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Modelling of Dual-Cycle Strategy with Straddle Carrier at Automated Container Terminals

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Abstract

With the improvement of automatic container terminal, the application of straddle carrier has been more extensive. Compared with the AGV, the straddle carrier can independently complete the operations of pick-up, handling, stacking, loading and unloading, etc., which greatly improves efficiency of terminal. In this paper, the straddle carrier is used as the horizontal transportation equipment, and the operation way is loading and unloading mode. The mathematical model with the shortest total operation time of straddle truck operation was established. Tabu search algorithm and simulate anneal algorithm were used to solve the problem. Compared with the AGV operating system, the results show that, under loading and unloading mode, the straddle carrider operating system is more efficient with the same wharf configuration.

Keywords

Straddle Carrier; Loading and Unloading; AGV; Automatic Container Terminal.

1. Introduction

In the past few years, with the continuous increase of Global trade volume, container terminals are also developing rapidly. Compared with the traditional container terminals, automated container terminals have greater advantages. Countries around the world have made great efforts to build shipping hubs and major ports in the world, and ports around the world have developed rapidly, leading to increasingly fierce competition among ports. The terminal needs to serve container ships as quickly as possible to improve efficiency and reduce terminal operating costs. In this context, for the modern container terminal, the terminal equipment needs to be effectively used in the process of container handling. Equipment coordination plays a very important role in terminal operation.

Container straddle carrier is the main type of container handling equipment. It usually undertakes the horizontal transportation from the quay to the yard and the stacking of containers in the yard. Through the straddle carrier, a variety of operations can be completed by one machine, including self collection, handling, stacking, loading and unloading, without the assistance of other machinery. Compared with the traditional horizontal transportation equipment such as container trailer and container automatic guided vehicle, the quay crane only needs to unload the container at the front of the wharf, and the straddle carrier can grab and transport the container by itself. It can save operation time and give full play to the operation efficiency of quayside crane equipment without accurate alignment loading and other truck related actions. It simplifies the type of loading and unloading, the number of equipment and the management of transportation system.

In order to improve the operation efficiency of the wharf, the operation mode is loading and unloading at the same time. When the container is picked up from the loading and unloading area of the ship to the loading and unloading area on the bridge, the container is returned to the shore when the ship is

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in the loading and unloading area. The straddle carrier needs to transport the imported containers unloaded from the ship to the import container area, then drive to the export box area, grab the containers to be exported and transport them to the quay crane exchange area. Each time a straddle truck unloads a container in the quayside crane handling area, it must also pick up a container. In this way, the operation efficiency of straddle carrier and quay crane can be greatly improved. In this paper, loading while unloading refers to that both quay crane and straddle carrier carry containers in the process of round trip.

