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Design of dynamic scheduling strategy for metering equipment in warehouse environment based on intelligent algorithm

Jiguang Xue[1], Zhibo Feng[1,✉], Xiaoze Liu[1], Xiaoyi Zhang[1], Leiyang Zhao[1]

[1] *Marketing Service Center, State Grid Liaoning Electric Power Company Limited, Shenyang, Liaoning, 110168, China*

ABSTRACT

In the operation of storage system, improper scheduling of shuttle and hoist will waste resources and affect the picking efficiency, so it is of great significance to optimize the operation scheduling of storage system. Based on queuing theory, this paper constructs a queuing model of ring RGV system and proposes queuing model assumptions of hoist system to analyze the reasonableness of storage layout. The operation activity scheduling mechanism is designed to execute the warehousing activities strictly in accordance with the established operation order. Agree on the ring track RGV operation rules, calculate the distance between any two points on the track, and ensure the shortest distance of the warehousing operation. Merge the shortest operation path and the shuttle car operation equilibrium rules to construct a dynamic scheduling decision model. Through the storage resources in and out of storage management and scheduling module, improve the measuring equipment intelligent storage system, apply the system to the actual storage operations, analyze the operational efficiency. After the implementation of the strategy proposed in this paper, the optimal scheduling result is 36min, the execution time of different types of work is different, and the operation time of equipment J1-J4 is 15min, 23min, 17min, 34min respectively. The pickup execution efficiency of the strategy used in this paper is improved by 66.38%, and the pickup efficiency is improved by 10% when the number of equipment is less than 300 pieces. The scheduling strategy proposed in this paper has a higher priority when facing a small number of devices.

Keywords: ring RGV system queuing model, operation activity scheduling, dynamic scheduling decision model, metrology equipment intelligent storage

1. Introduction

Logistics, as an important part of modern industry, is the third source of profit for social and

✉ Corresponding author.
E-mail address: wyy2xx@163.com (Z. Feng).
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economic development. With the arrival of Industry 4.0, intelligence is the current trend of the logistics industry. And intelligent storage system as a key link in the logistics industry, its efficiency affects the turnover rate of the whole logistics system [1]. Intelligent warehousing system is a storage place for electric energy metering equipment, which can provide convenient services for the automatic calibration of electric energy metering equipment [2]. Intelligent warehousing system through the cooperative scheduling of warehouse automation equipment (stacker crane, AGV, etc.), to realize the information management of automatic identification, sorting, warehousing, out of the warehouse, moving the warehouse, inventory and other work [3-5]. With the rapid development of industrial automation technology, the intelligent storage system can meet more and more diversified storage needs, and its automatic storage efficiency continues to improve [6-8]. The storage system based on intelligent algorithms can be designed to realize the efficient and orderly development of metrological calibration operations by seamlessly connecting with the calibration pipeline system to meet the needs of the full life cycle management of metrological equipment [9-10].

In order to improve the business level of the warehousing industry, can not be satisfied with the automation of warehousing automation achieved by the automated three-dimensional warehouse, but also on this basis to go one step further, optimize the task allocation, equipment scheduling, information processing, etc., to comprehensively improve the processing efficiency of the warehousing system [11-13]. At the same time to realize the dynamic adjustability of warehousing equipment and business, according to the condition of the equipment and the current business content intelligent selection of appropriate management scheduling strategy [14-16]. At present, China's warehousing system intelligent technology is still relatively basic, the technical coverage and depth is still lacking, so the study of warehousing intelligent key technologies to enhance the level of intelligence of the warehousing system, in order to improve the efficiency of warehousing operations, reduce warehousing costs, and realize the dynamic warehousing management.

Mao, J. et al. investigated the resource scheduling optimization problem of intelligent warehouse management system and proposed a distributed storage management system based on cloud model, which effectively integrates the resource information through intelligent technology in order to provide good warehouse management services [17]. Liu, Y. et al. constructed a multi-objective mathematical model applicable to warehouse automation equipment, aiming to improve the efficiency of warehouses and enhance the competitiveness of enterprises, and compared the performance of three genetic algorithms in optimizing the task scheduling of automated equipment, and found that the multi-objective adaptive genetic algorithm (MAGA) was more reasonable and effective [18]. Li, Z. et al. proposed a multi-task robot scheduling mechanism oriented to dynamic customer demand for the multi-task assignment problem existing in the intelligent storage system, and used particle swarm optimization heuristic algorithm to find the optimization of the established mathematical model, and simulation experiments verified the validity of the method [19]. Yu, J. et al. proposed the parallel ant colony optimization algorithm, which realizes the co-evolution of multi-subpopulations through the interaction of pheromones among them, and can effectively improve the mobilization efficiency of automated equipment in the intelligent warehousing system by smoothing the paths and reducing the number of automated equipment turns and the length of the paths [20]. Chen, H. et al. investigated the theory of the single-robot system's shortest path and the algorithms, based on artificial potential function (APF), proposed a path planning method for intelligent warehousing multi-robot system, and proposed a path planning improvement strategy that prioritizes tracking along the wall, successfully solving the problem of multi-robot system in the process of obstacle avoidance [21].

