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A Method for AGV Double-cycling Scheduling at Automated Container Terminals

Hongchang Zhang¹, Liang Qi¹ and Huijuan Ma²

¹ College of Computer Science and Engineering, Shandong University of Science and Technology, Qingdao 266590, China

² Qingdao New Qianwan Container Terminal Company Ltd., Qingdao 266500, China
qiliangsdkd@163.com

Abstract. Automated container terminal (ACT) plays an important role in the modern logistics and transportation industry. The utilization of automated guided vehicles (AGV) can be effectively promoted by reducing their empty running. The existing scheduling strategies of AGVs for most ACTs cannot ensure their full load, leading to underutilization. This work proposes a double-cycling AGV path planning model to maximize the loading rate of AGVs by scheduling their loading and unloading tasks. The randomness of the quay crane's operational time is considered. By allocating time intervals of AGVs arriving at the quayside, it determines a loading sequence of containers based on a genetic algorithm with a penalty function. Experimental results show that the model can realize double-cycling transport with AGVs and effectively reduce the operational cost of ACTs.

Keywords: Logistics, automated container terminals (ACTs), automatic guided vehicles (AGVs), double-cycling scheduling, and genetic algorithm.

1 Introduction

As a basic logistic model, maritime transportation plays a vital role in the global economy, trade, and cultural exchanges. Automated container terminals (ACTs) have been developed as critical components in modern logistic transportation systems. ACTs consist of three major facilities: quay cranes (QCs), yard cranes (YCs), and automatic guided vehicles (AGVs). AGVs cooperate with the operations of QCs and YCs.

Effective AGVs' scheduling is the key to reducing the operating cost of ACTs. In ACTs, the container transportation process has an AGV transport chain and a crane transport chain. In the former topic, Mohammad and Saeed propose a mathematical model composed of a job shop scheduling problem and a conflict-free routing problem [1]. The objective is to minimize AGVs' delay time and achieve multi-AGV integrated scheduling. A two-stage ant colony algorithm is proposed to solve it. Angeloudis and Bell study job assignments of AGVs in container terminals under various uncertainty conditions [2]. A flexible algorithm for real-time AGV scheduling is proposed. Most studies have significantly improved the utilization of AGVs and the operational efficiency of container terminals, but they cannot guarantee the full load of AGVs during transportation. In the crane transport chain, Huang and Li propose a bounded two-level dynamic programming algorithm aiming at a quay crane scheduling problem (QCSP) [3]. A method is proposed to evaluate the practicability of the algorithm. Ji *et al.* consider optimizing a loading sequence in container terminals [4]. A model is established to integrate the loading sequence and a re-handling strategy under parallel operations of multi-quay cranes. An improved genetic algorithm is proposed to solve the model. Tidal fluctuation and other factors will cause ship instability, resulting in QC operations not being fully automated. At present, most QC operations need manual assistance, resulting in the uncertainty of QC's operational time. The major problem is that most of the existing QC scheduling methods fail to fully consider the impact of uncertain factors, including tide fluctuation and manual operation on QC transportation tasks.

A double-cycling scheduling model requires that a crane transports a container, unloads it, and returns by taking another container. Meanwhile, AGVs transport a container to its destination and bring another one back. At present, double-cycling strategies have been used in QCSP, Yard Crane Scheduling Problem (YCSP), Yard Truck Scheduling Problem (YTSP), and Container Sequencing Problem (CSP), where the related studies are shown in Table 1. Most of these studies considering a double-cycling scheduling mode do not specifically consider the uncertainty of QC operation. In this work, a double-cycling model is proposed to realize the full load of AGVs by scheduling the loaded and unloaded tasks. Its objective is to minimize the waiting time of AGVs. A genetic algorithm with a penalty function is used to find a loading sequence of containers for each AGV.