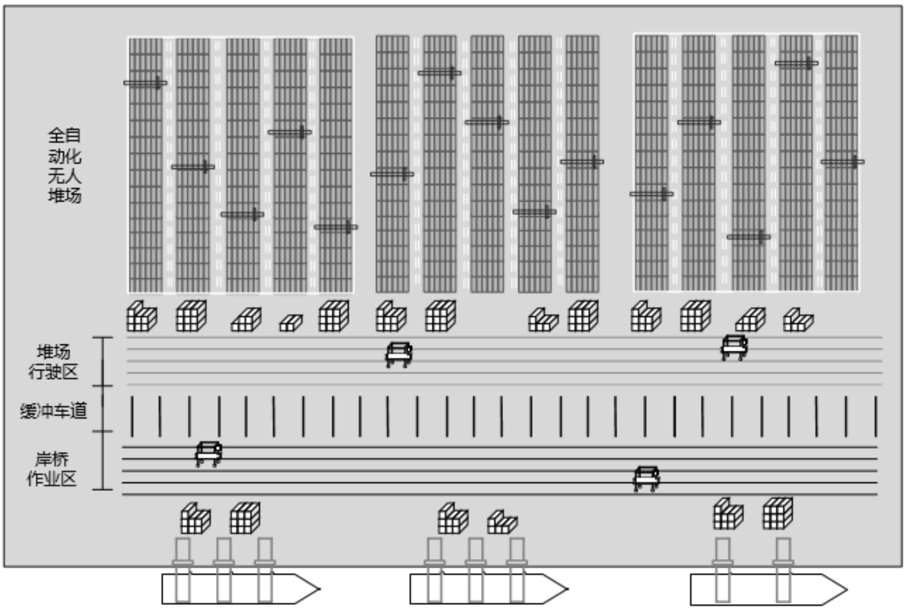

Figure 1. Schematic diagram of straddle carrier operation

2. Literature Review

Aiming at ASC scheduling problem, Liu Guanghong[1]summarized 10 typical general layout modes of automated container terminals, and analyzed the characteristics of each mode.According to the straddle carrier technology, the mode of "single trolley quay crane + straddle carrier (vertical wharf layout)" and "single trolley quay crane + straddle carrier + armg" mode are proposed.Cai[2-4]and others considered three objectives, namely, transportation time, waiting time and completion time of high priority container transfer operation, established a binary integer programming model, and proposed a boundary precision algorithm based on column generation (bbcg) and train generation method to solve the scheduling problem of automatic cross carrier.Skinner[5]solved the model by genetic algorithm, which improved the efficiency of container handling and ASC utilization. Hamdi Dkhil [6] proposes a comprehensive multi-objective problem, which considers both the container storage location problem and the cross truck scheduling problem, and uses tabu search algorithm to solve the problem. YUAN [7] researched the path optimization and task allocation of no collision ASC in the yard, and establishes a mathematical model to solve the problem.

For loading and unloading model,Zhang Rui[8] established an integer programming model of synchronous loading and unloading in the same bay. By optimizing the sequence of loading and unloading operations, reducing the operation time of quayside cranes, optimizing the loading sequence of containers in the yard and reducing the turnover time of yard bridges, a genetic algorithm was designed to solve the problem.In order to minimize the empty rate and the shortest moving distance of straddle carrier, Liang Chengji[9]established an integer programming model, and used heuristic algorithm and adaptive genetic algorithm to analyze and solve the problem.The model of loading and unloading based on quay crane AGV joint scheduling is established by Luo Jiabin[10]and solved by genetic algorithm.

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3. Model construction

3.1 Basic Assumptions

(1) In this paper, we only consider the loading and unloading operations, and do not consider the port collection and container handling business;

(2) All the containers in this paper are uniform in size and are all 20 foot boxes;

(3) Quay cranes and straddle carriers can only carry one container at a time;

(4) There are enough empty container spaces in the yard to accommodate containers.

3.2 Basic Parameter Setting

Table 1. parameter definition

Symbol	Definition
Q	Quantity set of quay crane Q
V	The quantity set of straddle carrier V
Y	The number set of field bridge y
hs	Operation time of quay crane
h	Single container operation time of quay crane
ts	Starting time of field bridge
t	Single container operation time of yard Bridge
πs	Ashc start time
π	Operation time of ashc single container
τ	Travel time of ashc from quayside crane loading area to container area
tei	Travel time of ashc in inlet and outlet tank areas
TS	Start time of the first container
TF	Last container completion time
bi	Import box area
be	Export box area
SA	Ashc first task set
FA	Ashc last task set
SQ	First task set of quayside crane
FQ	The last task set of quayside crane
SY	Field bridge first task set
FY	Last task set of field bridge
C	Number of containers to be exported in container area
N	Number of containers unloaded from the ship

3.3 Decision Variables

$$X_{(i,j)}^{(k,l)} = \begin{cases} 1, & \text{container(i, j)、(k, l)are worked by same ASHC, and(i, j)earlier than(k, l)} \\ 0, & \text{otherwise} \end{cases}$$

$$Y_{(i,j)}^{(k,l)} = \begin{cases} 1, & \text{(i, j)is inport container, (k, l)is export container} \\ 0, & \text{otherwise} \end{cases}$$

$$Z_{(i,j)}^{(k,l)} = \begin{cases} 1, & \text{container(i, j)、(k, l)are worked by same QC, and(i, j)earlier than(k, l)} \\ 0, & \text{otherwise} \end{cases}$$

$$W_{(i,j)}^{(k,l)} = \begin{cases} 1, & \text{container(i, j)、(k, l)are worked by same YC, and(i, j)earlier than(k, l)} \\ 0, & \text{otherwise} \end{cases}$$

$$\varepsilon_{(i,k)}^{b_i} = \begin{cases} 1, & \text{import container will be sent to corresponding area} \\ 0, & \text{otherwise} \end{cases}$$

$$\theta_{(k,l)}^{b_e} = \begin{cases} 1, & \text{export container will be sent to corresponding area} \\ 0, & \text{otherwise} \end{cases}$$

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3.4 Objective Function

$$\min\left(T_F - T_S\right)$$

$$\min\sum\left(X_{(i,j)}^{(k,l)} + Z_{(i,j)}^{(k,l)} + W_{(i,j)}^{(k,l)}\right)$$

