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Dynamic Path Planning of Multi-AGVs in Automated Terminal based on Co-Evolution

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Abstract

In order to solve the multi-AGVs path planning problem of the automated container terminal, considering the changes in traffic flow in the road network, a AGV dynamic road network model was proposed, and a dynamic path planning model of multi-AGVs with the goal of minimizing the operation time of the AGV system was established. To solve the model, a co-evolution genetic algorithm for the AGV dynamic road network model was designed. In the establishment of the fitness function, the road resistance coefficient in the dynamic road network model was added as a planning index, and a dynamic adjustment strategy of the path plan was proposed. Conducted a simulation experiment. The results show that the above methods can effectively solve the congestion and conflict problems and improve the efficiency of the AGV horizontal transportation.

Keywords

Automated Container Terminal; Multi-AGVs; Dynamic Model of the Road Network; Co-Evolution; Genetic Algorithm; Path Planning.

1. Introduction

The rapid development of the container transportation industry has higher requirements for the operation of the terminal. Automated container terminal can greatly improve the efficiency of loading, unloading and handling that reduce operating costs. In the AGV transportation operation of terminal, traffic congestion is prone to occur, which affects the operation efficiency of the automated container terminal. Therefore, reasonable path planning for the AGV system can improve the operation efficiency of the automated container terminal and reduce the operating cost of the terminal.

At present, scholars have conducted a lot of research on the path planning of AGVs in automated container terminals. Wei Yan [1] proposed a cost-based path planning method. Yang Yongsheng et al. [2] used the soft time window method to plan the AGV driving path. Also based on the time window, Liang Chengji et al. [3] realized conflict-free path planning for multiple AGVs. Zhong Meisu et al. [4] proposed a speed control strategy and used the Dijkstra-DFS algorithm to obtain the optimal path. Liu Yaohui [5] proposed a set of AGV path planning system scheme, which simplifies the calculation logic of the path planning system.

Other studies apply heuristic algorithms to AGV path planning in automated container terminals. Gao Wenwen et al. [6] designed a genetic algorithm and a tabu search algorithm considering the partial order relationship. Zeng Qingcheng et al [7] designed a multi-swarm ant colony algorithm based on dynamic path planning strategy. Cao Ying et al. [8] proposed an improved A* algorithm to solve the collision problem in AGV path planning. Song Qisong et al. [9] proposed an improved genetic algorithm to solve the problems of long time consuming and long travel paths for AGVs in docks. Xu Yixiang et al. [10] designed an AGV path planning model for loading and unloading, and used the

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simulated annealing algorithm to solve it. Lan Peizhen et al. [11] proposed an AGV control algorithm based on Ant-agent. Ji Shouwen et al. [12] proposed two-layer adaptive genetic algorithm and two-layer genetic algorithm based on conflict resolution strategy.

At the same time, some studies have applied traffic flow theory to terminal transportation operations. Zhou Qiang et al. [13] proposed a frontier traffic flow model for a container terminal. Kim [14] proposed a dynamic optimization method for AGV horizontal road network traffic flow based on genetic algorithm. Zhong Meisu et al. [15] proposed a traffic virtual roundabout strategy to solve the conflict and congestion problems when multiple AGVs are driving.

In summary, although there have been studies using heuristic algorithms for AGV path planning in terminal, there are few studies considering the dynamics of path planning. At the same time, the path planning of the AGV in terminal combined with the traffic flow theory can effectively solve the problem of congestion during the AGV driving process. Therefore, this paper proposes a AGV dynamic road network model. On this basis, a multi-AGV dynamic path planning model is established with the goal of minimizing the operation time of the multi-AGV transportation system, and a co-evolutionary genetic algorithm based on the dynamic path planning strategy is designed. The model is solved to obtain the optimal driving path of each AGV.

