

Research on joint scheduling optimization with AGVs and quay cranes consider replacement processes

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Abstract. Aiming at the joint scheduling problem of AGV and shore bridge in automatic container terminal, considering the waiting and power exchange process of AGV, a mixed integer programming model with the goal of minimizing the final completion time of AGV is constructed. The model considers the changes of buffer area, AGV power and the power consumption differences of AGV in light load, heavy load and waiting state. Genetic algorithm (GA) is used to solve it. Finally, through the analysis of different scale examples, the optimal allocation of shore bridges, the number of AGVs and the AGV power exchange threshold are obtained, so as to reduce the waiting time and the overall completion time.

Keywords: Automated container terminal; Automatic guided vehicle; Quay Crane ; genetic algorithm.

1. Introduction

The deepening of economic cooperation among countries around the world has strongly promoted the development of inter-country trade. Among them, the annual increase in container throughput has put forward higher requirements for the operation efficiency of automated container terminals. The joint scheduling of various equipment is one of the main reasons that affect the efficiency of automated terminals. In the process of port container cargo transfer, Quay Crane (QC) has become a necessary quayside operation equipment due to its high operating efficiency, while Automated Guided Vehicle (AGV), as an electric horizontal transportation tool, plays a connecting role. The pivot function of the quay crane and the yard, the efficient cooperation of the two can shorten the operation time and improve the container turnover efficiency. In actual operation, the AGV needs to be replaced in time, otherwise the normal operation of the entire automated container terminal will be affected. Therefore, in the joint scheduling process of quay crane and AGV, AGV power exchange is also an important part.

In order to improve the operation efficiency of the automated container terminal and put the equipment into operation safely and reliably, the scheduling problem of the automated container terminal equipment has become a research hotspot of scholars at home and abroad. YUE et al. [1] studied the joint scheduling optimization of quay cranes and AGVs with the goal of minimizing the no-load time of AGV and the waiting time of quay cranes, and considered the impact of the task sequence instruction scheduling process; XING et al. [2] established a quay crane based on the The optimization model with the shortest operation time as goal, and a new AGV allocation mode was designed, and finally the local search algorithm was used to solve it; Fan Houming et al. Capacity constraints optimize the energy consumption of quay cranes and AGVs; Zhou Qi et al. [4] based on the greedy algorithm and the minimum cost flow algorithm to schedule and configure AGVs, shorten the waiting time of AGVs under the quay cranes, and ease the congestion of AGVs Tian Yu et al. [5] analyzed the flow characteristics of containers between the ship and the yard in detail according to the operation characteristics of the dual-cycle AGV in the process of automatic terminal loading and unloading; Fan Zhiqiang et al. The quay crane scheduling problem under specific constraints such as crossing and safety distance; ZHONG et al. [7] studied the problem of conflict-free path planning for quay cranes and AGVs, which reduced the consideration of path optimization and integrated scheduling when the task assignment is known. The transportation time of the AGV that is constrained by conflicts, etc.;

In actual production, the AGV power exchange process affects the operation efficiency of automated container terminals to a certain extent, and the AGV power exchange problem has also attracted the attention of some scholars. Zhang Yaqi et al. [8] built a model to solve the problem according to the charging requirements during AGV operation and the characteristics of the transportation process, which improved the AGV charging utilization rate and reduced the AGV's no-load rate; FATNASSI et al. [9] proposed a static AGV charging scheduling strategy. The linear programming heuristic algorithm was used to solve it; MCHANEY et al. [10] studied the necessity of adding power constraints in the AGV scheduling process, proposed several modeling methods of charging constraints, and verified their feasibility by simulation. Zhou Xiaofan et al.[11] analyzed the influence of factors such as charging time, offline charging station ratio, and online charging station location selection on AGV scheduling in AGV offline and online charging modes; NITISH et al. [12] established an AGV with a time window. The mixed integer linear programming model of charging scheduling is solved by an adaptive large-scale neighborhood search algorithm; Shi Nanlu et al. [13] considered the difference in power consumption of AGV under different load states, and optimized the AGV operation sequence and the operation time window of the swap station. In order to reduce the queuing time for AGV replacement.