Table 1. The problems solved by using double-cycling strategies

Studies	Scheduling Problem	Uncertainty Considered?	AGV scheduling sequence obtained?
Luo & Wu, 2015 ^[5]	QCSP with YCSP	No	Yes
Zheng, Pang, Liu, & Xu, 2019 ^[6]	QCSP with CSP	No	No
Cao <i>et al.</i> 2018 ^[7]	Integrated QCSP-YTSP	No	Yes
Liu <i>et al.</i> , 2015 ^[8]	QCSP with CSP	No	No
Wang & Li, 2015 ^[9]	QCSP with CSP	No	No
Nguyen & Kim, 2010 ^[10]	YTSP	Yes	No
Meisel & Wichmann, 2010 ^[11]	QCSP with CSP	No	No
Zhang & Kim, 2009 ^[12]	QCSP	No	No
Goodchild & Daganzo, 2006 ^[13]	QCSP	Yes	No
Ahmed, Mohammed, Zayed, Alfalah & Alkass, ^[14]	Integrated QCSP-YTSP-YCSP	Yes	No
Our Work	Integrated QCSP-YCSP	Yes	Yes

The rest of this paper is organized as follows. Section 2 formulates a double-cycling AGV route planning model, which maximizes the loading rate of AGVs during their transportation by scheduling the loaded and unloaded tasks. Section 3 proposes a container scheduling sequence based on a genetic algorithm with a penalty function and gets the shortest waiting time of AGVs. Section 4 shows experimental results. Section 5 concludes this paper and discusses the future work.

2 AGV Double-cycling

2.1 Problem description.

In an ACT, QCs, YCs, and AGVs are responsible for loading/unloading containers on ships, loading/unloading containers on the yard, and transporting containers between the quayside and the yard. This work proposes an AGV double-cycling scheduling model. AGV carries a container at the quayside, drives to the yard to unload it, takes

another one from the yard, returns to the quayside for unloading, and repeats such a process. Firstly, we give the following assumptions:

- 1) Tidal fluctuation and other factors will cause ship instability, resulting in QC operations not being fully automated. At present, most QC operations need manual assistance, resulting in the uncertainty of QC's operational time. Etsuko mentions that the transportation time of containers on QC roughly conforms to a Gaussian distribution [15], which is adopted in our work. The probability that the distributed value in $(\mu-2\sigma, \mu+2\sigma)$ is 0.9544, and a time interval $(t+\mu-2\sigma, t+\mu+2\sigma)$ is adopted to the completion time of QC operation.
- 2) YC can prepare in advance for the arrival of containers [16], and we assume that YC can obtain the information of a container and move to it in advance.

AGVs are fully loaded in and out of the yard and quayside, thus realizing the double-cycling of AGVs. It is a basic constraint of our double-cycling model. Fig. 1 shows the flow chart.

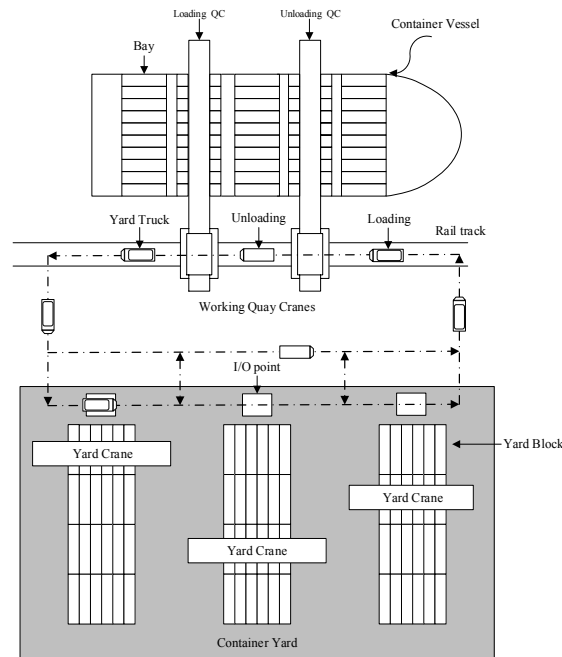


Fig. 1. A double-cycling AGV scheduling mode.

Another constraint is that no delay of QC should be guaranteed. QC operations' uncertainty leads to the uncertain time when an AGV arrives at the quayside. Thus, the latest time when an AGV arrives at the quayside (LTAQ) is defined. As mentioned above, the time of QC transporting containers conforms to the Gaussian distribution

with parameters (μ, σ^2) . Therefore, the LTAQ is the moment for QC to finish transporting the previous container.