In this paper, the metering equipment is regarded as the customer source and the circular track RGV is the service organization, and a queuing model based on the circular track RGV system is constructed, and relevant assumptions are put forward to propose a model to improve the queuing efficiency of the system. Based on the operation activity scheduling mechanism, the rule-based RGV congestion avoidance scheduling and shuttle path scheduling strategies are formulated. The model is applied to the intelligent storage system of metering equipment, importing the topographic map of the warehouse, constructing the corresponding spatial model, simulating the management scenario when the warehouse resources are in and out of the warehouse, and realizing the control of the entry of metering equipment into the warehouse. Warehouse resource scheduling module is proposed to optimize the system distribution scheduling problem through multi-objective optimization algorithm to ensure that the scheduling of metering equipment is completed within a short time.

2. Warehousing operations in the multi-measurement equipment coordinated scheduling methods

2.1. Warehouse layout rationality analysis based on queuing theory

2.1.1. Queuing model for ring RGV systems. The metering equipment can be considered as the customer source and the Circular Rail RGV as the service organization. The metering equipment arrives at the end of the conveyor and waits for the Circular Rail RGV to carry it, and when the RGV carries the metering equipment to the designated conveyor, the service of the Circular Rail RGV ends. The queuing model for the loop track RGV system is assumed as follows:

1) The arrival time of the metering equipment follows the Poisson distribution (parameter λ), and the service time of the RGV follows the exponential distribution (parameter μ).

2) The queuing rule is "first-come-first-served waiting system", i.e., the metering equipment needs to wait for the RGVs on the ring track until the end of service.

3) There are 4 RGVs on the circular track, i.e. there are 4 service windows, and each window works independently.

4) The ring-track RGVs are scheduled using heuristic rules, and the RGVs can only execute one job at a time [22].

Therefore, the queuing model of the circular track RGV system, which belongs to the multi-service window waiting mechanism, the average service rate of the system according to the above queuing model calculation method is:

$$\rho = \frac{\lambda}{n\mu} \tag{1}$$

The probability that all ring-track RGV trolleys are idle:

$$P_0 = \left[\sum_{k=0}^{n-1} \frac{\tilde{\lambda}^k}{k!\mu^k} + \frac{\tilde{\lambda}^n}{n!(1-\rho)\mu^n} \right]^{-1} \tag{2}$$

The average waiting captain for metering equipment is:

$$L_q = \frac{\lambda^n \mu^2}{\mu^n (n-1)!(n\mu - \lambda)^2} P_0 \tag{3}$$

Average waiting time for metering equipment:

$$W_q = \frac{L_q}{\lambda} \tag{4}$$

Average number of RGV trolleys in operation:

$$L_p = n\rho \tag{5}$$

2.1.2. Establishment of queuing model for hoist system. The queuing model of the hoist system is assumed as follows:

1) The arrival time of metering equipment and the service time of hoist are the same as the ring RGV system obeying the same mechanism with parameters λ', μ' respectively.
2) The queuing rule is also the same as the ring RGV system: the metering equipment needs to wait for the hoist to move until the end of service.
3) The system has only 1 hoist, i.e., 1 service window.
4) The hoist can only perform one operation per service.

Therefore, the hoist system queuing model belongs to the single service window waiting system M/M/1 queuing model, and considering the existence of scheduling and safety distance protection between ring-track multiple RGVs, the overall service efficiency of its ring-track RGV is $\eta = 0.7$. According to the above queuing model calculation method, the average service rate of the system is [23]:

$$\rho' = \frac{\lambda'}{\mu'} \tag{6}$$

The probability that the lifter is idle:

$$P_0' = 1 - \rho' \tag{7}$$

The average waiting captain for metering equipment is:

$$L_q' = \frac{\lambda'^2}{\mu'\left(\mu' - \lambda'\right)} \tag{8}$$

Average waiting time for metering equipment:

$$W_q' = \frac{L_q'}{\lambda'} \tag{9}$$

2.2. *Cooperative scheduling method for metering equipment in warehouse environment*

2.2.1. Mechanisms for the scheduling of operational activities. Figure 1 shows the Gantt chart of warehouse job execution activities, the activities of heterogeneous equipment under the same job type are in the same order, and the system can respond to multiple job requests at the same time [24]. Operational activities must be executed in strict accordance with the established order, but there are many factors affecting the activity plan, such as mechanical failure, communication instability, etc. will disturb the original operation schedule, so that the execution time of each activity is not completely consistent. Prior to the inability to accurately predict the execution time required for each activity, and limited storage equipment resources, the activities of the start of the implementation of the time is not certain, the common workshop production scheduling, resource scheduling and other static scheduling methods, can not guarantee that the storage of heterogeneous equipment in accordance with the operational process of co-operation, the allocation of storage equipment resources required to perform the activities of the storage equipment to control operational activities in accordance with step by step articulation is the solution to the collaborative scheduling of the warehousing equipment. The key to solving the cooperative scheduling of warehousing equipment.