In summary, at present, there are many studies on separate AGV scheduling and charging strategies, and there are very few studies on AGV power exchange in the joint scheduling process of quay cranes and AGVs. In this paper, the AGV power exchange process is considered in the whole process of container unloading, combined with the actual operation situation, the influence of the mutual waiting time of AGV and quay crane on the operation process is analyzed, and a joint scheduling model of AGV and quay crane that considers the power exchange process is established. The model is solved by genetic algorithm, and the optimal joint scheduling scheme of AGV and quay crane is obtained, which shortens the mutual waiting time of quay crane and AGV, effectively reduces the final completion time of AGV, and improves the operation efficiency of automated terminals.

2. Problem Description

Figure 1 is a partial schematic diagram of the automated container terminal, which is mainly divided into berth, quay crane-AGV interaction area, AGV waiting area, AGV work area, AGV-yard interaction area and storage yard. The AGV work area includes lanes and swap stations. During the unloading process of the automated container terminal, the container is unloaded by the corresponding quay crane when the ship arrives at the designated berth, and the container is picked up by the quay crane trolley and transported to the quay crane buffer zone. Before and after the container reaches the buffer zone, the AGV will receive the operation notification Signal, drive from the parking lot to the buffer zone to pick up the container for transportation. For container tasks of different scales, the quay crane and AGV are affected by the quantity and power exchange during the operation process, and there is a situation of waiting for each other. If the waiting time is too long, the operation efficiency of the equipment will be seriously affected.

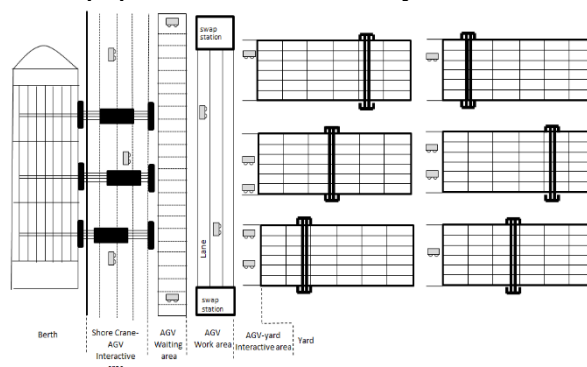


Figure 1 Partial schematic diagram of the automated terminal

Due to the large scale of the automated terminal, the long-term large-scale operation of the AGV as an electric-driven vehicle will cause the AGV to face insufficient power during transportation. If the AGV stops working on the road due to insufficient power, it will cause traffic congestion at the automated terminal, and even cause the terminal to stop production. Therefore, the AGV needs to arrive at the power exchange station before the power is exhausted, and the horizontal transportation will be carried out again until the power exchange is completed. The AGV operation cycle process is shown in Figure 2. The AGV arrives at the designated quay crane buffer to transport the container task to the target yard. After the task is completed, the AGV still has power to carry out the transportation of the next task. If the AGV power is lower than a certain threshold, it will be assigned to drive to the nearest power exchange station for power exchange, until the power exchange operation is completed, and it is transported to the next task. Since the power consumption rates of AGVs in no-load driving, heavy-load driving and waiting state are different, they need to be considered separately in the scheduling process.

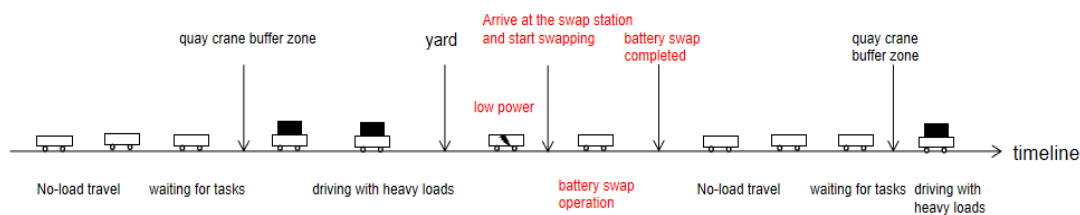


Figure 2 AGV operation cycle diagram considering the power exchange process

In view of the joint scheduling problem of quay crane and AGV, this paper considers the mutual waiting of quay crane and AGV and the influence of AGV power exchange on the operation efficiency, so as to improve the operation efficiency of each equipment and reduce the completion time of the final task.