2.2 Mathematical model.

Let $\mathbf{N} = \{1, 2, \dots\}$ represent the set of natural numbers, and $\mathbf{N}_m = \{1, 2, \dots, m\}$. The related symbolic definitions are given as follows:

M : $M = \{m_1, m_2, \dots, m_n\}$ is a set of task points, where $m_i = \{P_1^i, w, P_2^i, T_i\}$, P_1^i represents the location of container i on the ship, w represents the number of the yards, P_2^i represents the location of container i on the yard, and T_i represents the LTAQ of container i ;

X : a set of unloading task points that represent unloading the containers from the ship to the yard;

Y : a set of loading task points that represent loading the containers in the yard onto the ship;

n : the number of AGVs, $n \in \mathbf{N}$;

k : the index of the k -th AGV, $k \in \mathbf{N}_n$, remember as A_k ;

m_s : a virtual start task point;

m_e : a virtual end task point;

T_i^q : time taken to transport container i by QC;

V_Q : the average movement speed of QC;

C_i : a time-interval conforming to the Gaussian distribution, including the minimum and maximum time taken by QC to transport the container, $C_i = (C_1^i, C_2^i)$, where C_1^i and C_2^i are the minimum time and maximum time for QC to transport container i , respectively;

V_Y : moving speed of YC;

D_{ij}^Y : the moving distance of the YC from the position of container i to the position of container j . It represents the distance from the I/O point to the position of container j when $i=0$; it represents the distance moved from the position of container i to the I/O point when $j=0$;

V_y : movement speed of a spreader;

D_{ij}^y : the distance that the YC's spreader moves from the position of container i to the position of container j . It represents the distance of the spreader moved from the I/O point to the position of container j when $i = 0$; it represents the distance moved from the position of container i to the I/O point when $j=0$;

G_y : the speed at which the spreader moves up and down;

T_y : time required by spreader to transport a container at the I/O point;
 T_k : a set of waiting time of AGV, where $T_k = \{t_1, t_2, \dots, t_n\}$, $t_k (1 \leq k \leq n)$ is the waiting time of A_k
 V_A : the speed of AGV;
 D_q : the distance between two QCs;
 T : the time interval between two consecutive AGVs exiting the quayside;
 T_i^{q1} : the waiting time before task point i is unloaded at the quayside;
 T_i^{q2} : the waiting time before task point i is loaded at the quayside;
 T_i^{y1} : the waiting time before task point i is unloaded in the yard;
 T_i^{y2} : the unloading time of task point i in the yard;
 T_i^{y3} : the waiting time before task point i is loaded in the yard;
 T_i^{y4} : the loading time of task point i in the yard;
 H_{ij} : the empty running time of AGV loading task point v_i after unloading task point v_j in the yard.

Symbols used in the genetic algorithm are given next.

q : initial population size;
 q' : offspring population size;
 t : current iteration index;
 t_{max} : maximum iteration;
 P_u : a penalty factor on full loading;
 P_q : a penalty factor on LTAQ;
 P_c : crossover probability;
 P_v : mutation probability;
 P_r : reverse probability;
 P : individual fitness value.

Our double-cycling model focuses on the efficiency of the QC, and AGV should meet the full load constraint and the LTAQ constraints. Hence, the waiting time of AGV is a metric to evaluate the efficiency of the double-cycling model. The objective function of the model is to minimize the waiting time of AGVs:

$$\min \sum_1^n T_k \quad (1)$$

The decision variables are defined as follows:

$$\chi_j^i = \begin{cases} 1, & \text{an AGV transports task point } j \text{ after task point } i \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

$$\alpha^k = \begin{cases} 1, & \text{AGV } k \text{ drives out of the yard being fully loaded} \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

$$\beta^k = \begin{cases} 1, A_k \text{ drives out of the quayside being fully loaded} \\ 0, \text{otherwise} \end{cases} \quad (4)$$

$$\gamma_i^w = \begin{cases} 0, \text{the YC cannot be prepared in advance.} \\ 1, \text{the YC can be prepared in advance.} \end{cases} \quad (5)$$

where w is the number of the yard.

$$\delta_i = \begin{cases} 1, \text{task point } i \text{ is transported to the quayside} \\ 0, \text{task point } i \text{ is transported to the yard} \end{cases} \quad (6)$$

$$\varepsilon_w^i = \begin{cases} 1, \text{container } i \text{ is loaded in yard } w \\ 0, \text{container } i \text{ is unloaded in yard } w \end{cases} \quad (7)$$

$$\epsilon = \begin{cases} 1, \text{AGV loads at the same yard after unloading} \\ 0, \text{AGV loads at the different yard after unloading} \end{cases} \quad (8)$$