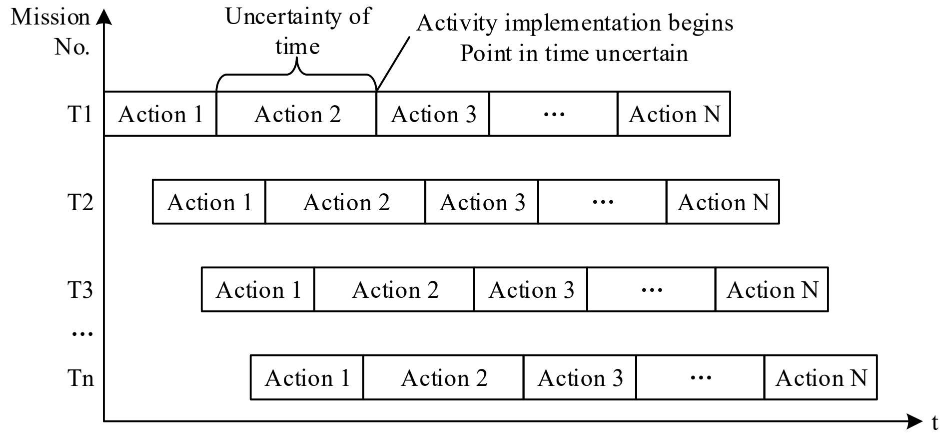


Fig. 1. Gantt chart for warehouse job execution activities

2.2.2. Rule-based scheduling for RGV congestion avoidance. The scheduling problem for a circular track RGV can be described as follows: $Task = \{task_i \mid i = 1, 2, \cdots, n\}$ is the queue of jobs to be scheduled, $task_i$ denotes the i rd job, n denotes the total number of jobs, $RGV = \{rgv_j \mid j = 1, 2, \cdots, J\}$ is the set of RGVs, rgv_j is the j th RGV vehicle, J denotes the total number of RGVs in the system, $C = \{c_k \mid k = 1, 2, \cdots, K\}$ is the set of conveyors, c_k denotes the k th conveyor, and K denotes the total number of conveyors in the system. The circular track RGV blockage avoidance scheduling problem involves assigning a handling trolley rgv_j to a job $task_i$ and planning the location of the starting and ending conveyors for rgv_j the travel to reduce the probability of multiple RGVs blocking each other due to handing over metering equipment to the conveyors.

1) Related Conventions:

(1) The RGV travels in a fixed sequence as shown in the diagram within the loop track and may not travel in reverse.

(2) The RGV can only carry one measuring device at a time.

(3) S0 is the starting point of the track, RGVs are numbered in counterclockwise order, and conveyors are numbered in clockwise order.

(4) If a conveyor fails, the operation on the conveyor will not enter the scheduling queue for the time being, and will enter the scheduling queue only when the failure is solved or when it is carried to other conveyors.

(5) Operations are generally in accordance with the “first-come-first-executed” waiting strategy scheduling.

2) The formula for calculating the distance between any two points on the track. Figure 2 shows the distance between any two points on the track. Several position points are set up on the circular track for real-time acquisition of the position of RGVs, and the positions of the five conveyors are aligned with the specific position points to allow the warehouse control system to capture the intersection of RGVs and shuttles. Taking the warehousing operation as an example, C_1, C_2 and C_3 are the starting conveyors for the warehousing operation, and C_4 and C_5 are the target conveyors. According to the above principle of “closest to the end of the queue”, the closest and free RGVs on the ring track should be assigned to Conveyor C_3 in priority, followed by Conveyor C_2 and Conveyor C_1:

$$D_{A \to B} = \left(P_B - P_A + N\right) \bmod N \tag{10}$$

Therefore, the loop track RGV assignment can be converted into a two-point distance calculation problem as shown in equation (10). Where $D_{A\to B}$ denotes the distance from A to B, P_A and P_B denote the position points of A and B, respectively, N denotes the total number of position points on the track, and mod denotes the number of residuals. If conveyor C_3 requests a stocking operation, rgv_1, rgv_2, and rgv_3 are idle, and 16 position points are set up on the track, then the distance from rgv_1 to conveyor C_3 is $=(4-6+16)\%16=14$, the distance from rgv_2 to conveyor C_3 is $=(4-2+16)\%16=2$, and the distance from rgv_3 to conveyor C_3 is $=(4-14+16)\%16=6$, with the shortest distance being rgv_2, and the stocking operation on conveyor C_3 shall be executed by rgv_2.