2. Automated Container Terminal Layout and Analysis of AGV Transportation Operations

2.1 Automated Container Terminal Layout

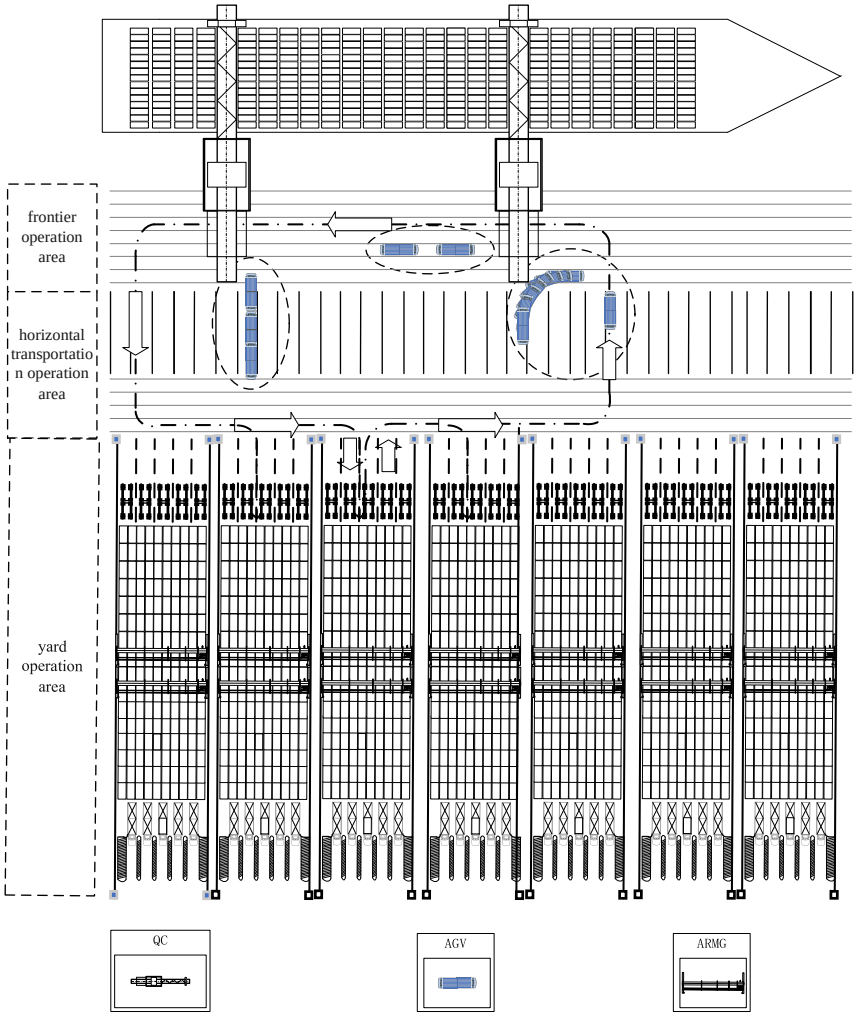

Fig. 1 Schematic diagram of container terminal layout

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The automated container terminal consists of frontier operation area, yard operation area and horizontal transportation operation area. The schematic diagram of the terminal layout is shown in Fig. 1 below.

2.2 AGV Transportation Operation

In the transportation operation of AGV, there are the following problems:

(1) Multiple AGVs driving in the same direction on the same road section cause congestion.

(2) When multiple AGVs arrive at the intersection node at the same time, a cross conflict occurs.

(3) AGVs traveling in opposite directions cause conflicts. Generally, the driving path of AGV is one-way driving, so this paper does not consider this situation.

3. Multi-AGV Dynamic Traffic Network Planning Model

3.1 AGV Dynamic Road Network Model

Over time, the traffic flow in the AGV road network also changes. Therefore, this paper proposes a dynamic road network model for terminal AGV. The dynamic road network model is not only a simple abstract expression of the AGV road network of the automated container terminal, but also considers the real-time update of the traffic flow in the AGV road network, and describes the smoothness of the road network section by introducing the road resistance coefficient. The dynamic road network model is described as follows:

$$G = \{V, E, T, S, K\} \tag{1}$$

$$V = \{v_i \mid i = 1, 2, 3, \ldots, n\} \tag{2}$$

$$E = \left\{ \left\langle v_i, v_j \right\rangle \mid i \neq j, v_i \in V, v_j \in V \right\} \tag{3}$$

$$T = \{t_0, t_1, t_3, \ldots, t_i, t_{i+1}, \ldots, t_{m-1}\} \tag{4}$$

$$S = \{s_{ij} \mid v_i \in V, v_j \in V, i \neq j\} \tag{5}$$

$$K = \{k_{ij}(t) \mid v_i \in V, v_j \in V, i \neq j, t \in T\} \tag{6}$$

In the formula, G is the dynamic traffic network of the terminal AGV, which represents a weighted directed graph; V is the set of all nodes in the AGV road network; E is the set of edges, representing the set of directed road segments connected by each node in the AGV road network; T is the set of time series, the AGV transportation system in terminal will update the traffic flow information of each road section in the road network at regular intervals, T is the set of update time points; S is the set of edge lengths, representing the length of each road segment in the road network; K is the set of road resistance coefficients, and kij(t) represents the road resistance coefficient of the edge < vi, vj > at time t, which can be calculated by the traffic flow theory using the number of AGVs in each road section of the road network and the accommodating number of each road section:

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$$k_{ij}(t)=q_{ij}(t)/l_{ij}, q_{ij}\in Q, l_{ij}\in L, v_i\in V, v_j\in V \tag{7}$$

In the above formula, Q is the set of the number of AGVs in each road section of the road network; L is the set of the number of AGVs that can accommodate each road section of the road network.

According to the road resistance coefficient and the length of the road section, the driving speed of the AGV at time t can be restricted as follows, and the driving time of the AGV through a road section at time t can be further calculated:

$$v(AGV)_{ij}(t)=\frac{v(AGV)_{k=0}}{\left(1+k_{ij}(t)/k_{\max}\right)} \tag{8}$$

$$T(AGV)_{ij}(t)=\frac{s_{ij}}{V(AGV)_{ij}(t)}=\frac{s_{ij}}{V(AGV)_{k=0}/\left(1+k_{ij}(t)/k_{\max}\right)} \tag{9}$$

3.2 Multi-AGV Dynamic Path Planning Model

This paper makes the following reasonable assumptions about the research question:

(1) The influence of force majeure factors is not considered;

(2) The situation of insufficient AGV power is not considered;

(3) Each quay crane serves multiple yard container areas and the positions of the quay crane and yard container area are known;

(4) The situation of AGV waiting in the handover area of the yard container area and the quay crane handover area is not considered;

(5) At the node where the conflict occurs, the deceleration time of the AGV is not considered.

The model parameters and variables are set as follows:

① set

O:The set of transport tasks;M:The set of AGVs;N:The set of all nodes in the road network;R:The set of all road segments in the road network;R_m:The set of road segments included in the travel path of the mth AGV.

② parameter

r_m: The rth road segment in the driving path of the mth AGV;$Q_{(R_m)}$: The number of road segments included in the driving path of the mth AGV;S_r:The length of the corresponding road segment r between two adjacent nodes in the road network;C_r:The number of AGVs that the corresponding road segment r between two adjacent nodes in the road network can accommodate;D_r^t:The number of AGVs corresponding to the road segment r between two adjacent nodes in the road network at time t;T_{mr}^o:The leave time of the mth AGV on the road segment r when performing task o;T_m^{os}:The start time of the mth AGV performing task o;T_m^{of}:The end time of the mth AGV performing task o;v_{mr}^o:The driving speed of the mth AGV in the road segment r when the mth AGV performs task o;E:Length of AGV;ST:maximum completion time;G:a very large number;H:available time.

③ decision variables

$U_{mm'}\in\{0,1\}$,indicates that when the priority of the transportation task performed by the m'th AGV is higher than the transportation task performed by the mth AGV, it is 1, otherwise it is 0;

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$B_m^o \in \{0,1\}$,indicates that when the transportation task o is performed by the mth AGV, it is 1, otherwise it is 0;

$X_{mm'} \in \{0,1\}$,indicates that when the m'th AGV collides with the mth AGV, it is 1, otherwise it is 0;

$Y_m^{nt} \in \{0,1\}$,indicates that when the mth AGV reaches node n at time t, is 1, otherwise it is 0;

$Z_{mr} \in \{0,1\}$,indicates that when the mth AGV is driving on the road section r and the road section r is congested, it is 1, otherwise it is 0;

In this paper, the path planning model is established with the goal of minimizing the operating time of the AGV system. As shown below, formula (10) is the objective function.