The constraints are defined as follows:

$$\sum \chi_i^j = 1, \quad \forall M_i \in M + \{m_e\} \quad (9)$$

$$\sum \chi_i^j = 1, \quad \forall M_i \in M + \{m_s\} \quad (10)$$

$$\sum \chi_{x'}^x = 0, \quad \forall M_x, M_{x'} \in X \quad (11)$$

$$\sum \chi_{y'}^y = 0, \quad \forall M_y, M_{y'} \in Y \quad (12)$$

$$\alpha^k = 1, \quad \forall k \in \mathbf{N}_m \quad (13)$$

$$\beta^k = 1, \quad \forall k \in \mathbf{N}_m \quad (14)$$

$$C_1^i = (\mu - 2\sigma) + V_Q/D_i^q + \Delta t_i \quad (15)$$

$$C_2^i = (\mu + 2\sigma) + V_Q/D_i^q + \Delta t_i \quad (16)$$

$$C_1^i < T_i < C_2^i \quad (17)$$

$$T_i = \sum_{k=0}^{i-2} T_k^q + C_2^{i-1}, \quad \delta_i = 1 \quad (18)$$

$$T_j^i = T_j^q + \frac{D_i^q}{V_Q} \quad (19)$$

$$T_i^{q1} = T_{i-1}^{q1} + T_{i-1}^q + \frac{D_i^q}{V_Q} \quad (20)$$

$$T_i^{q2} = T_{i-1}^{q2} + T_{i-1}^q + \frac{D_i^q}{V_Q} \quad (21)$$

$$T_i^{y1} = \begin{cases} 0 & , \gamma_i^w = 1 \\ \max(T_{i-1}^3 + T_{i-1}^4 - T, 0) & , \varepsilon_w^{i-1} = 1, \gamma_i^w = 0 \\ \max\left(T_{i-1}^{y1} + T_{i-1}^{y2} + \frac{D_{(i-1)0}^y}{V_y} - T, 0\right) & , \varepsilon_w^{i-1} = 0, \gamma_i^w = 0 \end{cases} \quad (22)$$

$$T_i^{y3} = \begin{cases} \max\left(\frac{D_{0(t-1)}^y}{V_y}, \frac{D_{0(t-1)}^y}{V_y}\right) + \frac{d_i}{G_y} + T_G & , \epsilon = 1 \\ H_{ij} & , \gamma_i^w = 1, \epsilon = 0 \\ \max(T_j^{y3} + T_j^{y4} - P_{ij}, 0), \epsilon_w^j = 1, \gamma_i^w = 0, \epsilon = 0 \\ \max(T_j^{y1} + T_j^{y2} - P_{ij}, 0), \epsilon_w^j = 0, \gamma_i^w = 0, \epsilon = 0 \end{cases} \quad (23)$$

Equations (9)-(12) describe the container transportation mode at ACTs, where (9) denotes that all task points, including the virtual end task point, have only one prefix task point. Equation (10) suggests that all task points, including the virtual start task point, have only one suffix task point. Equation (11) indicates that all the unloading task points' prefix and suffix cannot be unloading task points. Equation (12) requires that all loading task points' prefix and suffix cannot be loading task points. Equations (13) and (14) describe the double-cycling mode, where (13) indicates that all AGVs driving out of the yard must be fully loaded and (14) requires that all AGVs moving out of the quayside must be fully loaded. Equations (15) and (16) describe the minimum and maximum time for QC to transport container i . The minimum time is the average time needed by the QC transporting container i minus a time-interval conforming to the Gaussian distribution; The maximum time is the average time needed by the QC transporting container i plus a time-interval conforming to the Gaussian distribution. Equation (17) describes the uncertainty of the QC operation, indicating that no matter the loading operation or unloading operation, the QC completes the transportation of container i within the time interval $[C_1^i, C_2^i]$. Equation (18) describes the LTAQ. When container i is transported to the quayside, the LTAQ is the latest time when the QC completes transporting the previous container. Equations (19)-(21) describe the situation of AGVs entering and leaving the quayside, where (19) indicates the time interval between two consecutive AGVs driving out of the quayside. The time interval is the second AGV's loading time in quayside. (20) indicates the waiting time before task point i is unloaded at the quayside. The waiting time is the previous task point's waiting time before unloading plus the unloading time of the previous task point. (21) indicates the waiting time before task point i is loaded at the quayside. The waiting time is the previous task point's waiting time before loading plus the loading time of the previous task point. Equations (22) and (23) describe the specific situation of AGVs entering and leaving the yard, where (22) indicates the waiting time before task point i is unloaded in the yard. It has two cases: 1) when the YC is prepared in advance, the waiting time is 0; 2) when the YC cannot be prepared in advance, there are two situations: if the YC is loading a container, the