3. Model Building

This paper is to study the joint scheduling research problem of AGV and quay crane considering the power exchange process. The problem is based on the operation background of the automated terminal, and only considers the situation of unloading the container. The mathematical model established is to minimize the final completion time of the AGV as The target, which is the time for the AGV to complete the last task.

3.1 Model assumptions

- (1) It is assumed that the number of batteries in the swap station is sufficient;
- (2) The congestion of the AGV path and the waiting situation of the power exchange process are not considered.

3.2 Symbol description

(1) Model collection:

R: Unload task set, $i \in R$;

Q: Set of quay cranes, $k \in R$;

V: AGV set, $g \in G$;

A: Virtual start task;

Z: virtual end task;

F: the set of all swap stations, $f \in F$;

(2) Model parameters:

b_1, b_2, b_3 : They are the power consumption per unit time of the AGV under no-load driving, heavy-load driving, and parking waiting state;

e_1 : AGV no-load speed;

e_2 : AGV Heavy-duty travel speed;
 H: AGV Change the power threshold;
 M: It is a very large positive number;
 r_{if} : Swap station f time to replace the battery once;

(3) Model variables:

u_{ik0} : The moment when the quay crane k extracts the task i;
 b_i : The time of the quay crane operation task;
 v_{ik1} : The moment when the quay crane k completes the task i;
 W_{igk} : The time that the quay crane k and the AGV g wait for each other;
 u_{igk} : The moment when AGV g starts to transport task i;
 h_{igk} : The distance from the quay crane buffer zone to the yard;
 h_{ifkg} : The travel distance of the AGV g for the power exchange task from no-load; driving to the power exchange station f;
 c_{igk} : The no-load travel distance before the AGV g transport task i;
 s_{ifkg} : The distance from the AGV g carrier task to the immediate task after the battery is replaced;
 R_{igk} : The last moment of the AGV to complete task i;
 T_{igk} : The remaining power of the AGV at the start of task i;
 Z_{igk} : The remaining power of the AGV when task i is completed;

(4) Decision variables:

p_{ik} : Whether the quay crane unloads task I, if so, then $p_{ik}=1$, otherwise $p_{ik}=0$;
 y_{ig} : Indicates whether AGV g performs transport task i, if so, then $y_{ig} = 1$, otherwise $y_{ig} = 0$;
 p_{ijk} : Whether the quay crane k first operates i and then operates j, if so, then $p_{ijk} = 1$; otherwise $p_{ijk} = 0$;
 y_{ijg} : Whether AGVg does job i first and then job j, if so, then $y_{ijg} = 1$, otherwise $y_{ijg} = 0$;
 x_{ijk} : Whether the quay crane k, AGV g first work i and then work j, if so, then $x_{ijk}=1$, otherwise $x_{ijk} = 0$;

3.3 Restrictions

$$T = \min \omega \tag{1}$$

Equation (1) represents the objective function;

$$\omega \geq \max \{R_{igk}\}, \forall i \in R, g \in V \tag{2}$$

Equation(2)represents the minimum AGV job completion time;

$$\sum_{i=1}^R p_{ik} = 1, \forall k \in Q \tag{3}$$

$$\sum_{i=1}^R y_{ig} = 1, \forall g \in V \tag{4}$$

Equation (3) indicates that a quay crane can only transport one task at a time; Equation (4) indicates that an AGV can only transport one task at a time;

$$\sum_{i \in R} p_{ihk} - \sum_{j \in R} p_{hjk} = 0, \forall h \in R, \forall k \in Q \tag{5}$$

$$\sum_{i \in R} y_{ihg} - \sum_{j \in R} y_{hjk} = 0, \forall h \in R, \forall g \in V \tag{6}$$