$$\min ST \tag{10}$$

$$ST \geq T_m^{of}, \forall m \in M, o \in O \tag{11}$$

$$T_m^{of} = \sum_{r=1}^{Q_{(R_m)}} t_{mr}^o + T_m^{os} + GZ_{mr}, \quad r \in R, \forall m \in M, o \in O \tag{12}$$

$$\sum_{m \in M} B_m^o = 1, \forall o \in O \tag{13}$$

$$D_r^t \leq C_r, \forall t \in (0, H), r \in R \tag{14}$$

$$\sum_{m \in M} Y_m^{nt} \leq 1, \forall n \in N, \forall t \in H \tag{15}$$

$$\left| T_{m'r'}^{o'} - T_{mr}^o \right| \geq t_{mr}^{ow} U_{mm'} + t_{m'r'}^{o'w} U_{mm}, \quad m, m' \in M, o \in O, r, r' \in R \tag{16}$$

Among them, Equation (11) indicates that the maximum completion time is not less than the completion time of any transportation task; Equation (12) indicates that the time when the AGV completes the transportation task is equal to the task start time, the travel time on the road section and the delay time caused by the congestion of the road section. The sum; Equation (13) indicates that each transportation task can only be assigned once; Equation (14) indicates that the number of AGVs at any time on the AGV driving section does not exceed the maximum capacity of the section; Equation (15) indicates that any AGV road network There can only be one AGV at a node at the same time; Equation (16) indicates that the time difference between two conflicting AGVs arriving at the intersection nodes of road segments r and r' at the same time is not less than the waiting time of the AGV with a lower transport task priority.

4. Algorithm

The co-evolutionary genetic algorithm designed in this paper constructs a population of each AGV in the multi-AGV path planning problem, and multiple populations evolve simultaneously according to the co-evolutionary mechanism. At the same time, a dynamic path planning strategy based on the terminal AGV dynamic road network is proposed. The algorithm is described in detail as follows:

(1) Initialization condition

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Initialize road network information, obtain AGV transportation tasks, and map N AGVs to N populations.

(2) Encoding

Using the method of symbol coding, the node number in the AGV road network model corresponds to the gene in the chromosome, and the adjacent genes are adjacent nodes.

(3) Initialize the populations

The initial population is randomly generated, and the chromosomes are randomly generated in various groups.

(4) Design the fitness function

Combined with the terminal AGV dynamic road network model and the terminal multi-AGV dynamic path planning model proposed in this paper, the fitness function is determined as:

$$f\left(P_{n,m}\right)=\sum_{i,\,j\in P_{n,m}}\frac{s_{ij}}{v(AGV)_{k=0}/\left(1+k_{ij}(t)/k_{ij\max}\right)} \tag{17}$$

(5) Evolution operation

After each group performs selection, crossover, and mutation operations independently, each individual in each group compares its fitness value with the fitness value of the overall best representative, and then performs evolutionary operations to generate new individuals.

(6) Co-evolution of multiple populations

Select the current optimal representatives from various groups to form the optimal representative set to represent the optimal driving path of each AGV currently planned. An individual with the best fitness value in the representative set will co-evolve with individuals in various groups, and the representative set will be continuously updated until convergence or genetic algebra is reached.

(7) Dynamic path planning strategy

Based on the co-evolutionary genetic algorithm, an initial path planning scheme is generated, and each AGV travels according to the initial optimal path. If there is a conflict between the AGVs, the conflict is resolved according to the rules. At the same time, the road network status table and the driving status table of each AGV are dynamically updated during the driving process of the AGV, and the average road resistance coefficient of the entire dynamic road network is calculated. When the set value α is reached, the current position of each AGV is located. The next node takes this node as the starting point, and the original end point remains unchanged, and the co-evolutionary genetic algorithm is used to plan the path again.

5. Case Analysis

5.1 Example Solution

In order to verify the validity of the model and algorithm proposed in this paper, an empirical analysis is carried out with the actual data of an automated container terminal. The terminal is equipped with 3 quay cranes in the front operation area, 6 container areas in the yard operation area, and 2 yard bridges in each container area. The road network is abstracted as a weighted directed graph, as shown in Fig.2, the numbers in the figure are the numbers of each node in the road network, and there are 84 road network nodes in total.