waiting time is the waiting time of previous task point plus the loading time of the previous task point and minus the time interval between two consecutive AGVs driving out of the quayside. It may be less than zero, and we use 0 instead; If the YC is unloading container, the waiting time is the waiting time of unloading at the previous task point plus the unloading time of task point minus the time interval from the arrival at the yard at the previous task point. (23) describes the waiting time before task point i is loaded in the yard. Specifically, 1) If AGVs are loaded in the same yard, the waiting time is the time needed by YC moving to the I/O Point after the unloading operation. 2) If the AGVs are loaded in another yard, there are two situations. When the next target yard's YC can be prepared in advance, the waiting time before the loading is when the AGV runs empty to the target yard; When the next target yard's YC cannot be prepared in advance, there are also two situations. If the yard is conducting a loading operation, the waiting time is the waiting time of the previous task point plus the loading time of the task point minus the empty running time of the AGV. If the yard is conducting an unloading operation, the waiting time is the waiting time of the previous task point plus the unloading time of the task point minus the empty running time of the AGV.

3 Genetic Algorithm with Penalty Value

This model is to find a container transport sequence. It minimizes the total waiting time of AGV in the transport process and satisfies the double-cycling requirement and the LTAQ constraints.

A penalty function is used to search for the optimal solution. The number of non-conforming double-cycling task points is k , the number of non-conforming LTAQ task points is a , the penalty coefficient at the LTAQ is P_q , and the penalty coefficient at the double-cycling value is P_u . Then, we have

$$P = \begin{cases} a * P_q + T, & k = 0 \\ k * P_u, & k > 0 \end{cases} \quad (26)$$

Individual fitness value P includes 1) all AGVs' waiting time and 2) the penalty value of task points in the scheduling sequence that do not conform to the LTAQ. The final individual fitness value is the sum of them. During the generation of solutions, the generated solutions may not meet the conditions of double-cycling, so before calculating the fitness, the scheduling sequence should be judged whether it meets the basic condition of double-cycling. If not, the fitness value is adjusted to the $k * P_u$ to

speed up eliminating the generated solution.

Algorithm 1 AGV double-cycling model solving algorithm

Input:

Unloading task point set X , loading task point set Y , AGV number m , initial population number q , offspring population number q' , maximum iteration number t_{max} , the LTAQ penalty coefficient P_q , the double-cycling penalty coefficient is P_u , crossover probability P_c , mutation probability P_v , and reversal probability P_r .

Output:

A legitimate scheduling sequence with minimum fitness P .

Step 1:

Individual coding. For q individuals, arrange a scheduling sequence in an ascending order according to the LTAQ of X and Y , add $n-1$ AGV segmentation number at the end of the sequence, and set the current iteration times $t=1$.

Step 2:

Calculate the fitness and select the generation of progeny population. For each individual, its fitness P is calculated, and the smaller the fitness is set, the greater the probability of being selected. q' individuals are assigned according to roulette to generate offspring population.

Step 3:

Perform crossover, mutation, and reversal operators. The offspring population is combined in pairs, and the crossover operation is carried out with probability P_c , and then the mutation and reversal operation is carried out with probabilities P_v and P_r , respectively, for each individual.

Step 4:

Elite reserve iteration and output the solution. Re-insert q' children into the original population to generate a new population, and select p individuals from the new population. If $t=t_{max}$, the optimal individuals will be output; Otherwise, $t=t+1$, return to **Step 2**.

4 Simulation Experiment

In this paper, Matlab_R2019a is used to solve the double-cycling model. In this work, a queue is formulated for each quay or yard. The task points are arranged in the queue according to transportation order. The waiting time of the task point and the number of task points that do not meet the LTAQ are calculated according to the relationship among the task points in the queue. Then the scheduling sequence with the least number

of task points that do not meet the LTAQ and the least AGV waiting time is obtained using a genetic algorithm. We now discuss the critical parameters to determine the influence of double-cycling mode in practical application.