Equation (5) (6) represents the quay crane balance constraint, and the input and output of each quay crane task are balanced; Equation (5) represents the AGV balance constraint, and the input and output of each AGV task are balanced;

$$\sum_{i \in R} p_{ijk} - \sum_{j \in R} p_{jik} = 0, \forall k \in Q \tag{7}$$

$$\sum_{i \in R} y_{ijg} - \sum_{j \in R} y_{jig} = 0, \forall g \in V \tag{8}$$

Equation (7) indicates that each task processed by the quay crane has one and only one predecessor task and one immediate successor task; Equation (8) indicates that each task processed by the AGV has one and only one predecessor task and immediate successor task;

$$v_{ik1} = u_{ik0} + b_i, \forall i \in V, \forall k \in Q \tag{9}$$

Equation (9) indicates that the completion time of the quay crane processing task is equal to the sum of the starting time of the processing task and the time of each task of the quay crane operation;

$$u_{jk0} - v_{ik1} \geq (1 - p_{ijk})M, \forall i \in R, \forall j \in R, \forall k \in Q \tag{10}$$

Equation (10) represents the operation sequence of the quay crane;

$$v_{jk1} \geq v_{ik1} + b_j + (1 - p_{ijk})M, \forall i \in R, \forall j \in R, \forall k \in Q \tag{11}$$

Equation (11) indicates that the end time of the quay crane task is the sum of the end time of the previous task and the operation task time of the quay crane;

$$\sum_{i \in R} p_{Aik} = 1, \forall k \in Q \tag{12}$$

$$\sum_{i \in R} p_{iZk} = 1, \forall k \in Q \tag{13}$$

$$\sum_{i \in R} y_{Aig} = 1, \forall g \in V \tag{14}$$

$$\sum_{i \in R} y_{iZg} = 1, \forall g \in V \tag{15}$$

Equation (12) indicates that each quay crane always has a virtual start task a; Equation (13) indicates that each quay crane always has a virtual end task z; Equation (14) indicates that each AGV always has a virtual start task a; Equation (15) indicates that each AGV always has a virtual end task z;

$$u_{igk} \geq v_{ik1} + W_{igk}, \forall i \in R, \forall g \in V, \forall k \in Q \tag{16}$$

Equation (16) indicates that the time for the AGV to start the task i is equal to the sum of the completion time of the quay crane and the mutual waiting time of the AGV;

$$W_{igk} = \max\{u_{igk} - v_{ik1}, 0\}, \forall i \in R, \forall g \in V, \forall k \in Q \tag{17}$$

Equation (17) represents the time that the AGV waits for the task under the quay crane;

$$R_{jgk} \geq R_{igk} + h_{jgk} / e_2 + W_{jgk} + b_j + (x_{ijk} - 1)M + (1 - k_{ig})h_{jgk} / e_1 + k_{ig}(h_{jfg} / e_1 + r_{jfg} + s_{jfg} / e_1), \tag{18}$$

$$\forall i \in R, \forall j \in R, \forall g \in V, \forall k \in Q, \forall f \in F$$

Equation (18) indicates that the completion time of the common unloading task is the completion time of the predecessor task, the time for the AGV to travel to the quay crane with no load, the operation time of the quay crane, the mutual waiting time of the AGV on the quay crane, and the time for the AGV to travel to the container area under heavy load. The sum; the completion time of the power exchange task is the completion time of the previous task, the time from the AGV no-load travel to the power exchange station, the power exchange process time, the time for the AGV no-load travel to the quay crane buffer, the quay crane operation time, and the AGV waiting. the sum of the task time;

$$T_{jgk} \leq k_{jg}Z_{igk} + (1 - k_{jg})H + (1 - x_{ijk})M, \forall i \in R, \forall j \in R, \tag{19}$$

$$\forall g \in V, \forall k \in Q$$

Equation (19) indicates that the AGV processing ordinary task j starts to be equal to the power formula at the end of the power exchange i ; the power level at the beginning of the power exchange task is not greater than the power exchange threshold;

$$Z_{igk} = (1-k_{ig}) (T_{igk} - b_1 c_{igk} / e_1 - b_3 W_{igk}) + k_{ig} (100 - b_1 s_{jfg} / e_1) - b_2 h_{igk} / e_2, \forall i \in R, \forall g \in V, \forall k \in Q, \forall f \in F \quad (20)$$