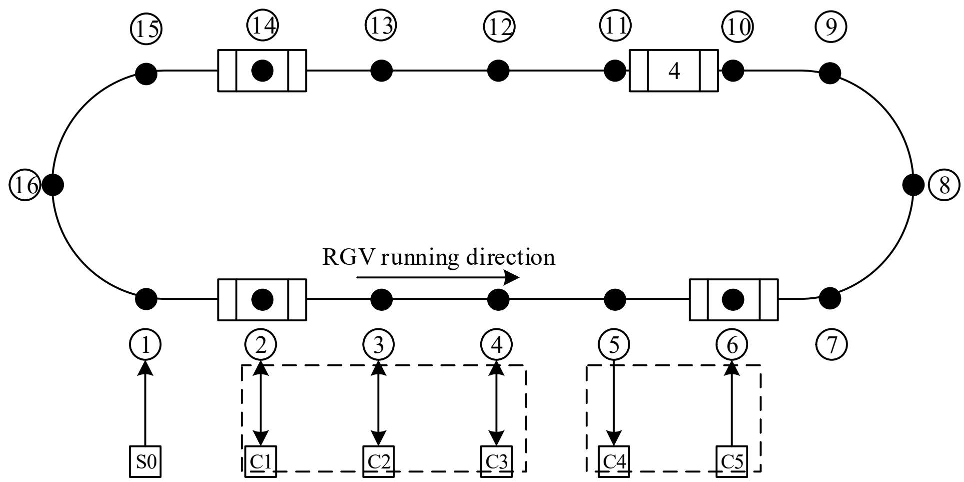


Fig. 2. The distance between any two points on the orbit

2.2.3. Rule-based shuttle path scheduling:

1) The shortest hoist operating path rule. Assuming that the hoist is a uniform speed operation, the shorter its running distance, the shortest time to complete all tasks. When the target channel has a shuttle, the elevator only needs to move the measuring equipment from the conveyor to the target channel, this time no decision-making. When the target channel does not have a shuttle, you need to first decide out of the shuttle, and then moved to the target channel by the elevator, and finally let the elevator will be metering equipment to the target channel, storage operations elevator operation path is as follows:

$$D_{ij} = L_{ij} + L_{2ij} + 2L_{3i} \tag{11}$$

The outbound operation hoist operation path is as follows:

$$D_{ij} = L_{1ij} + L_{2ij} + L_{3i} \tag{12}$$

where: D_{ij} for the elevator using the shuttle j to perform operations i need to run the distance, L_{1j} for the elevator from the initial position to the shuttle j where the distance of the channel, L_{2j} for the shuttle j where the distance of the channel to the target channel, L_3 for the entrance and exit to the distance of the target channel.

2) Shuttle operation equalization rule. In order to avoid overloading the shuttle, which affects the operation efficiency and the life of the shuttle, the remaining power of the shuttle is used to determine its probability of being selected, and the more remaining power, the greater the probability of being selected.

3) Decision model. The above two rules are merged into F_{ij}, F_{ij} for the shuttle j to perform operation i decision-making indicators, F_{ij} small means that the power of the selected shuttle is sufficient, the operation path of the hoist is short, and the scheduling results are superior. E_j indicates the remaining power of the shuttle car j, $0 < E_j \leq 100\%$, when the power is equal to 0, the car alarm, the system controls its charging back to the set point.

$$F_{ij} = \frac{D_{ij}}{E_j} \tag{13}$$

2.3. Measuring equipment intelligent storage system realization and application

For people for measuring equipment intelligent storage system performance requirements, in the software optimization part of the warehousing resources scheduling module and warehousing resources into the warehouse management module to carry out the design, so as to enhance the use of measuring equipment intelligent storage system performance.

2.3.1. Warehouse resources access management module. Before the optimization of this module, the topographic map of the warehouse is firstly imported into the system to construct the corresponding spatial model, and the entrance point of the warehouse is set as o, A_0 indicates the starting position of the equipment transporter, A_1 indicates the designated storage position of the equipment, X indicates the horizontal distance of the movement of the equipment transporter when it carries out the operation of warehousing, and Y indicates the vertical distance of the movement of the equipment transporter when it carries out the operation of warehousing. The travel time from the warehouse entrance to the designated storage location of the equipment A_1 can be expressed as follows:

$$\begin{gathered} T_{ALL} = 2\left(T_i + T_j + T_w\right) \\ s.t: 0 < i < 30, 0 < j < 5 \end{gathered} \tag{14}$$

In the above formula, T_{ALL} indicates the total time of the transporter storage operation, T_i indicates the time spent by the transporter in the horizontal direction from the entrance to the designated storage location of the equipment, T_j indicates the upper limit of the time spent by the transporter in the designated location of the storage, T_w indicates the lower limit of the time spent by the transporter in the designated location of the storage. In the process of transportation, T_w is a fixed value, which does not affect the efficiency of the transporter, if this parameter is ignored, the storage time of the equipment can be expressed as:

$$T'_{ALL} = 2\left(i*u / w_x + (j-1)T_j / w_y\right) \tag{15}$$

Considering only the transportation of equipment into storage, the running time of a multi-batch storage job can be expressed as:

$$\begin{gathered} T^n_{ALL} = \sum_{a=1}^{n} T_{ALL}a \\ s.t: 1 \leq a \leq 3 \end{gathered} \tag{16}$$

