (2,5,1)   | 28     | (3,8,1)   |
| 9      | (1,4,1)   | 19     | (2,6,1)   | 29     | (1,16,1)  |
| 10     | (4,12,1)  | 20     | (1,14,1)  | 30     | (4,18,1)  |
Table 4. Container allocation from 31 to 50.

| number | location | number | location |
|--------|----------|--------|----------|
| 31     | (4,18,2) | 41     | (2,16,1) |
| 32     | (4,8,1)  | 42     | (4,6,1)  |
| 33     | (4,7,2)  | 43     | (3,9,1)  |
| 34     | (2,9,2)  | 44     | (2,1,1)  |
| 35     | (2,10,1) | 45     | (3,14,2) |
| 36     | (3,1,1)  | 46     | (2,18,1) |
| 37     | (1,2,1)  | 47     | (2,13,1) |
| 38     | (3,18,2) | 48     | (2,2,1)  |
| 39     | (3,14,1) | 49     | (2,17,1) |
| 40     | (3,4,1)  | 50     | (2,2,2)  |

Figure 4. The result of container allocation.

Table 5. Travel distance calculation.

| method | direct distance/m | number of pressure boxes | conversion distance/m | total distance/m |
|--------|-------------------|--------------------------|------------------------|-----------------|
| new    | 2895.575          | 2                        | 82.898                 | 2978.473        |
| normal | 2475.873          | 9                        | 1113.691               | 3589.564        |

It can be seen from Table 5 that under new method the total distance traveled by the automatic rail crane is 2978.473m while under normal method the distance is 3589.564m. The design algorithm reduces the overall travel distance by 17.02%.

5. Conclusions

According to the operation of the container in the automated terminal, this paper considers the energy consumption of the terminal into the influencing factors of the allocation of the container. The objective function is established by placing the automatic rail crane to the running distance generated by the corresponding box, and the genetic algorithm in the heuristic algorithm is used to solve the problem. After 400 iterations, the optimal allocation scheme is obtained.

However, the travel distance of the automatic rail crane is directly equivalent to energy consumption in this article, and in the actual situation it should be measured by the fuel consumption caused by the start and stop of the main rail and auxiliary trolley of the automatic rail crane. At the same time, when calculating the moving distance of the automatic rail crane generated by the pressure box this paper only uses the approximate method, and the optimal position of the secondary movement is not considered. In addition, this paper only considers the energy consumption at the yard. In the future, future research can be comprehensively optimized from the entire container operation at the terminal.

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References

[1] Park T, Choe R, Kim Y H, et al. Dynamic adjustment of container stacking policy in an automated container terminal[J]. International Journal of Production Economics, 2011, 133(1):385-392.

[2] Bazzazi M, Safaei N, Javadian N. A genetic algorithm to solve the storage space allocation problem in a container terminal[J]. Computers & Industrial Engineering, 2009, 56(1):44-52.

[3] Ünlüyurt T, Cenk Aydar. Improved rehandling strategies for the container retrieval process[J]. Journal of Advanced Transportation, 2012, 46(4):378–393.

[4] Guldogan E. Simulation-based analysis for hierarchical storage assignment policies in a container terminal[J]. Simulation Transactions of the Society for Modeling & Simulation International, 2011, 87(6):523-537.

[5] Luo J, Wu Y, Mendes, André Bergsten. Modelling of integrated vehicle scheduling and container storage problems in unloading process at an automated container terminal[J]. Computers & Industrial Engineering, 2016:S0360835216300031.

[6] Bo L U, Jiazhi L, Qingcheng Z. Integrated optimization model for automated lifting vehicles scheduling and yard allocation at automated container terminals[J]. Systems Engineering-Theory & Practice, 2017.

[7] Zhou C, Chew E P, Lee L H. Information-Based Allocation Strategy for GRID-Based Transshipment Automated Container Terminal[J]. Transportation Science, 2017:trsc.2017.0736.

[8] Huang J S, Ren Z Z. Research on SA-Based Addressing Model of Slot in Container Terminal[J]. Applied Mechanics & Materials, 2011, 97-98:985-989.

[9] Expósito-Izquierdo C, Melián-Batista B, Moreno-Vega M. Pre-Marshalling Problem: Heuristic solution method and instances generator[J]. Expert Systems with Applications, 2012, 39(9):8337-8349.

[10] Huirong Wu, Xiaoning Zhu, Container Slot Allocation Model of Mixed Storage in"Ships, Yard, Trains"Yard[J]. Journal of Transportation Systems Engineering and Information Technology, 2015,15(4):198-203.

[11] Ding Y, Wei X J, Yang Y, et al. Decision support based automatic container sequencing system using heuristic rules[J]. Cluster Computing, 2017, 20

[12] Mengjue X, Ning Z, Weijian M. Storage Allocation in Automated Container Terminals: the Upper Level[J]. Nephron Clinical Practice, 2016, 23(s1):160-174.