Research on Optimization of Multi-AGV Path Based on Genetic Algorithm Considering Charge Utilization

Jianjun Wang1,*, Junnan Pan1, Jikun Huo1, Ran Wang1, Li Li2, Tiantian Nian3

1School of Economics and Management, North China Electric Power University, Beijing, China
2School of Economics and Management, Beijing Information Science & Technology University, Haidian district, Beijing, China
3Jiangsu Pharmaceutical Co., Ltd, Yibin City, Jiangsu Province, China

*Corresponding author’s email: wangjianjunhd@126.com

Abstract. The rapid development of e-commerce and artificial intelligence technology has led to the rapid development of unmanned warehousing automation technology in the logistics industry. Unmanned warehousing and automated guided vehicle (AGV) equipment in unmanned warehousing have also increased. Since the AGV needs to be charged, based on the traditional simple path optimization, if the sorting efficiency of logistics needs to be further improved, the charging problem of the AGV needs to be considered. This paper constructs a multi-AGV path optimization model in an unmanned storage environment based on the charging utilization rate. The model takes the shortest path and the highest charging utilization rate as the dual goals, and selects the genetic algorithm as the method to solve the model, which is verified by simulation experiments. The proposed model and algorithm have certain validity and feasibility.

Keywords. AGV, charge utilization, path optimization

1. Introduction
The rapid development of e-commerce has caused the logistics industry, known as the "third source of profit", to have great application requirements for new technologies such as the Internet of Things, visual recognition, robots, and warehousing smart machines. Unmanned warehouse automation in the logistics industry technology is currently developing at a relatively rapid rate, making the logistics industry in a stage of revolutionary change. Unmanned storage is a comprehensive application of various information technologies and systems such as the Internet of Things technology, RFID, GPS, ERP (Enterprise Resource Planning), WMS (Warehouse management system), etc. Automated guided vehicles refer to the main automated equipment that processes materials in an unmanned storage environment and realizes unmanned sorting and distribution. It has fundamental practical significance for the realization of large quantities of multi-variety materials in modern logistics under unmanned storage, especially the large unmanned warehouse, and the demand for AGV will be greater.
At present, most of the researches on AGV path optimization often sets the AGV normal transportation task and the AGV path emergency task in the model, and the optimization operation is performed with the shortest path as the goal. In 2011, some scholars applied the Q-learning technology to the optimization of the AGV route of the port terminal[1]. In 2012, J. Rubaszewski developed an effective planning method based on a genetic algorithm in order to solve the problem of minimizing the total travel distance considering the load and empty travel based on the traditional one-way network flow path design problem[2]. In 2017, Fazlollahtabar developed the Lagrangian relaxation method based on AGV processing and waiting for time scheduling, routing, and the existing path in the job shop manufacturing system, and established a sub-gradient algorithm to minimize the total delay of the AGV, including Advance and delay[3-4]. In 2017, Han Z et al. used three crossover heuristic operators to generate more optimal offspring in an improved genetic algorithm. Through the minimum constraints of both the AGV total path and the single path, the shortest total was obtained. The optimal solution in the path. The simulation results show that the improved genetic algorithm shortens the total path distance of all AGVs and the longest single AGV path distance[5]. In 2018, Jens Heger et al. proposed mixed-integer linear programming (MILP) formula to generate the best timetable for automatic guided vehicles (AGVs) in a blocked and reentrant workshop environment with different jobs[6]. Liu and Peng proposed a path optimization algorithm based on priority sorting queues and locking processing of node time windows to find the conflict-free path with the lowest transportation cost. Under the normal transportation task of unmanned storage, the trolley gets the target point after receiving the task, and it is the trolley that optimizes the path for a single destination point. However, In current actual operations, AGVs usually use 24V or 48V DC batteries as power. Due to the current development of battery technology, AGVs always only can run for 4 hours continually. When the power is lower than a certain threshold, AGV must accept the charging instruction and go to the charging area, meanwhile, AGV needs to quit the handling task while charging, then drive to the work area after the charging is completed. This process is prone to excessive no-load and queues waiting time, and charging behavior will have a greater impact on the efficiency of AGV handling. Therefore, in an unmanned storage environment, it is necessary to combine the charging requirements for AGVs, and the path optimization research considering the charging utilization rate will further improve the operation efficiency of AGVs, reduce the phenomenon of vehicle idling, and reduce the cost of logistics enterprises.