In the above equation, $T_{ALL}a$ represents the time spent by the a nd transporter in the warehousing operation. Considering the time spent by the equipment from the freight elevator place to the warehouse entrance, the overall inbound process can be shown as:

$$T_n = 2\sum_{a=1}^{n}\left(\left(i*u / w_x + (j-1)T_j / w_y\right) + v_a / s\right) \tag{17}$$

In the above equation, v_a is the speed of the equipment transporter. The above calculation process is written into this module to control the inbound warehouse of the equipment. Similarly, the process of controlling the outbound warehouse of the equipment can be obtained, and through the above formula, the inbound and outbound management of storage resources can be realized.

2.3.2. Warehouse resource scheduling module. In addition to the control of equipment in and out of the warehouse, in the measurement of equipment intelligent warehouse management also needs to optimize the system distribution scheduling problem. In this study, it is set in the form of a mathematical model and this part of the research process is realized through a multi-objective optimization algorithm. Set the number of equipment in and out of the warehouse as c, d represents the number of sorting equipment, k represents the number of RGV transportation equipment, F represents the collection of outbound/warehousing numbers, F' represents the collection of sorting numbers, R represents the collection of RGV transportation equipment numbers, T_{ALL} represents the time of equipment in and out of storage, t_{ih} represents the time when the h th RGV transportation equipment arrives at the sorting table i, d_{ih} represents the time when the h th RGV transportation equipment arrives at the sorting table i from the storage location, and j_{ih} represents the time when the h th RGV transportation equipment arrives at the sorting table from the warehouse entrance The time of i, U_h represents the operating state of the h th RGV transport equipment, so that the metering equipment scheduling model can be integrated as follows:

$$\begin{gathered} \min \sum_{i \in U} \sum_{k=1}^{k} \left(d_{ih} - j_{ih} + U_h * T_{ALL} \right) \\ s.t: d_{ih} > j_{ih} \end{gathered} \tag{18}$$

In order to ensure the calculation accuracy of the above formula, the constraints are set as follows according to some of the solution ideas in the genetic algorithm:

$$U_h = \begin{cases} 1, & the\ hth\ RGV\ is\ in\ idle\ state \\ 0, & the\ hth\ RGV\ is\ in\ working\ state \end{cases} \tag{19}$$

$$Q_{ih} = \begin{cases} 1, & hth\ RGV\ assigned\ to\ give\ inbound\ work \\ 0, & the\ hth\ RGV\ is\ not\ assigned\ a\ job \\ \text{-}1, & the\ hth\ RGV\ is\ being\ loaded\ or\ unloaded \end{cases} \tag{20}$$

According to the above calculation process, the shortest time for equipment transportation can be determined. In order to enhance the system's ability to control the entry and exit of equipment, to ensure that the shortest possible time to complete the assembly of measuring equipment.

2.3.3. Application effects. The system test applies the functions of warehousing entity setting, cargo space optimization and warehousing equipment scheduling, and the application results show that the optimization by the proposed method improves the stability of the shelves, shortens the operation path of the elevator, improves the warehousing operation time, and improves the accuracy of the warehousing operation.

Therefore, the intelligent cargo space optimization and equipment scheduling system for dense warehousing can effectively solve the dynamic cargo space optimization and implementation of equipment scheduling problems, reduce warehouse operating costs, improve the efficiency of warehousing operations, the system application results. Not only can it improve the efficiency and quality of intensive warehousing decision-making, promote the rationalization of intensive warehousing decision-making, but also promote the application of intensive warehousing in the logistics industry, and provide a theoretical and technical basis for supporting lean warehousing.

3. Example analysis

3.1. Performance comparison

A provincial power company measuring equipment verification center intelligent three-dimensional warehouse as an example. The system contains the number of RGV N = 4, the number of lifts F = 4, shelf length of 18 m, high 16.5 m. A total of 6 rows of shelves, a single layer of each side of the 13 spaces, each row of 23 layers, a total of 10,764 spaces. The height of the unit cargo space h = 0.45 m, width w = 0.7 m, depth d = 0.5 m. The horizontal speed of the RGV $V_x = 2m/s$, the speed of the elevator $V_y = 1.5m/s$. In order to verify the effectiveness of this paper's model for solving the problem, randomly generate a job group containing 4 cargo space points, respectively, with the basic AFSA algorithm, quantum particle swarm optimization algorithm (QPSO) algorithm and this paper's model for example simulation comparison.