Corresponding waiting areas are set up at the quayside and the yard for storing AGVs that need to wait. AGVs in the waiting area can choose to turn off the engine or keep starting the engine for waiting according to the estimated waiting time. The waiting time of the AGV that remains in the starting the engine is the key object to be considered in the double-cycling model. Table 2 shows the experimental results under multiple experiments, including the total waiting time of AGVs (Total Waiting Time), the number of task points that do not conform to LTAQ (Not Conform LTAQ), the number of task points that do not conform to double-cycling (Not Conform Doble-cycling), the fitness value, and the number of iterations.

Table 2. Results of multiple experiments in our double-cycle model

Experiment number	Not Conform Doble-cycling	Not Conform LTAQ	Fitness Value	Number Of Iterations	Total Waiting Time
1	0	0	971	265	971
2	0	0	978	356	978
3	0	0	964	151	964
4	0	0	1003	135	1003
5	0	2	21039	255	1039
6	0	0	1004	115	1004
7	0	0	906	164	906
8	0	0	987	206	987
9	0	0	978	307	978
10	0	0	944	139	944
11	0	0	976	191	976
12	0	0	989	311	989

In the experimental results, we can get some valuable conclusions. First of all, a time disturbance that conforms to Gaussian distribution is randomly added to the time of QC operation, so the experimental results are highly likely to be different each time.

In the double-cycling model, the experimental results show that most scheduling schemes satisfy both double-cycling and LTAQ. This work simulates the time disturbance existing in the QC operator, so a few experimental results cannot meet LTAQ in all task points based on double-cycling. A few experimental results show that the number of task points that do not conform to LTAQ differs significantly from other experimental results. This situation is generally caused by the significant difference between the QC operation time and other experiments' QC operation time, leading to the algorithm not normally converging to an appropriate fitness value. Therefore, we believe the AGV cannot reach the quayside in time due to the operator's operation error. This part of the data should be discarded or recalculated. The operator's status should be adjusted in actual situations. However, according to the experimental results in Table 3, there exists the phenomenon that the number of task points is 0 in the optimal scheduling sequence, which leads to resource waste. To further improve the efficiency of the double-cycling system, this work continues to consider the influence of the number of AGVs on the efficiency of the double-cycling system. Tables 3-4 show the experimental results of changing the number of AGVs under a different number of task points, including the total waiting time of AGV and the number of task points that do not conform to LTAQ.

Table 3. The experimental results of different number of AGVs at 20 task points

Number of AGV	Number of task points	Experiment number	Total Time	Waiting	Not Conform LTAQ
3	20	1	1054		8
		2	1039		10
		3	1007		8
4	20	1	980		0
		2	1038		0
		3	1032		2
5	20	1	981		0
		2	964		0
		3	984		0
6	20	1	1089		0
		2	1094		0
		3	1098		0

Table 4. The experimental results of different number of AGVs at 30 task points

Number of AGV	Number of task points	Experiment number	Total Time	Waiting	Not LTAQ	Conform
4	30	1	1595		4	
		2	1575		6	
		3	1537		2	
5	30	1	1504		0	
		2	1507		2	
		3	1550		0	
6	30	1	1588		0	
		2	1602		0	
		3	1726		0	
7	30	1	1859		0	
		2	1884		4	
		3	1805		2	
8	30	1	2134		0	
		2	1809		2	
		3	2133		0	

For the different number of task points, we set different numbers of AGVs. The number of AGVs is gradually reduced until AGVs cannot meet the requirement of all task points conforming to LTAQ, and the number of AGVs is set as the lower bound to transport the number of task points successfully. The number of AGVs is gradually increased until the number of task points of some AGVs is still 0 in the AGV scheduling sequence after several experiments, and the number of AGVs is regarded as the upper bound under the number of task points. Tables 3 and 4 show that for different numbers of task points, there is a corresponding number of AGV to ensure that all task points meet LTAQ and have the minimum waiting time. Fewer AGVs will increase the number of task points that do not conform to LTAQ, and more AGVs will cause a significant rise in waiting time and fluctuations in the number of task points that do not conform to LTAQ. Therefore, only a certain number of AGVs can improve the efficiency of the double-cycling model and make full use of transportation resources.