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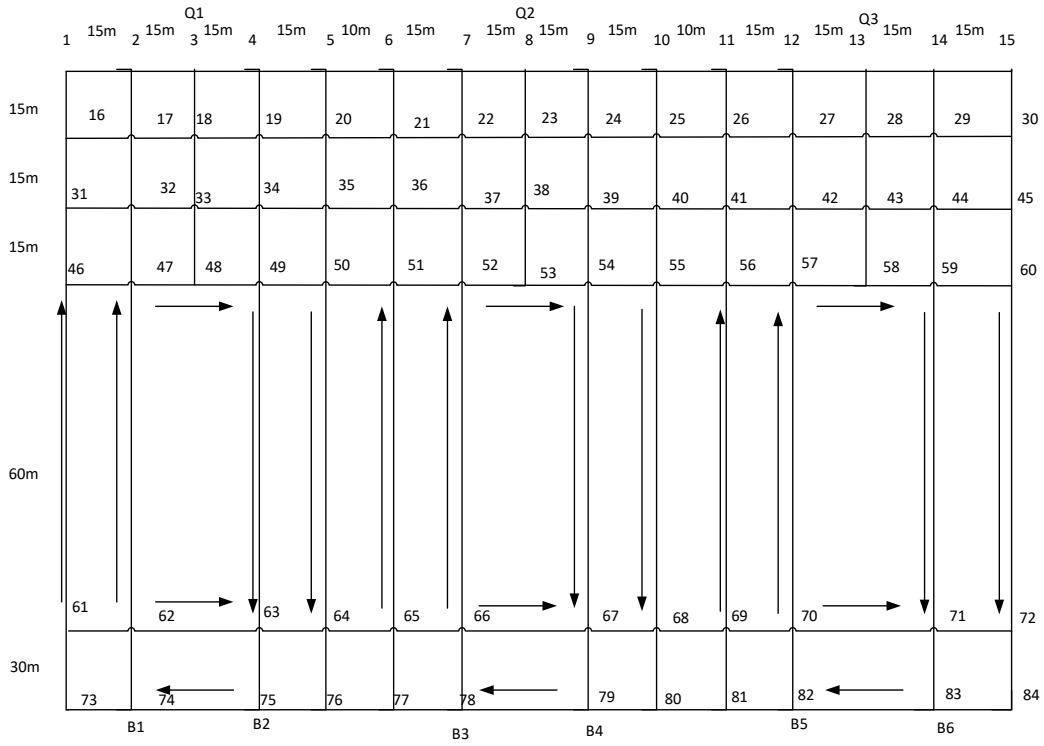

Fig. 2 AGV road network layout

Parameter setting: AGV's initial travel speed v(AGV)=6m/s, AGV's length E=6m, and safety distance D=3m. α=0.2.

Using python to conduct simulation experiments, dynamic path planning for the assigned AGV transportation tasks, and finally obtain the minimum travel time of each AGV to complete the transportation task and the corresponding travel path, as shown in Table 1. At the same time, the simulation diagram of AGV path planning nodes and time information is obtained, as shown in Fig.3. In the iterative process of the algorithm, the change of the adaptive value and the number of iterations are shown in Fig.4.

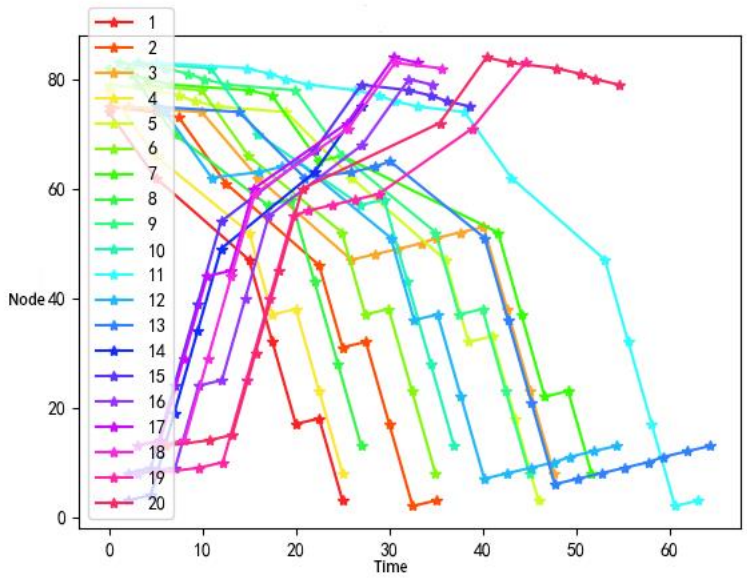

Fig. 3 Node and time information simulation diagram

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Table 1. AGV path planning scheme