2. Construction of AGV path optimization model in unmanned storage
The traditional AGV path optimization problem is mostly to build a single-object model that seeks the smallest total distance. The objective function of the model is as follows:

\[ Z = \min \sum_{i=1}^{I} \sum_{j=1}^{J} x_{ij} d_{ij} \]  

(1)

The constraints are as follows:

\[ \sum_{i=1}^{I} \sum_{j=1}^{J} x_{ij} = I \]

\[ \sum_{j=1}^{J} x_{ij} = 1 \]

\[ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{s=1}^{N} y_{ijys} = I \]  

(2)

\[ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{s=1}^{N} y_{ijw0} = 1 \]
Among the constraints, the first one means that $J$ AGVs will perform a total of $I$ tasks; the second one means that one task can only be performed by one AGV; the third one means that all AGV vehicles must start from the loading point; the forth Means that all the carts will return to the loading point after the completion of the task; the fifth means that the final completion time of the task must be within the allowable interval; the last two set the value interval for the independent variable.

It can be seen from the above analysis that in unmanned storage, if there are multiple AGV charging conflicts, there will be waiting time. The longer the waiting time, the coordination utilization between the charging pile and the AGV charging is bad. Since it is assumed that all the AGV charging is completed in the charging pile, there is no power exchange phenomenon in the unmanned storage, so the charging utilization rate of the AGV can be equivalently measured by measuring the charging time efficiency of the AGV.

Based on the above analysis, the method for measuring the charging utilization rate of multiple AGVs in unmanned storage is defined. First, the charging utilization rate of a single AGV can be calculated using the following formula:

$$\eta = \frac{\sum_{j=1}^{96} (T_{\text{wait}})}{T_{\text{day}}} \quad (3)$$

Among them, $t$ represents the charging time, $j = 1, 2, ..., J$, $J$ is the maximum number of AGV cars. It is the charging waiting time after the AGV arrives at the charging pile, and the working time is specified for the AGV of a single working day. Since it is an unmanned warehouse, the working time of a working day is 24 hours. Assuming the minimum split time of charging is 15 minutes, take the value is 96. If there are $J$ AGV vehicles in an unmanned storage environment, the charging utilization rate of the entire unmanned storage AGV can be measured using the following.

$$\eta_T = \frac{\sum_{j=1}^{96} \sum_{i=1}^{J} (T_{\text{wait}})}{J \times 96} \quad (4)$$

Drawing on the idea of time window, if the charging behavior of all AGVs is represented by a matrix, it can be represented by a 0-1 decision matrix with $J$ rows and 96 columns, which will form a charging scheduling matrix

$$O_{\text{ele}} = \begin{bmatrix} ele_{11} & ele_{12} & ... & ele_{196} \\ ele_{21} & ele_{22} & ... & ele_{296} \\ ... & ... & ... & ... \\ ele_{91} & ele_{92} & ... & ele_{996} \end{bmatrix} \quad (5)$$

Based on this matrix, if there are $j$ elements of 1 in the same column, it means that there are $j$ AGVs that need to be charged at that point in time. If $j$ exceeds the number of charging piles $k$, there are $j-k$ cars waiting. Therefore, the charging utilization rate of the AGV in the entire unmanned warehouse can be calculated using the following equation
among them:

\[
f_{\text{max}}(\sum_{j=1}^{J} \text{ele}(j,t) - k) = \begin{cases} 
0 & \sum_{i=1}^{N} \text{ele}(j,t) - k \leq 0 \\
\sum_{i=1}^{N} \text{ele}(j,t) - k & \sum_{i=1}^{N} \text{ele}(j,t) - k > 0
\end{cases}
\]

(7)

The constraints are:

\[\text{ele}(j,t) \in \{0,1\}\]

(8)