3.1.1. Analysis of the convergence process. Figure 3 shows the convergence process curves of the three algorithms, from which it can be seen that the model proposed in this paper is able to avoid falling into a local optimum as well as speeding up the late convergence due to the formulation of the rule-based congestion-avoidance scheduling for RGVs, which converges to the optimum after about 110 iterations, and the optimal results are obtained.

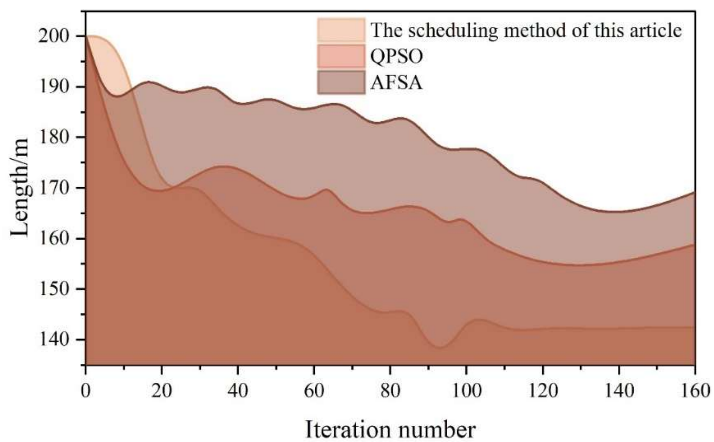


Fig. 3. The convergence process curve of three algorithms

3.1.2. Comparison of scheduling strategies. This section analyzes and compares the “first-come-first-served” scheduling strategy proposed in the paper with the QPSO and AFSA strategies in terms of average waiting time (MWT) and average queue length (MQL), respectively. The specific parameters of the system are as follows: the number of queues n=8, the initial length of each queue is $L_i(i=1,2,\ldots,8)$, and the capacity of each queue buffer $Lim_i = (i=1,2,\ldots,8)$ is 12, $\Delta t = 15\min$. Fig. 4 shows the comparison of the average waiting time and Fig. 5 shows the comparison of the average queue length.

As can be seen from Fig. 4 and Fig. 5, in an hour's time, although the average waiting time (MWT) and the average length (MQL) of the queue in the initial stage of the “first-come-first-execute” scheduling strategy proposed in the paper are longer, the system can keep the average waiting time and the average length of the queue within a certain range, and the average length of the queue is kept at about 6m, which has a longer waiting time and longer queue length. The average queue waiting time and the average length of the queue can be kept within a certain range, and finally the average waiting time is kept in the range of 4~4.5min, and the average queue length is kept around 6m, which is superior, on the contrary, the other two scheduling strategies ignore the overall demand and real-time changes of the system, which results in the average waiting time and the average length of the queue in the late scheduling period. On the contrary, the other two scheduling strategies ignore the overall system demand and real-time changes, which leads to the average waiting time and average queue length in the late scheduling period, easily causing system congestion and "starvation" phenomenon.

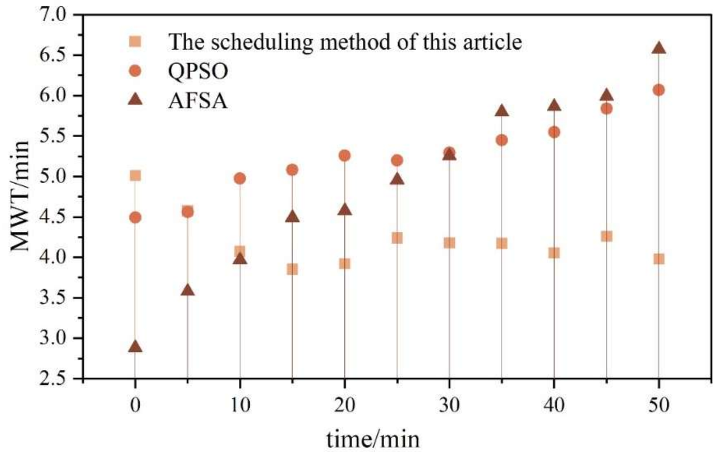


Fig. 4. Average waiting time comparison

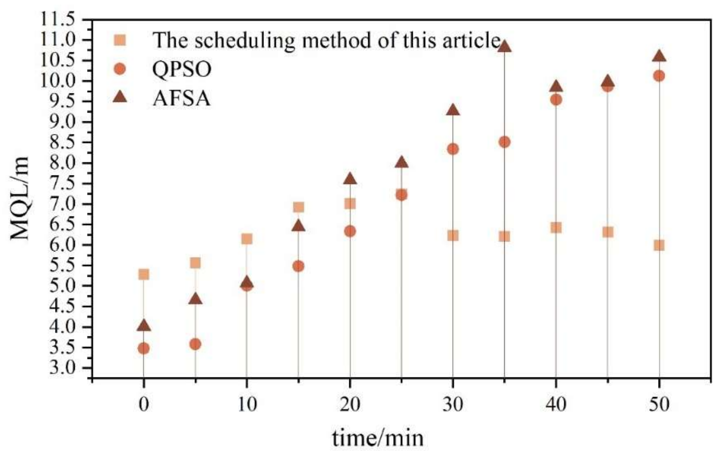


Fig. 5. Average queue length comparison

3.2. Intelligent Warehouse System Operation Efficiency Research

3.2.1. Analysis of the results of the scheduling of measuring equipment. The steps of dynamic scheduling of measuring equipment based on the intelligent storage system in this paper are as follows:

Step 1: All workpieces are sorted by weight from largest to smallest, and if the weight is the same, then the arrival time is sorted from smallest to largest to get the sequence of workpieces L.