Equation (20) corresponds to the remaining power of the AGV when the ordinary task and the power exchange task are completed;

$$u_{jgk} \geq k_{ig} R_{igk} + (1-k_{ig})(h_{jfg} / e_1 + r_{jf} + s_{jfg} / e_1 + W_{jgk}) + (x_{ijkg} - 1)M, \forall i \in R, \forall j \in R, \forall g \in V, \forall k \in Q, \forall f \in F \quad (21)$$

Equation (21) represents the time for the AGV to transport the power exchange task, which is the completion time of the previous task, the time for the AGV to travel to the charging station without a load, the time for power exchange, the time for the AGV to travel to the quay crane buffer zone without a load, and the quay crane AGVs waiting for each other sum of time.

4. Algorithm To Solve

The joint scheduling model of AGV and quay crane established in this paper belongs to NP-hard problem, which is easy to fall into local optimal solution, while GA is an algorithm that can realize global search, and GA coding rules are simple and effective for integer type coding, so The genetic algorithm can be used to solve the problem in this paper to obtain an approximate optimal solution.

(1) Chromosome coding: In this paper, the real number system is used for the coding of chromosomes, as shown in Figure 3, and the chromosome length is 2*the number of tasks

The left side is the AGV number assigned by the task, and the right side is the corresponding quay crane number. For example, task 2 is completed by No. 5 AGV and No. 2 quay crane.

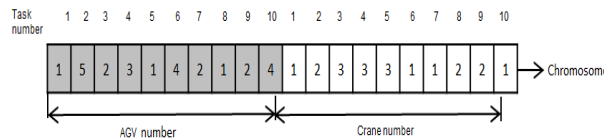


Figure 3 Schematic diagram of chromosome coding

(2) Chromosome repair: The chromosomes in the initial population are all randomly generated, and there is a situation where a certain AGV or quay crane is not assigned a task. For example, 5 AGVs and 3 quay cranes are to be allocated. As shown in Figure 2, the chromosomes only randomly generate AGVs 1 to 4 and quay cranes 1 to 2. If a similar situation occurs, this chromosome will be regenerated until all AGVs and quays are allocated, as shown in the repaired chromosome in Figure 4.

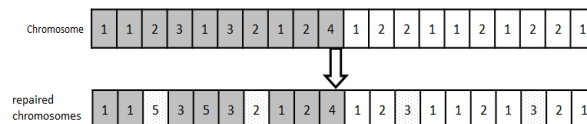


Figure 4 Schematic diagram of chromosome repair

(3) Fitness function: The fitness function in this paper adopts the reciprocal of the shortest AGV transit time at the end of the objective function, that is, $1/T$.

(4) Selection: This article adopts the roulette selection method.

(5) Crossover: This paper adopts a multi-point crossover method. As shown in Figure 5, two intersection sites are randomly generated in the AGV and the crane section respectively. The intersection segments of parent 1 are P1 and P2, and the intersection segments of parent 2 are P3 and P4. The cross segment P1 of parent 1 is exchanged with P3, and P2 and P4 are exchanged to generate child 1 and child 2.