Based on the above analysis, the final path optimization problem of multiple AGVs is as follows:
The objective function is a dual objective function, with the shortest operating path \(z_1\), and the highest charging utilization rate \(z_2\) measured by the least charging waiting time.

\[
\text{obj} \quad z_1 = \min \sum_{i=1}^{J} \sum_{j=1}^{J} x_{ij} d_{ij}
\]

(9)

\[
z_2 = \min \eta_f
\]

(10)

the constraints are as follows:

Task assignment AGV car complete constraints:

\[
\sum_{j=1}^{J} \sum_{i=1}^{I} x_{ij} = 1
\]

(11)

Each AGV car can only perform one operation constraint at a time:

\[
\sum_{j=1}^{J} x_{ij} \leq 1
\]

(12)

AGV power constraint:

\[
d_{j,k}^{\text{max}} \leq d_{j,d}^{\text{max}}
\]

(13)

The farthest distance \(d_{j,k}^{\text{max}}\) for the j-th vehicle to reach the k-th charging pile should be less than or equal to the longest distance \(d_{j,d}^{\text{max}}\) that the j-th vehicle can travel under the state of remaining power.

The i-th car should run above the minimum power setting before charging, that is, it needs to be higher than the minimum power setting before the charging command, and the maximum after charging does not exceed the full state, because the full state can last 4 hours, that is, it can work 16 quarter hours, so there are behavioral constraints on AGV charging power:

\[
P_{\text{min}} \leq P_i + \sum_{j} \text{ele}(j,t) \leq 16
\]

(14)

3. AGV optimization path algorithm based on genetic algorithm
After constructing the above-mentioned AGV path optimization model considering the charging utilization rate, the model needs to be solved. In the unmanned storage environment, the optimal path planning of the AGV has always been a hot and needs to be studied[7]. The solution of the AGV
vehicle routing problem belongs to the category of combinatorial optimization problems. In the algorithm, it is often attributed to NP-hard complete problems. If the scale is large\[8\], it is difficult to solve the global optimization solution with conventional algorithms. Therefore, it is necessary to use intelligent algorithms to solve the problem, find a satisfactory solution.

3.1. The basic idea of using genetic algorithm to solve

Genetic algorithm is a kind of swarm intelligence optimization algorithm\[9\]. The algorithm simulates the survival of the fittest and the survival of the fittest in the biological population, and uses the global parallel search method of the population to search for the optimal individual in the population\[10\]. It can obtain the optimal solution that meets specific requirements has attracted the attention of many scholars. After years of application in various fields, the practicability of the algorithm has been proved. Therefore, this paper also chooses to use the genetic algorithm as an intelligent algorithm to solve the problem.

The basic idea of using genetic algorithm to solve is as follows:

1) First create 4 sets. The T set represents the time window under the shortest path of the first j-1 AGVs, the F set represents the time window after conflict coordination, and the P set represents the time window closest to the F set in the T-F set. Establish a node set U and place the predecessor node of the current node. For example, \( U(t_j^i) = t_0^i \) indicates that the predecessor node of node 2 is node 1;

2) Initialization, set the time window occupied by the AGV at the starting point to \( t_0^5 \), and the value of \( L(t_0^5) \) to be \( nowf \), the initial F set is \( t_0^5 \), and the U set is empty

3) For each \( t_i^j \in T-F \):
   a) For \( t_i^j \in F \), first calculate the \( f_w \) and \( f_m \) from point j to point i; based on this, judge whether there is a collision between point i and point j in time and space;
   b) For the time window \( f_k^j \) in the set F, let \( F_{min} = \min \{ F_{go} \} \);
   c) For \( t_i^j \), if \( L(t_i^j) > F_{min} \), then \( L(t_i^j) = F_{min} \), \( U(t_i^j) = t_i^j \);
   d) \( t_i^j \) join set \( P \);
   e) Observe whether the target node appears in the F set, if it appears, continue to execute downward; otherwise, return to the second step;
   f) Starting from the last target node, follow \( U(t_i^j) = t_i^j \) to push out the predecessor nodes in sequence until the initial node.