Step 2: Read the first idle device k, set the idle moment as t, and set the latest start processing time of device k as $t+T$, where T is 80% of the longest processing time of a single batch.

Step 3: Group batches of workpieces to be dispatched for each family of workpieces arriving before moment t according to sequence L. If there is a certain workpiece family to be dispatched weight reaches the minimum processing weight, then priority is given to scheduling the weight of the largest workpiece family processing, update the idle moment of the equipment for the completion of the batch, go to step 5.

Step 4: If moment t is not less than the latest start time of the equipment, and the workpieces to be dispatched arriving before moment t are not empty, then the workpiece family with the largest total weight to be dispatched is scheduled for machining, and the equipment's next idle moment is updated to be the completion time of the batch, go to step 5, then the workpieces arriving in the next time window are taken into account, i.e., moment t is updated to make $t = t + T / 3$, go to step 3.

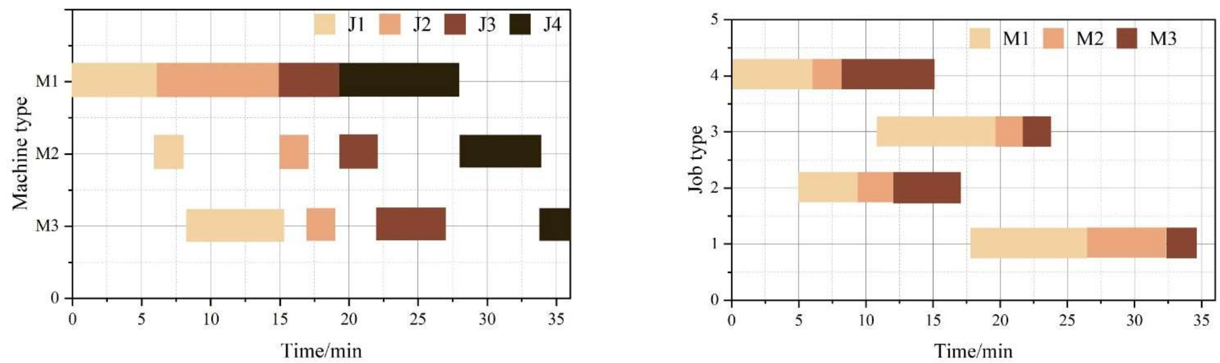
Step 5: If all workpieces are scheduled, output the scheduling result, then, go to step 2.

The effectiveness of the intelligent warehouse scheduling system in this paper is verified by a small-scale example of 4 measuring devices. There are 3 workpiece family types in the arithmetic example, 3 equal batch processors, and the capacity of the equipment is 15, which are named M1, M2, and M3, respectively.The arrival time, weight, size, and workpiece family type of the workpieces are shown in Table 1. Taking equipment 1 as an example, the arrival time, weight, dimensions and equipment family are (1,4,4,1), respectively. The family loading machining time coefficients for the three devices are 1 and 2, respectively, and the dimensional machining time coefficients are 3 for all devices.

Table 1. Arrival Time, Weight, Size and Job Family of Jobs J1-J4

/	J1	J2	J3	J4
Arrival time	1	2	3	4
Equipment weight	4	3	2	1
Equipment size	4	3	2	1
Group of equipment	1	1	3	2

Based on the proposed warehousing job execution activities, the obtained Gantt chart is shown in Figure 6. As can be seen from Figure 6, the optimal scheduling results for 36min, this paper, “first come, first executed” scheduling strategy, considering the actual production line of metering equipment, there are three groups of production machines and four types of work, according to the arrival time of the order of the implementation of scheduling strategy, to obtain the optimal production sequencing of the different jobs in each machine can be The prerequisites for different jobs to run on each machine thus define how the different machines and jobs work together. The execution time of different job types is also different, the time of J1-J4 is 15min, 23min, 17min and 34min respectively.