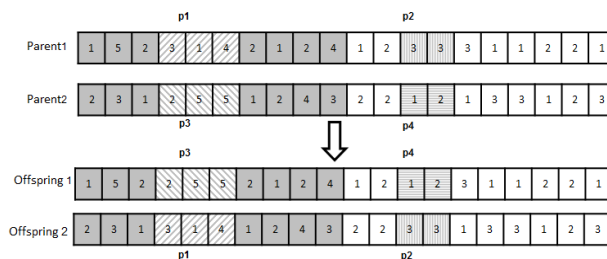


Figure 5 Schematic diagram of crossover

(6) Variation: This paper adopts the single-point mutation method. As shown in Figure 6, a mutation site is randomly generated in the AGV and the quay crane section, respectively, and the T1 and T2 gene loci of the parent generation are randomly mutated to generate offspring with different AGV and quay crane numbers from this locus.

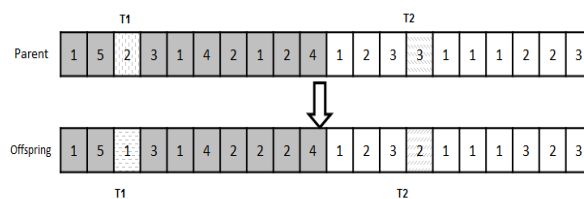


Figure 6 Schematic diagram of variation

5. Example Analysis

5.1 Parameter setting of the example

In order to evaluate the accuracy of the model and the effectiveness of the algorithm, the following examples are analyzed. Generate 1000 container task samples whose attributes are shown in Table 1. Set the initial population size $pop = 200$, the maximum number of iterations $gen = 200$, the crossover probability $pc = 0.7$, the mutation probability $pm = 0.05$, the distance between the power station - the yard - the quay crane is shown in Table 2. Let the charging threshold be 20%, the AGV empty and heavy vehicle travel speeds are 4m/s and 3m/s, respectively, and the AGV empty, heavy vehicle and waiting states are 0.01%, 0.02%, and 0.02%, respectively. 0.005%, set up two charging piles.

Table 1 task properties

Task number	target location	Earliest start time/s
1	yard4	60
2	yard1	103
...
999	yard6	34184
1000	yard2	34206

Table2 Swap—Yard—Quay crane distance

	Y1	Y2	Y3	Y4	Y5	Y6	S1	S2
QC1-1	335	316.22	304.13	300	304.13	316.22	492.44	492.44
QC2-2	360	335.41	316.22	304.13	300	304.13	538.51	538.51
QC3-3	390	360.55	335.41	316.22	304.13	300	585.23	585.21
Y1-1	0	50	100	150	200	250	316.22	316.22
Y2-2	50	0	50	100	150	200	364.00	364.00
Y3-3	100	50	0	50	100	150	412.31	412.31
Y4-4	150	100	50	0	50	100	460.97	460.97
Y5-5	200	150	100	50	0	50	509.91	509.90

Y6-6	250	200	150	100	50	0	559.01	559.01
S1-1	316	364	412	460	509	559	0	0
S2	316	364	412	460	509	559	0	0

5.2 Analysis of results

Table 3 Example results

Quay crane*AGV* task volume	GA operation result/s	waiting time/s	Average number of charges per AGV	operation hours/s	Quay crane*AGV*task volume	GA operation result/s	waiting time/s	Average number of battery swaps per AGV
3*5*50	3011.41	761.75	0.00	45.95	3*5*500	28725.39	1261.31	4.00
3*5*100	5703.02	1055.95	0.20	76.65	3*5*800	45859.16	1289.74	6.20
3*5*200	11429.79	1223.20	1.13	158.19	3*5*1000	57288.18	1555.21	8.00
3*10*50	2063.05	595.53	0.00	38.82	3*10*500	18322.80	6801.60	2.39
3*10*100	3741.87	1046.68	0.00	74.08	3*10*800	28344.37	10282.65	3.60
3*10*200	7562.27	2429.74	0.41	166.78	3*10*1000	35446.15	13674.72	4.80
3*20*50	2078.61	487.93	0.00	45.04	3*20*500	17912.17	7629.85	1.90
3*20*100	3790.81	904.09	0.00	90.06	3*20*800	28171.62	11582.17	3.20
3*20*200	7159.13	2950.23	0.00	181.65	3*20*1000	35051.45	15711.31	4.35
2*5*50	2921.70	486.65	0.00	45.72	2*5*500	28215.17	1462.84	4.00
2*5*100	5570.06	430.63	0.13	184.05	2*5*800	45046.53	1893.11	6.00
2*5*200	11288.11	575.26	1.00	251.41	2*5*1000	56160.02	1740.07	8.13
2*10*50	2022.40	543.08	0.00	49.18	2*10*500	18089.27	6690.07	2.40
2*10*100	3794.44	445.01	0.00	82.56	2*10*800	28198.74	10552.52	3.70
2*10*200	7506.60	2256.11	0.40	174.32	2*10*1000	35456.16	14483.97	4.70
2*20*50	2020.79	426.43	0.00	59.55	2*20*500	17968.70	6770.15	1.95
2*20*100	3858.46	917.97	0.00	99.37	2*20*800	28144.12	5995.77	3.25
2*20*200	7120.52	2673.37	0.00	192.10	2*20*1000	34960.05	15659.08	4.30