5 Conclusions

To improve the utilization rate of AGV in the process of ACTs, this work proposes a double-cycling model of AGV, which specifies that AGV should enter and exit the yard and quayside with the full load during transportation. By considering the uncertainty of the QC's operational time. To not affect the QC work efficiency, the LTAQ is stipulated. The AGV needs to arrive at the quayside before the earliest time that the previous task point is completed. Considering the different situations when AGV arrives at the yard, the container scheduling sequence is reasonably arranged to prevent AGV from accumulating. AGV should meet the constraints of LTAQ and pursue the shortest waiting time. Experiments are designed to obtain the scheduling sequence satisfying the double-cycling conditions and LTAQ constraints. Furthermore, to adjust the number of AGVs and the time disturbance of QC operation followed different Gaussian distributions, obtaining the optimal scheduling sequence, proving the feasibility of the double-cycling mode in practical application.

Although the experimental results successfully prove the feasibility of the double-cycling mode in practical application. There are still some improvements. To further improve the transport efficiency of the double-cycling mode, the scheduling problem of multiple QC can be continued to be considered so that it can simultaneously load and unload multiple bays in a ship.

References

1. Saidi-Mehrabad M., Dehnavi-Arani S., Evazabadian F., and Mahmoodian V.: An Ant Colony Algorithm (ACA) for solving the new integrated model of job shop scheduling and conflict-free routing of AGVs. *Computers & Industrial Engineering* 86, 2-13(2015).
2. Angeloudis P. and Bell M. G. H.: An uncertainty-aware AGV assignment algorithm for automated container terminals. *Transportation Research Part E: Logistics and Transportation Review* 46(3), 354-366(2010).
3. Huang S. Y. and Li Y.: A Bounded Two-Level Dynamic Programming Algorithm for Quay Crane Scheduling in Container Terminals. *Computers & Industrial Engineering* 123, 303-313(2018).
4. Ji M., Guo W., Zhu H. and Yang Y.: Optimization of loading sequence and rehandling strategy for multi-quay crane operations in container terminals. *Transportation Research Part E: Logistics and Transportation Review* 80, 1-19(2015).

5. Luo J. and Wu Y.: Modelling of dual-cycle strategy for container storage and vehicle scheduling problems at automated container terminals. *Transportation Research Part E: Logistics and Transportation Review* 79, 49-64(2015).
6. Zheng F., Pang Y., Liu M. and Xu Y.: Dynamic programming algorithms for the general quay crane double-cycling problem with internal-reshuffles. *Journal of Combinatorial Optimization* 39(3), 708-724(2020).
7. Cao J. X., Shang X. and Yao X.: Integrated quay crane and yard truck schedule for the dual-cycling strategies. In *CICTP 2017: Transportation reform and change—Equity, inclusiveness, sharing, and innovation* 1346-1357(2018).
8. Liu, M., Chu, F., Zhang, Z., and Chu, C.: A polynomial-time heuristic for the quay crane double cycling problem with internal-reshuffling operations. *Transportation Research Part E: Logistics and Transportation Review* 81, 52-74(2015).
9. Wang D. and Li X.: Quay crane scheduling with dual cycling. *Engineering Optimization*,” *Engineering Optimization* 47(10), 1343-1360(2015).
10. Nguyen V. D. and Kim K. H.: Minimizing empty trips of yard trucks in container terminals by dual cycle operations. *Industrial Engineering and Management Systems* 9(1), 28-40(2010).
11. Meisel F., and Wichmann M.: Container sequencing for quay cranes with internal reshuffles. *OR Spectrum* 32(3), 569-591(2010).
12. Zhang H. and Kim K. H.: Maximizing the number of dual-cycle operations of quay cranes in container terminals. *Computers & Industrial Engineering* 56(3), 979-992(2009).
13. Goodchild A. V. and Daganzo C. F.: Double-cycling strategies for container ships and their effect on ship loading and unloading operations. *Transportation Science* 40(4), 473-483(2016).
14. Ahmed E., El-Abbasy M. S., Zayed T., Alfalah G. and Alkass S.: Synchronized scheduling model for container terminals using simulated double-cycling strategy. *Computers & Industrial Engineering* 154, 2021.
15. E. Nishimura.: Yard and berth planning efficiency with estimated handling time. *Maritime Business Review* 5(1), 5-29(2020).
16. Guo X., Huang S. Y., Hsu W. J. and Low M. Y. H.: Yard crane dispatching based on real time data driven simulation for container terminals. In *Proceedings of the 2008 Winter Simulation Conference* 2648–2655(2008).