Objective function 1 represents the shortest total operation time, and function 2 represents the minimum total equipment movement times, which means the highest operation efficiency.

$$\sum \varepsilon_{(i,j)}^{b_i} = 1 \quad (1)$$

$$\sum \varepsilon_{(i,j)}^{b_e} = 1 \quad (2)$$

$$\sum_{(i,j)\in S_A} X_{(i,j)}^{(k,l)} = 1 \quad (3)$$

$$\sum_{(k,l)\in F_A} X_{(i,j)}^{(k,l)} = 1 \quad (4)$$

$$\sum_{(i,j)\in S_Q} Z_{(i,j)}^{(k,l)} = 1 \quad (5)$$

$$\sum_{(k,l)\in F_Q} Z_{(i,j)}^{(k,l)} = 1 \quad (6)$$

$$\sum_{(k,l)\in F_Q} Z_{(i,j)}^{(k,l)} = 1 \quad (7)$$

$$\sum_{(k,l)\in F_Q} Z_{(i,j)}^{(k,l)} = 1 \quad (8)$$

$$\sum X_{(i,j)}^{(k,l)} \geq (N+C)/2 \quad (9)$$

$$h_{(i,j)}^{s} + h_{(i,j)} + t_{(i,j)} \leq \pi_{(i,j)}^{s} \quad (10)$$

$$\pi_{(k,l)}^{s} + \pi_{(k,l)} + \tau_{i(k,l)}^{e} \times y_{(i,j)}^{(k,l)} \leq h_{(k,l)}^{s} \quad (11)$$

$$h_{(m,n)}^{s} = \left[h_{(k,l)}^{s} + h_{(k,l)} + t_{(k,l)}\right] \times Z_{(k,l)}^{(m,n)} + c_1, \quad c_1 \in C \quad (12)$$

$$t_{(i,j)}^{s} = \left[\pi_{(k,l)}^{s} + \pi_{(k,l)} + \tau_{i(k,l)}^{e} \times y_{(i,j)}^{(k,l)}\right] \times X_{(i,j)}^{(k,l)} + c_2, \quad c_2 \in C \quad (13)$$

Formula (1) indicates that all the import containers unloaded from the ship will be transported to the import container area; formula (2) all the export containers unloaded from the ship will be transported to the export container area; formula (3) indicates that the first operation task of straddle carrier is (I, J), and after completing the current task, the next container task will be executed immediately; formula (4) the last operation task of straddle carrier is (k, l), and before completing the current task, Formula (5) indicates that the first operation task of quayside crane is (I, J), and the next container task will be executed immediately after completing the current task; formula (6) indicates that the last operation task of quayside crane is (k, l), and the previous container task has just been completed

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before completing the current task; equation (7) indicates that the number of cross carrier operations is greater than the total number of containers,In other words, each container will be operated; formula (8) means that when the container is transported from the quayside crane to the container area, the quayside crane shall take the box to the quayside crane loading and unloading area in advance to wait for the straddle carrier operation; formula (9) when the container is transported from the container area to the quayside crane, the straddle carrier shall take the box to the quayside crane loading and unloading area in advance, waiting for the quayside crane to be loaded and unloaded; formula (10) means that after the quayside crane completes the previous task, the next task will be carried out immediately without time interval;The time interval between loading and unloading is 11.

4. Solving algorithm

In this paper, the greedy algorithm and simulated annealing algorithm are mixed to study the equipment scheduling of quayside crane, straddle carrier and yard area. It combines the advantages of the two algorithms in solving the problem and has better adaptability.

Greedy algorithm is a simpler and faster design technique for finding the optimal solution.Each greedy selection simplifies the problem to a smaller subproblem. Through each greedy selection, an optimal solution of the problem can be obtained. Although the local optimal solution must be obtained at each step, the global solution may not be optimal sometimes.This paper is divided into three sub problems: the shortest operation time of quay crane, the shortest operation time of straddle carrier and the shortest operation time of yard bridge.Taking the quayside crane operation as an example, when the quayside crane grabs the container in the loading and unloading area, the nearest container without waiting is preferred for operation.At the same time, the operation mode of straddle carrier and yard bridge is the same as that of quayside crane.For each subproblem, the shortest operation time of each equipment is selected as the stage cost, and the sum of all the stage costs is used to obtain the minimum total time, which is the objective function value, and an initial solution is generated.