AGV	Transport task	Driving path	Complete time /s
1	B1-Q1	74-62-47-32-17-18-3	25.00
2	B2-Q1	75-74-73-61-46-31-32—17-2-3	35.00
3	B2-Q2	75-74-62-47-48-49-50-51-52-53-38-23-8	47.60
4	B3-Q2	78-66-52-37-38-23-8	25.00
5	B4-Q1	79-78-77-76-75-74-62-47-32-33-18-3	45.97
6	B4-Q2	79-78-66-52-37-38-23-8	34.93
7	B5-Q2	82-81-80-79-78-77-65-66-52-37-22-23-8	51.63
8	B5-Q3	82-70-57-58-43-28-13	27.00
9	B6-Q2	83-82-81-80-79-78-66-52-37-38-23-8	44.97
10	B6-Q3	83-82-70-57-58-43-28-13	36.93
11	B6-Q1	83-82-81-80-79-78-77-76-75-74-62-47-32-17-2-3	63.07
12	B1-Q3	74-62-63-64-65-51-36-37-22-7-8-9-10-11-12-13	54.33
13	B2-Q3	75-74-62-63-64-65-51-36-21-6-7-8-9-10-11-12-13	64.37
14	Q1-B2	3-4-19-34-49-63-75	27.00
15	Q2-B2	8-9-24-39-54-67-79-78-77-76-75	38.67
16	Q2-B4	8-9-24-25-40-55-68-80-79	34.60
17	Q3-B6	13-14-29-44-45-60-72-84-83	33.00
18	Q3-B5	13-14-29-44-59-71-83-82	35.60
19	Q2-B6	8-9-10-25-40-55-56-57-58-59-71-83	44.57
20	Q3-B4	13-14-15-30-45-60-72-84-83-82-81-80-79	54.57

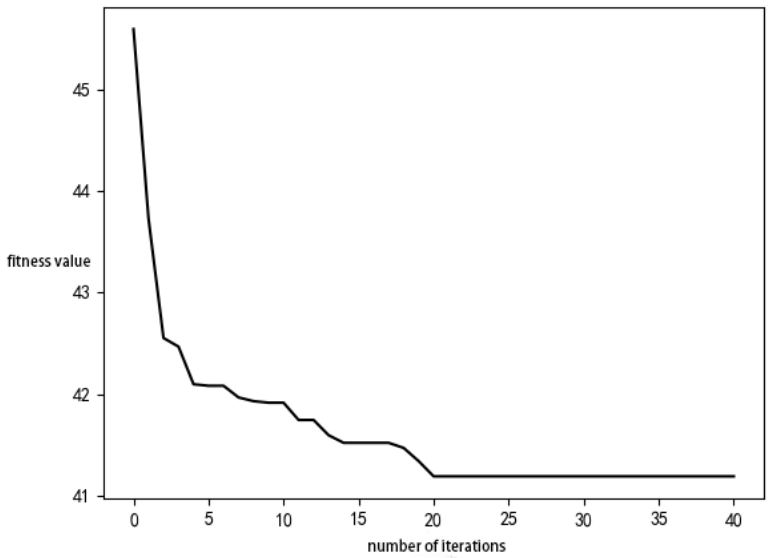

Fig. 4 Algorithm iteration

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5.2 Comparative Analysis

In order to verify the effectiveness of the algorithm proposed in this paper, the standard genetic algorithm is used to solve the assigned AGV transportation tasks in Table 1. The solution results are shown in Table 2, and the driving conditions of the AGV are shown in Fig.5.