In order to verify the effectiveness of the model and algorithm, based on the above parameters, run 10 times to solve the completion time, waiting time, and average number of power changes of each AGV for different container task scales, quay cranes, and AGV numbers, as shown in Table 3.

Table 3 shows the proportion of waiting time to the total task completion time under different container task volumes and the number of AGVs and quay cranes, as shown in

Figure7. It can be seen that with the same number of AGVs, the overall waiting time of 2 quay cranes is lower than that of 3 quay cranes. The number of quay cranes is constant.

As the scale of the task increases, the proportion of waiting time for 5 AGVs shows a downward trend, but the overall completion time is longer; the waiting time for 10 and 20 AGVs both fluctuate and increase, and 20 AGVs are higher than 10. The proportion of waiting time for AGVs has increased. To sum up, the effect of allocating 2 quay cranes and 10 AGVs is better.

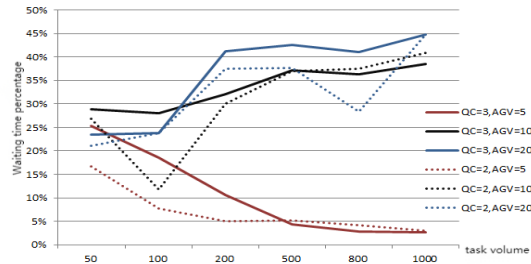


Figure 7 Waiting time as a percentage of total task completion time

As shown in Table 3, when the tasks are matched with different numbers of AGVs, the average number of power changes for each AGV is also different, and AGVs for small-scale tasks rarely change power. As shown in Figure 8, the large-scale 500 container task is equipped with 2 quay cranes and 10 AGVs, and some AGV power changes. For example, the power of the AGV9 decreases evenly during the transportation of the container, and after the power reaches the power exchange threshold, it will go to the nearest power exchange station for power exchange.

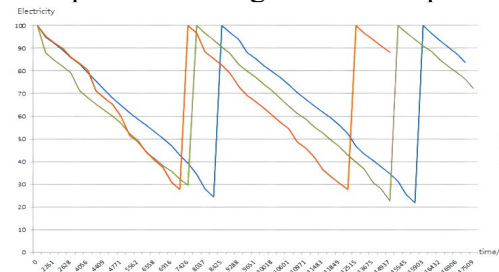


Figure 8 Part of the AGV power change diagram

5.3 Analysis of the influence of the AGV power exchange threshold on the results

After the above comparative analysis, it can be seen that the AGV power exchange threshold has a great impact on the final completion time. Therefore, the power exchange threshold is set in the range of 20%-35% according to the actual situation of the automated terminal, and the container task volume is 500 and QC=2 , AGV=10 for comparative analysis, and finally the completion time corresponding to different power exchange thresholds is shown in Figure 9. It can be seen that changing the power exchange threshold can affect the final completion time. Under the influence of different power exchange thresholds, the task completion time varies around 170s. When the power exchange threshold is 32%, the completion time is the shortest and the effect is the best.