4. Case analysis

Select the sorting area of a logistics center for modeling operations to form a topological map. The sorting area after the topological map can be abstracted is 20×20. There are 9 charging piles distributed in the sorting area. At the beginning of the simulation, a total of 9 AGVs in the area were working together. The grid is used as a node in platform sorting. The AGV's straight speed is one cell per minute. The abstracted map is shown in Fig. 1(a). The red in the picture is the starting position of the AGV trolley, and the purple is the position of the charging pile.

In the simulation environment, the program sets up a random job generator to generate a sorting job list. The job list contains the coordinates of the job. After the simulation order is generated, the AGV needs to perform job sorting behavior, it also contains the number of AGVs required for the operation. It is assumed that in the simulated environment, the trolley can only move forward in the way assumed by the track. From the figure, it can only move forward in a square manner, that is, between two points can only be carried out on a right angle It is not possible to move forward in a diagonal manner, so the shortest distance calculation method for the trolley to perform work is the sum of the absolute value of the difference between the corresponding values of the horizontal and vertical coordinates of the point where the trolley is located and the point where the work is located.
To solve the AGV path optimization problem in the above environment, select the genetic algorithm mentioned above and use the MATLAB 2019a environment to program the solution. The genetic algorithm has been tested for many times and its parameters are set as follows: the maximum number of iterations is 100 generations, the scale is 10, the crossover probability is 0.85, and the mutation probability is 0.2.

4.1. Multi-AGV path optimization solution analysis considering only the shortest path
When the environment is set to consider only the shortest single-objective optimization of the job path, the job assignment is performed through genetic algorithm, and when the power is less than the predetermined power threshold, the AGV is given a charging command. The working circuit diagram obtained after the solution and the result when it first arrives at the charging station for charging and the time window of the AGV are shown in Fig.1(a) and Fig.1(b).

![Figure 1(a). Route map without considering vehicle conflicts](image1)

![Figure 1(b). Time window diagram](image2)

As shown in the upper left corner of Fig.1(b), before considering the conflict problem and coordinating the scheduling, when only the shortest path is considered, the overlapped part of the time window appears in the upper left corner of the left image, indicating that there is a conflict in the path.

4.2. Optimal solution of multi-objective AGV collision-free path considering the charging utilization rate.
When the environment is set to consider not only the shortest single-objective optimization of the operating path, but also the scheduling and allocation of operations in the case of collision avoidance and deadlock considering the charging utilization rate in the charging path of multiple AGVs result. The charging priority is set as follows: the charging tasks of the vehicles are arranged according to the priority, the lower the power, the higher the priority, and the conflicting vehicles are coordinated. Under the same job list, the job assignment is solved by genetic algorithm. The job circuit diagram obtained...
after the solution, the result of the first time when the charging pile is reached for charging, and the time window of the AGV are shown in Fig.2(a) and Fig.2(b).

Fig.2(a) shows the conflict-free time window under the conflict avoidance model. The non-overlapping conflict part can be seen intuitively, indicating that the AGV has re-selected the conflict path and finally formed the collision-free path shown in Fig.2(b).

Through the comparison and analysis of the results, it can be seen that if the relevant scenarios of the charging utilization rate are considered, the genetic algorithm is used to solve the problem, and the algorithm proposed in this article is used for planning and scheduling, the AGV car can choose a more reasonable charging pile and charging path according to its own location, remaining power and the location distribution and charging situation of the charging pile, which avoids the phenomenon of AGV cars being concentrated on some charging piles for charging and queuing before the charging utilization rate is not considered. Occurred, making the charging path of the AGV car faster and more convenient.

5. Conclusion
This paper constructs a multi-AGV path optimization model in an unmanned storage environment based on the charging utilization rate. The model takes the shortest path and the highest charging utilization rate as the dual goals, and combines the constraints of job assignment, time window, and collision avoidance to form a dual goal planning model, and choose genetic algorithm as the method to solve this model. On the basis of the above-mentioned theory, the actual scenario of AGV charging operation is simulated. The path planning algorithm proposed in this paper has been further verified, which shows that the model and solution algorithm designed in this paper have certain validity and feasibility.

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