Table 2. Genetic algorithm solution result

AGV	Transport task	Driving path	Complete time /s
1	B1-Q1	74-62-47-32-17-2-3	25.00
2	B2-Q1	75-74-73-61-46-31-16-1-2-3	35.00
3	B2-Q2	75-74-73-61-46-31-16-17-18-19-20-21-22-7-8	56.60
4	B3-Q2	78-66-52-37-22-23-8	25.00
5	B4-Q1	79-78-77-76-75-74-73-61-62-47-32-17-2-3	48.97
6	B4-Q2	79-78-77-65-51-36-37-38-23-8	39.93
7	B5-Q2	82-81-80-79-78-66-52-37-38-23-8	42.47
8	B5-Q3	82-70-57-42-27-12-13	27.00
9	B6-Q2	83-82-81-80-79-78-77-65-51-36-21-6-7-8	49.97
10	B6-Q3	83-82-81-69-56-41-26-11-12-13	40.93
11	B6-Q1	83-82-81-80-79-78-77-76-75-74-62-47-32-17-18-3	64.47
12	B1-Q3	74-62-47-48-49-50-51-52-37-22-23-8-9-10-11-12-13	58.33
13	B2-Q3	75-74-62-63-64-65-51-36-37-22-7-8-9-10-11-12-13	71.67
14	Q1-B2	3-4-19-34-35-50-64-76-75	32.00
15	Q2-B2	8-9-24-39-54-67-68-80-79-78-77-76-75	43.67
16	Q2-B4	8-9-24-39-40-55-68-80-79	37.00
17	Q3-B6	13-14-15-30-45-60-72-84-83	33.00
18	Q3-B5	13-14-29-44-59-71-83-82	35.60
19	Q2-B6	8-9-10-11-12-13-14-29-30-45-60-72-84-83	52.87
20	Q3-B4	13-14-15-30-45-60-72-84-83-82-81-80-79	54.57

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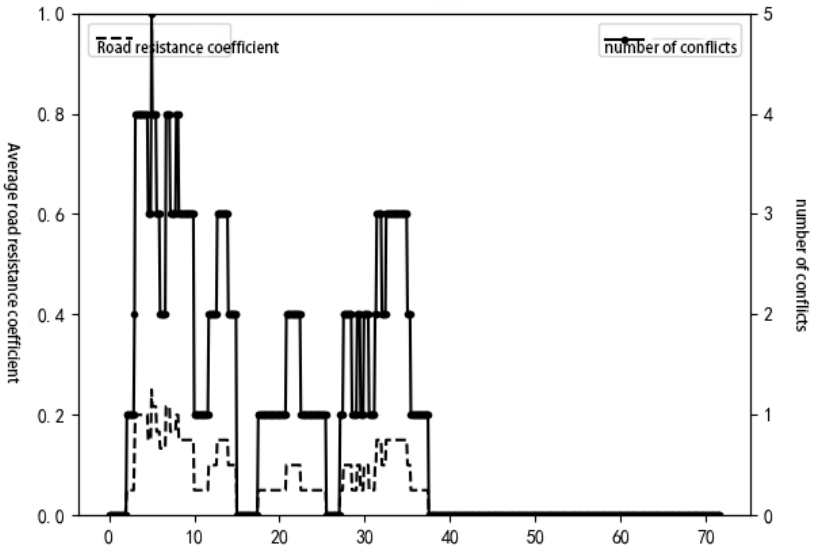

Fig. 5 AGV driving condition of genetic algorithm solution scheme

From Table 2 and Fig.5, it can be concluded that the solution solved by the standard genetic algorithm has many conflicts between AGVs, a high repetition rate of road sections, and the road network is relatively congested. However, the solution AGV system solved by the co-evolutionary genetic algorithm designed in this paper has a shorter job completion time, which is reduced from 71.67s to 64.37s, and has fewer conflicts and a low repetition rate of road sections. It can be seen that the algorithm in this paper is better in global optimization.

In order to verify the effectiveness of the path planning for AGVs combined with the dynamic road network model, experiments were carried out on whether to consider the change of road resistance coefficient. Fig.6 shows the driving conditions of each AGV obtained by considering the change of road resistance coefficient for path planning. Fig.7 shows the driving condition of each AGV obtained by without considering the change of road resistance coefficient for path planning.

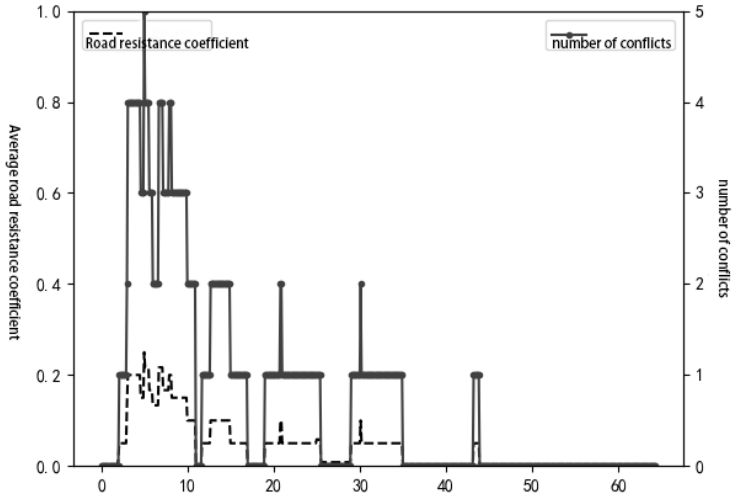

Fig. 6 AGV driving condition of the path plan combined with the change of the road resistance coefficient