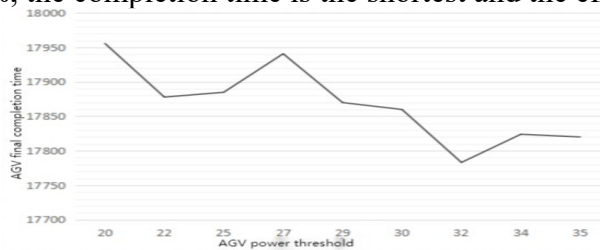


Figure 9 Completion time corresponding to different power exchange thresholds

6. Conclusion

With the general increase of human life span, the aging of population age structure has become increasingly tense, which has become a key factor affecting social development, economic development, ideology and individual life style. In the context of the aging society, the field of gerontology has been widely studied. In the aging society, geriatric sociology, which takes the elderly as the starting point and the main research object, will continue to exist. Based on the geriatric social science, this paper analyzes and summarizes the problems of the elderly, such as family and age discrimination

References

- [1] Lijun Yue , Houming Fan , Mengzhi Ma.Optimizing configuration and scheduling of double 40ft dual-trolley quay cranes and AGVs for improving container terminal services[J].Journal of Cleaner Production,2021,292:<http://doi.org/10.1016/j.jclepro.2021.126019>.
- [2] Y. Xing, K. Yin, L. Quadrifoglio, B.X. Wang. Dispatch Problem of Automated Guided Vehicles for Serving Tandem Lift Quay Crane[J]. Transportation Research Record, 2012, 2273: 79-86.
- [3] Fan Houming, Guo Zhenfeng, Yue Lijun, Ma Mengzhi. Combined configuration and scheduling optimization of dual-trolley quay cranes and AGVs in container terminals considering energy saving [J]. Journal of Automation, 2019.
- [4] Zhou Qi, Zhang Qin. The key technology of automatic container loading and unloading by double trolley quayside container crane[J]. lifting and transporting machinery,2016(3) : 70-73 .
- [5] Tian Yu, Zhou Qiang, Zhu Benfei. Research on the integrated scheduling of dual-cycle AGV and yard bridge in automated container terminals [J]. Transportation System Engineering and Information.2020,20(04): 216-223+243.
- [6] Fan Zhiqiang, Le Meilong. Dual-objective optimization of quay crane operation scheduling and its genetic algorithm to minimize the maximum completion time and waiting time[J]. Journal of Systems Management,2013,22(1) : 120-127.
- [7] Meisu Zhong,Yongsheng Yang,Yasser Dessouky,et.al.Multi-AGVscheduling forconflict-free path planning in automated container terminals[J].Computers&Industrial Engineering,2020,142:<https://doi.org/10.1016/j.cie.2020.106371>.
- [8] Zhang Yaqi, Yang Bin, Hu Zhihua, Tian Maojin. Research on integrated scheduling of AGV charging and operation in automated terminals [J]. Computer Engineering and Applications,2017,53(18) : 257-262 .
- [9] Fatnassi E,Chaouachi J.Scheduling automated guided vehicle with battery constraints[C]/ International Conference on Methods & Models in Automation & Robotics. IEEE, 2015.
- [10] McHANEY, R.Modelling battery constraints in discrete event automated guided vehicle simulations[J]. International Journal of Production Research, 1995, 33(11):3023-3040.
- [11] Zhou Xiaofan. AGV scheduling in container terminal considering charging and waiting time[J].Journal of Shanghai Maritime University, 2019, 40(3):1-5.
- [12] Nitish Singh,Quang-Vinh Dang,et.al.A matheuristic for AGV scheduling with battery constraints[J].European Journal of Operational Research,2021,14:<http://doi.org/10.1016/j.ejor.2021.08.008>.
- [13] Shi Nanlu, Liang Chengji. AGV scheduling optimization of automated terminals considering the power exchange process [J]. Modern Manufacturing Engineering,2019, 461(02): 12-17+145.