(a)Machines deal with sequential logic (b)Work processing sequential logic

Fig. 6. Optimal production scheduling sequence

3.2.2. Analysis of strategy implementation efficiency. In this paper, we choose the commonly used randomized space allocation strategy as the comparison object. Set the shelf “place to column” as “randomly place to available column”, “place to row” as “randomly place to available row “. The simulation running results □ show irregular fluctuation due to the system random allocation of cargo space, the average time spent for each piece of cargo is not affected by the number of goods accessed in a single batch. Tables 2-4 show the simulation running results of this paper's scheduling strategy, QPSO strategy and random allocation strategy, respectively. Table 5 shows the comparison of simulation running results, and the comparison results can be analyzed:

1) The strategy used in this paper results in a significant improvement in the efficiency of the pickup process, especially when the number of devices is 10, the pickup efficiency is improved by 66.38%, and when the number of devices is less than 300, the pickup efficiency is improved by less than 10% in all cases. At the same time, there is an improvement in the total efficiency, which is suitable for production warehousing with high requirements for real-time supply, to ensure the supply of equipment for automated production lines.

2) QPSO strategy to improve the total efficiency, but the magnitude of the improvement is small, the performance is slightly better than the strategy proposed in this paper, so in the number of equipment for the 300 or less, give priority to the strategy proposed in this paper.

3) As the number of goods accessed in a single batch increases, the overlap between the two strategies and the randomized space allocation strategy increases, resulting in a decrease in the efficiency improvement. In practice, the number of goods accessed in a single batch is rarely greater than 300.

Table 2. The scheduling strategy of this article

Equipment quantity	Inventory time(s)	Shipping time(s)	Total time(s)	Running distance(m)	Average time per device(s)
10	412.96	118.66	531.62	715.56	53.162
50	2054.53	826.152	2880.682	4215.56	57.61364
100	3948.92	2031.64	5980.56	8356.54	59.8056
200	7596.51	4823.25	12419.76	16883.61	62.0988
300	10628.96	8156.61	18785.57	26486.69	62.61856667
400	13769.15	11985.16	25754.31	35987.64	64.385775
500	16485.26	16287.64	32772.9	45698.66	65.5458

Table 3. QPSO strategy

Equipment	Inventory	Shipping	Total	Running	Average time per

quantity	time(s)	time(s)	time(s)	distance(m)	device(s)
10	253.88	268.65	522.53	726.65	52.253
50	1394.61	1423.96	2818.57	3915.25	56.3714
100	2863.65	2948.61	5812.26	7934.59	58.1226
200	5934.05	5936.46	11870.51	16352.95	59.35255
300	9156.66	9065.96	18222.62	24894.64	60.74206667
400	12364.96	12349.15	24714.11	32488.69	61.785275
500	16158.69	16237.96	32396.65	45169.65	64.7933

Table 4. Random allocation strategy

Equipment quantity	Inventory time(s)	Shipping time(s)	Total time(s)	Running distance(m)	Average time per device(s)
10	286.64	352.94	639.58	852.64	63.958
50	1569.61	1625.96	3195.57	4165.15	63.9114
100	3215.15	3345.48	6560.63	8951.65	65.6063
200	6348.55	6458.49	12807.04	17698.54	64.0352
300	9465.65	9186.64	18652.29	27485.64	62.1743
400	12348.59	12887.46	25236.05	33598.56	63.090125
500	16284.68	16356.45	32641.13	45666.95	65.28226

Table 5. Simulation results compare

Number of equipment (parts)	"First to first" strategy		QPSO strategy	
	Pickup efficiency improved(%)	Overall efficiency improvement(%)	Pickup efficiency improved(%)	Overall efficiency improvement(%)
10	**66.38%**	16.88%	23.88%	**18.30%**
50	**49.19%**	9.85%	12.42%	**11.80%**
100	**39.27%**	8.84%	11.86%	**11.41%**
200	**25.32%**	3.02%	8.08%	**7.31%**
300	**11.21%**	0.00%	1.31%	**2.30%**
400	**7.00%**	0.00%	4.18%	**2.07%**
500	**0.42%**	0.00%	0.72%	**0.75%**

4. Conclusion

This paper analyzes the rationality of storage layout based on queuing theory, explores the scheduling mechanism of operational activities, and formulates the RGV trajectory blockage avoidance scheduling and shuttle path scheduling based on the rules. From the two modules of warehousing resource access management and warehousing resource scheduling, the intelligent warehousing system for measuring equipment is established. Through the algorithm performance comparison and operational efficiency, the implementation effect of the strategy proposed in this paper is analyzed. In the strategy proposed in this paper, the rule-based RGV congestion avoidance scheduling is formulated, which can converge after 110 iterations and get the optimal results, and the convergence speed is the fastest among the three algorithms. Meanwhile, the average waiting time and the average queue length of the “first-come-first-served” scheduling strategy are about 4~4.5min and 6m, respectively. The optimal scheduling result of this paper's strategy is analyzed through the Gantt chart, and the calculation results show that the optimal scheduling result of this paper's strategy is 36min, and the time of the equipment J1-J4 is 15min, 23min, 17min, and 34min, respectively. The efficiency of this paper's strategy in the pickup phase has been greatly improved, and the efficiency of pickup has been improved by 66.38% in the case of the number of equipment is 10 pieces.

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