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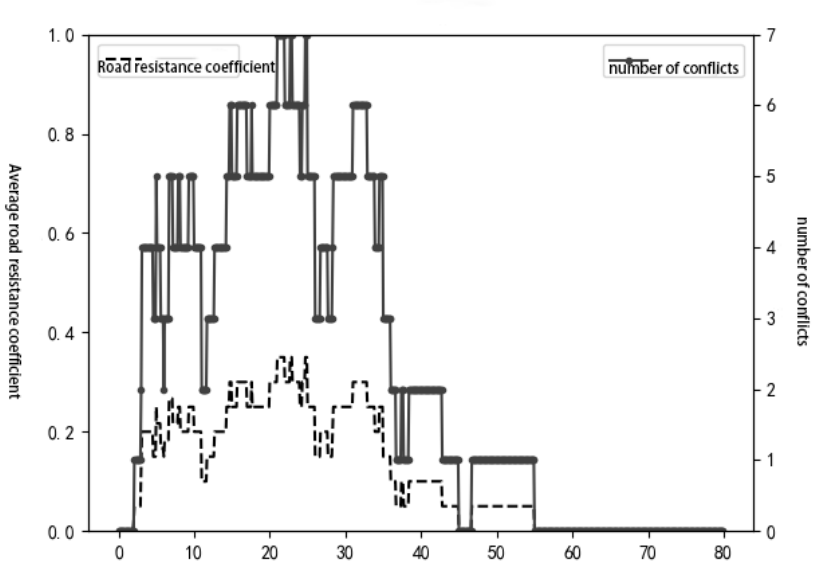

Fig. 7 AGV driving condition of the path plan without considering the change of the road resistance coefficient

It can be seen from Fig.6 and Fig.7, compared with not considering the change of road resistance coefficient, the completion time of the scheme obtained by dynamic path planning combined with the change of road resistance coefficient decreases from 79.97s to 64.37s. At the same time, the conflict between AGVs is greatly reduced, and the average road resistance coefficient in the entire AGV road network is also small, indicating that the congestion in the AGV transportation system has been alleviated.

In order to further verify the influence of the dynamic road network model on the path planning of AGV, this paper compares the solution results of whether the change of road network resistance coefficient is considered under different task scales, and the results are shown in Table 3. It can be seen from Table 3 that with the increase of the amount of tasks, the completion time of the work increases. The plan obtained by combining the change of the road resistance coefficient is always better, and the difference between the completion time of the two plans is also greater. Combining the dynamic road network model for path planning, each AGV travel path is more reasonable, thereby improving the operation efficiency of the AGV system.

Table 3. Comparative analysis under different task scales

Task volume /TEU	Complete time /s	
	Consider the dynamic road resistance coefficient	Do not consider dynamic road resistance coefficient
20	64.37	71.67
30	87.55	105.87
40	145.65	194.47

6. Conclusion

In order to solve the congestion and conflict problems in the multi-AGV path planning problem in automated container terminals, this paper proposes a dynamic road network model for AGVs in the

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terminal. With the goal of minimizing the operating time of the AGV system, a multi-AGV path planning model is established. At the same time, a co-evolutionary genetic algorithm based on the dynamic path planning strategy is designed, and the road resistance coefficient in the dynamic road network is added as a planning index to the establishment of the fitness function, and the effectiveness of the method is verified by an example. According to the experimental results, the path planning of AGVs combined with the dynamic road network model can effectively reduce the congestion during the AGV driving process. The operational efficiency of the AGV system.

This paper considers the dynamics of AGV path planning, but in a dynamic continuous environment, the real-time adjustment and optimization of AGV path planning is still insufficient, which can be combined with reinforcement learning for in-depth research.

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