However, the initial solution generated by greedy algorithm will have local optimal phenomenon, so it is necessary to use simulated annealing algorithm for further optimization.The objective function of this algorithm is to minimize the total time cost. In the simulated annealing algorithm, the total cost corresponds to the current state energy of physical annealing process.According to metropolis acceptance criteria, the state acceptance function is designed as follows:

$$p_k(i \to j) = \begin{cases} 1 & R(i) \geq R(j) \\ \exp\left(\dfrac{R(i)-R(j)}{T_k}\right) & R(i) < R(j) \end{cases}$$

Where $R(i)$ Represents the total cost of solution I, $R(j)$ Represents the total cost of the current j solution.When $R(j) < R(i)$ When the total cost of the current solution becomes smaller, the current solution is accepted $R(j) > R(i)$ Indicates that the total cost of the current scheme increases and is generated randomly ζ=U(0,1) If $\exp\left(\dfrac{R(i)-R(j)}{T_k}\right) > \zeta$, the current solution is accepted.The choice of annealing strategy is reflected in the setting of cooling function $T_{k+1} = T_k \cdot r$ In which $r \in (0.95, 0.99)$. T_{k+1} Represents the new temperature, T_k Represents the last temperature state.The ending strategy of annealing algorithm is to set the termination temperature and the maximum number of iterations.

5. Numerical analysis

5.1 Parameter Setting

This section uses the actual port data to verify the validity of the model proposed in this paper. The parameter settings of the model are shown in the table.

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Table 2. Parameter Setting

Parameter	Value	Parameter	Value
Number of quayside cranes in storage yard	8	Single container operation time of quay crane	100s
Number of cross yard transport vehicles	24	Single container operation time of yard Bridge	55s
Number of yard bridges	20	Pick up time of single container of straddle carrier	35s
Number of export box areas	10	Travel time of straddle carrier from quayside crane loading area to container area	15s
Number of import box areas	10	Travel time of straddle carrier in entrance and exit box areas	13s
Number of containers to be exported in container area	300	Number of containers unloaded from the ship	300

5.2 Resulting Analysis

This paper analyzes the different benefits brought by different horizontal transportation equipment to the wharf. The main difference between quay crane AGV yard bridge and quay crane straddle carrier yard bridge is that the horizontal transportation equipment is different, which leads to the different loading and unloading process of wharf. Compared with straddle carrier, AGV does not have the function of picking up containers independently, so it needs to cooperate with quay crane and yard bridge. Therefore, the waiting time cost should be added to the AGV model w Without the operation time of straddle carrier π After the completion of loading and unloading task, AGV drives to another quay crane / yard bridge for another container task, adding travel time t_q, t_y. Constraints 10 and 11 show that the time for quayside crane to pick up containers should be greater than or equal to the completion time of the previous container, and the time for field bridge to pick up containers should be greater than or equal to the completion time of the previous container. In order to make the results more comparative, the yard parameters are configured with 8 quay cranes and 20 yard cranes to load and unload 600 containers. With reference to multiple automated container terminals, the quay crane AGV ratio is set at 1:5, with a total of 40 AGVs. The algorithm is designed to operate with the same span carrier.

Table 3. Result Analysis

Parameter	QC number	Number of horizontal data devices	RTG number	Container number	total operation time
Straddle carrier	1:3	24	20	300	120min
AGV	1:5	40	20	300	142min

The results show that the efficiency of straddle carrier is higher than that of AGV system when loading and unloading mode is adopted and container yard configuration is the same. It shows that when the number of horizontal transport vehicles is sufficient, the quay crane and the yard bridge do not need to wait for the straddle truck operation in the straddle truck operation system, and can coordinate the shore and yard operations independently, and the utilization rate of the quayside and yard bridges is high. Because AGV operation system needs to wait for quay crane and yard bridge in loading and unloading area, it can only realize loading and unloading operation mode of quay crane and yard bridge, and it needs more waiting time cost to realize bidirectional heavy load of AGV.

6. Conclusion

The type of horizontal equipment determines the loading and unloading efficiency of the terminal to a certain extent. This paper compares the straddle carrier and AGV. The results show that under the same configuration of container terminal, when the terminal adopts the mode of loading and unloading, the straddle carrier has higher efficiency than AGV. But there are still some shortcomings in this paper: first, the import box and the export box are assumed to be equivalent, and there is no

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consideration of empty grab when the number of boxes is different. Second, the specific location of the container area is not considered. By default, the distance between the horizontal transport equipment and the import and export container areas is the same. In the actual situation, the distance should be constantly changing, which is not reflected in the model. Third, compared with AGV operation system, it is not comprehensive enough to analyze from multiple angles. In the future research, the above defects can be considered, which will be of great help to improve the efficiency of automated terminals.

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